Improving Water Supply Systems Resilience to Floods: Developing a Measurement Tool for Tanzania

Lukuba Ngalya Sweya

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Supervised by:

Professor Pierre Quenneville

Dr Alice Yang Chang-Richard

and

Professor Suzanne Wilkinson

Department of Civil and Environmental Engineering

The University of Auckland

New Zealand

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Abstract

Tanzania is a tropical country in the East Africa region that has experienced the impacts of flooding for more than a decade. Hundreds of people have lost their lives and lifeline infrastructures such as roads and water systems were damaged. Failure of water supply systems (WSSs) during floods has shown grave consequences to Tanzanians. The failure could be in the form of systems breakdown or water contamination. System breakdown leaves the majority without access to safe water as bottled water is costly and nearly unaffordable to poor populations. Given that less than 85% have access to conventional water supply services delivered by the Water Supply and Sanitation Authorities (WSSAs), a good number is still relying on unimproved water systems, posing a worry due to use of contamination-prone water. Such situations underline the need for improving the Tanzania water supply systems' resilience to better prepare for future risks of flooding. However, resilience can be improved when there is the ability to measure it. Thus, the current study developed a multi-dimensional qualitative resilience measurement tool for the country's water supply systems. The study applied an expert's judgement elicitation through five stages—variables pre-assessment, variables pretesting, tool development using Delphi survey, final tool evaluation, and validation. The tool has five dimensions—technical, organizational, social, economic, and environmental, addressing the diverse resilience issues in the water supply systems. Each dimension contains principles, indicators, measures, and assessment scales. When evaluated in selected Tanzania water supply systems, the tool can indicate the current resilience level of the system and suggest the aspects that need strengthening. Results can support decision making in terms of prioritization and budgeting for the appropriate measures to improve the resilience of the water supply systems. Validation results indicate further that the tool is a valid measure in terms of reliability, relationship pattern of the indicators, applicability, and generality. The tool leads to sustainable water supply services during flooding and aids in reducing the global temperature to achieve the Paris Agreement. Also, assists in attaining sustainable development goals related to water supply and infrastructures resilience. Thus, it can be used for Tanzania water supply systems and in other developing countries around the world.

Dedication

"God works by whom He will. He sometimes selects the humblest instrument to do the greatest work, for His power is revealed through the weakness of men. We have our standard, and by it we pronounce one thing great and another small; but God does not estimate according to our rule" (Ellen G. White)

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Now to Him "our Almighty God" who is able to do exceedingly abundantly above all that we ask or think, according to the power that works in us," I express my heartfelt thanks for you have manifested Your powers to the weakest man like me through my PhD studies at the University of Auckland. Lord, I believe, without Your presence, this step could not have been reached. Now I believe that those who indeed obey Your voice and keep Your covenant shall be a special treasure to You above all people; for all the earth is Yours. And they shall be to You a kingdom of priests and a holy nation.

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Glossary

AACL	Absorptive-adaptive-coping-learning
COWSO	Community-based water supply organization
DAWASA	Dar es Salaam water supply and sewerage authority
DAWASCO	Dar es Salaam water supply and sewerage cooperation
EIA	Environmental impact assessment
EMA	Environmental management Act
ESIA	Environmental and social impact assessment
EWURA	Energy and water utilities regulatory authority
GAR	Global assessment report
GCM	Goal cascade methodology
GDP	Gross domestic product
GHG	Greenhouse gases
GLOWS-FIU	Global water sustainability program-Florida international university
IPCC	Intergovernmental Panel on Climate Change
JICA	Japan International Cooperation Agency
LGA	Local government authority
MC	Municipal council
MoNRT	Ministry of natural resources and tourism
MoW	Ministry of water
MORUWASA	Morogoro water supply and sanitation authority
NBS	National bureau of statistics
NEMC	National environmental management council
NP-WSSA	National projects-water supply and sanitation authority
NRW	Non-revenue-water
PMO	Prime minister office
PPP	Public-private-partnership
SDG	Sustainable development goal
TANESCO	Tanzania Electric Supply Company Limited
TFS	Tanzania forest services agency
TMA	Tanzania meteorological agency

TOEE	Technical-organizational-economic-environmental
TOSE	Technical-organizational-social-economic
UN	United nations
UNDRR	United nations office of disaster risk reduction
UNICEF	United Nations International Children's Emergency Fund
UNSD	United nations statistics division
URT	United republic of Tanzania
WEF	World economic forum
WHO	World health organization
WSDP	Water sector development program
WSS	Water supply system
WRMA	Water resources management Act

Chapter 1
Introduction

1.1 OVERVIEW OF THE STUDY

The world's most significant devastation is currently due to disaster risks—their consequences range from deaths and physical damages of infrastructures to environmental, ecological and economic losses. Environmental risks, for example, have persisted in the top ten for the past decade (WEF, 2019). For the first time in the history of the Global Risks Perception Survey, environmental concerns have dominated the top five long-term risks by likelihood, and three of them out of the top five in terms of impacts (WEF, 2020). Besides, extreme weather, natural disasters, and failure of climate change mitigation measures and adaptation are among the commonest of the frequently occurring and high impacts risks. WEF (2020) indicate that climate change is striking harder and more rapidly than expected—the last five years are on track to be the warmest on record, natural disasters are becoming more intense and more frequent.

Failure of climate change mitigations and adaptation suggests that environmental risks such as extreme weathers, will continue to propagate and cause more harm to communities and infrastructures. Besides, global temperatures are on track to increase by at least 3^{o}C twice what climate experts have warned is the limit to avoid the most significant economic, social, and environmental consequences (WEF 2020). Already, about 500,000 Hiroshima atomic bombs extra heat energy equivalent is absorbed by accumulated greenhouse gases in the atmosphere daily, leading to a more disrupted water cycle with more evaporation causing tropical cyclones, severe rains and flooding[1]. If such climate change patterns persist, hydro-meteorological disasters will intensify, become more frequent (URT, 2003 & IPCC, 2014), become more unpredictable, and become more devastating, leading to more causalities, destructions, and economic losses caused in short times of occurrences.

Approximately 68.5% of all global economic losses in the period from 2005 to 2017 were due to extensive risk events heavily absorbed by poor communities in the developing countries (UNDRR, 2019). Expectations are that death rates and damages will surpass the already inadequate mitigation, response, and transfer mechanisms (UNDRR, 2019). Besides, with the increased risks, coastal flooding is projected to cause more significant damage in many

[1] https://www.weforum.org/events/world-economic-forum-annual-meeting-2019

areas of the world than riverine floods underlining the increase in infrastructure and assets that stand to be damaged. As such, there is the need for immediate measures to cap the temperature increase below 15^{o}C and increase the countries' ability to deal with climate change impacts (UN, 2015; IPCC, 2018; WEF, 2019 and UNCC, 2019). The Sendai Framework for Disaster Risk Reduction through its seven global targets 18(d) calls for substantial reduction of disaster damage to critical infrastructure and disruption of essential services, including developing resilience (UNISDR, 2015).

WEF (2020) suggests that the 2020—the decade of delivery for sustainable development goals—also needs to be the resilience decade for climate, requiring governments and businesses to identify and prioritize risks and develop metrics and strategies to manage them, in order to have resilient infrastructure that can better cope with the impacts of disaster risks. The resilience concept therefore with its genesis back in 1973 (Holling, 1973), has come into prominence after the catastrophe of Hurricane Katrina in August 2005 (Tierney & Bruneau, 2007) to prepare for the increasing threats of disaster risks (Hwang, Forrester, & Lansey, 2013). For that reason, initiatives such as the Sendai framework through its priority of action number three associates investing in disaster risk reduction for resilience such that national and local levels are required 30(c) to strengthen, as an appropriate, disaster-resilient public and private investment through structural and non-structural and functional disaster risk prevention and reduction measures in critical facilities such as physical infrastructure. Also, building better from the start to withstand hazards through proper design and construction, and taking into account economic, social, structural, technological and environmental impact assessments (UN, 2015).

1.2 BACKGROUND AND SIGNIFICANCE OF RESEARCH

Tierney & Bruneau (2007) indicate that critical infrastructure systems play an essential role in communitywide disaster mitigation, response and recovery, and therefore are high-priority targets for resilience enhancement. Any resilience consideration must begin with a focus on service and functional activities that constitute the critical infrastructure so-called the backbone of the community functioning (Bruneau et al., 2003). Societies are highly dependent on such critical infrastructure systems which have gradually become increasingly complex and interdependent such that failure of one or drastically reducing its performance, may lead to low performances in others (Mattsson & Jenelius, 2015). Improving the resilience of such critical infrastructures as water supply is highly essential for overall community resilience. Water infrastructure and other critical infrastructures such as power, critical facilities, and emergency response management are examples of the backbone-infrastructure systems; they enable communities to respond, provide for the wellbeing of their residents and initiate recovery activities (Bruneau et al., 2003).

Usually, water supply infrastructure systems experience flooding impacts prompting for the need for resilience. As noted earlier, water supply systems provide essential services that support communities' lives (Brown, Milke, & Seville, 2010). They encompass catchments/water sources, water treatment facilities, distribution networks, raw water and clean water transmission pipes, electronic facilities and cyber systems (Van Leuven, 2011). As critical infrastructure with direct relation to the communities and the managing organizations, water supply systems are multi-dimensional with social-ecological-technical systems encompassing natural, physical, organizational, and social networks (Newman et al., 2011). This composition that provides significant opportunities for disaster risks (Karamouz, Sadaati, & Ahmadi, 2010), requires a systemic approach (UNDRR, 2019) to ensure an adequate reduction of risks.

Tanzania is in the East Africa region, bordered by the Indian Ocean in the east. The country suffers flood risks which have shown significant impacts on water supply systems. In 2019, the south coast of the country experienced two cyclones—Idai and Kenneth—having severe impacts in the neighboring countries, showing that the country's water supply systems will yet be affected by weather-related disasters. Currently, Tanzania urban water supply systems encompass 26 Regional Water Supply and Sanitation Authorities (R-WSSAs) and eight (8) National Project Water Supply and Sanitation Authorities (NP-WSSAs) in the Mainland-Tanzania, such authorities are the principle water services providers directly serving an average of 74.2% and 55% respectively of the population in their service areas (URT, 2018). NP-WSSAs such as Kahama Shinyanga Water Supply and Sewerage Authority (KASHUWASA) are also bulk water suppliers to other WSSAs while serving villages in their areas. Others are privately-owned infrastructure, community-based organization facilities, individual boreholes, and direct fetching of water from streams, rivers, lakes and locally dug wells. The country's water supply systems are less developed as reports show that whereas about 70.4% of the population is in rural areas (URT, 2012a), only 45.36% have access to improved water sources (WHO & UNISEF, 2015), and only 74.2% have access to public water supply in the urban areas (URT, 2018). Such information suggests that more than half and about 25% of rural and urban populations respectively are either in water crisis or consumes water from unimproved sources—showing that several Tanzanians are likely suffering or are likely to experience future flood impacts due to lacking adequate essential services such as water during disasters.

Due to the multi-dimensional nature of water supply systems, resilience is an integrating concept that allows multiple risks, shocks and stresses and their impacts on the ecosystem and vulnerable people to be considered jointly in the context of development programs (Mitchell & Harris, 2012). Such a concept helps address natural hazards that are capable of impacting anyone and anywhere. For instance, from the Indian Ocean Tsunami to the South Asia earthquake, from the damage caused by hurricanes and cyclones in the United States, the Caribbean and the Pacific, to severe flooding across Europe and Asia, hundreds of people have lost their lives, and millions their livelihoods, to natural catastrophes (UNISDR, 2005). Globally, disasters such as the 2003 North American power grid blackout, 2008 snowstorm in China, the 2004 Tsunami in Asia, 3000 flooded septic tanks in 2000 in Chokwi and Xia-Xia cities of Mozambique, the 2007 Bangladesh flood event, and the 2011 Christchurch earthquake had grave consequences to water supply systems. Likewise, 1992/1993 and 1997/1998 El Nino episodes, and 2011, 2014, 2015, 2016, and 2017 floods in Tanzania were associated with widespread water-related diseases and infrastructure destructions among others (Paavola, 2008 & URT, 2003 and EM-DAT). As such, resilience is needed by both developed and developing countries, wealthier and more deprived communities as no one is immune to the impacts of disaster risks (Comfort, Boin & Demchak, 2010 and Coppola, 2006)

Resilience intends to increase the ability of a system, community, or society exposed to hazard to resist, absorb, accommodate to and recover from the effects of hazards in a timely and efficient manner, including through prevention and restoration of its essential basic structures and functions (UNISDR, 2009). Such a notion aligns with Tierney & Bruneau et al. (2007) suggesting that the concept reflects a concern of improving the capacity of physical and human systems to respond to and recover from extreme events. For infrastructure systems, resilience associates with the enhancement of the ability of a system to reduce the chances of a shock and to recover quickly after the shock (Bruneau et al., 2003). That said, resilient systems reduce the probability of failure; the consequences of failure, and the time of recovery (Tierney & Bruneau, 2007). Besides, the more resilient is the system, the larger the disturbance it can absorb without shifting into an alternate regime (Walker et al., 2006).

1.3 PROBLEM STATEMENT

Global water supply systems are at risk to flood disasters. More so Tanzania systems' flood risks are exacerbated by aging infrastructures, unbalanced investments, insufficient rehabilitation, systems interdependency, rapid population growth, rapid urbanization, lack of understanding of the systems connectedness, seawater intrusion, groundwater pollution, unimproved sources, and lack of community support (Sweya et al., 2018). Also, poor planning, poverty, weak infrastructure, and non-functioning stormwater drainage escalate the flood risks (Earhart & Twena, 2006; Sakijege, Lupala & Sheuya, 2012; Kebede & Nicolls, 2011). Such issues put more pressure on water managers to ensure that water service is always available enhancing smooth community recovery should disasters hit the country. By acknowledging the existence of climate change impacts and disaster risks, Tanzania established the National Adaptation Program of Action (NAPA-2007), the National Adaptation Strategy and Action Plan-2009, and the National Climate Change Strategy-2012. Through the Department For International Development (DFID) and the World Health Organization (WHO), the country-in 2015 developed guidelines for the implementation of water safety plans resilient to climate change, while in the same year a Disaster Management Act was established. Besides, the country has implemented a few water projects focusing on climate change and resilience. For instance, the Adaptation to Climate Change in Coastal Dar es Salaam (ACC-Dar) project which revealed that Dar es Salaam community's water supply is facing climate change impacts such as seawater intrusion, needing adaptability to climate change to enhance resilience. The Africa Caribbean Pacific-European Union (ACP-EU) Natural Disaster Risk Reduction Program funded by World Bank focusing on building resilience in Tanzania water sector, aimed at reducing the vulnerability of the rural and urban community to hydrometric hazards.

The Tanzania Water Security for Growth Project funded by World Bank aims to strengthen bulk water security of prioritized urban areas and bring critical water source areas under sustainable watershed management. The project concept report suggests that for the water sector to be more resilient, better water management, including building resilience and exploring innovative approaches to operationalize its water management framework, is needed. The Water Sector Development Program (WSDP) focuses on the service coverage "up to 90%, and 100% by 2025 for rural and urban areas respectively (URT, 2006a)," in which the country implements the Simiyu climate resilience project funded by KfW-Germany. Such initiatives align with the Tanzania statement made at the Global Platform for Disaster Risk Reduction-2019 indicating that the country is taking an important step towards reducing disaster risks.

However, the country's primary concern is about the inadequate mechanism and capacity to build resilience said the Permanent Secretary-Prime Minister's Office[2]. More so, such inadequacy of mechanism and capacity underlines the gap between the theory of improving water supply systems through building resilience and operationalization of the concept in the country's water sector to ensure a continuous providence of water service to the communities in the presence of disaster risks.

Whereas measuring the resilience would bridge the gap between resilience theory and operationalization in the country's water sector leading to appropriate improvement measures for water supply systems (D'Lima & Medda, 2015); there is no universally accepted measure (Willis, 2015). Measuring resilience is compounded by several factors such as physical, social, and cultural (Prior, 2015) needing a better understanding of the assessment variables (Hughes & Healy, 2014) to which Tanzania is not immune. Urban areas of the country being affected by poor drainage systems and unplanned settlements—they are the most affected. Also, reliable alternative water sources when public water systems are not functioning are costly and poor populations are unable to afford, ending up consuming unreliable water with questionable qualities. Thus, a comprehensive tool to sufficiently and systematically measure the resilience to flooding risks addressing the multi-dimensional problems of water supply systems, and appropriate to all urban areas of the country is needed. As such, the current research attempts to develop such a comprehensive qualitative-based multi-dimensional resilience measurement tool, that is consistent and appropriate to addressing diverse problems facing the Tanzania water supply systems during flooding.

The predominant research question of the current research is: "How can Tanzania water supply systems resilience to flooding hazards be improved to adapt to the increasing flood risks?" In order to address this question, the research examines the following sub-questions;

1. How can resilience to flood hazards be described in relation to other concepts in the context of Tanzania water supply systems?
2. How can resilience of Tanzania water supply systems be measured?
3. How can the resilience measures be validated?
4. What could be the improvement measures for Tanzania water supply systems resilience?

[2] https://www.preventionweb.net/english/policies/v.php?id=68441&cid=184

1.4 RESEARCH OBJECTIVES

In answering the above questions, the study aims to achieve the under listed specific objectives:

1. To evaluate the concepts related to resilience, determine factors affecting resilience in the context of water supply systems and apply them to assess the problems affecting Tanzania water supply systems and the need for developing a resilience measurement tool
2. To develop a tool for measuring the water supply systems resilience to floods in Tanzania
3. To evaluate the validity of the measurement tool through content validation and applicability and generality testing in selected Tanzania water supply systems
4. To evaluate measures for improving Tanzania water supply systems resilience and propose an appropriate implementation plan.

1.5 SCOPE OF THE RESEARCH

The research is on improving water supply systems resilience to flooding risks through developing a qualitative-based measurement tool focusing on urban water supply utilities. The water supply system in the current research includes the physical infrastructure, institutions that operate the infrastructure, the environment within which water sources, catchments and recharge areas exist, the water users, and funding mechanism. The research first examines the problems facing the resilience of water supply systems to evaluate the need for a resilience measurement tool. The tool development process applies an expert's judgement elicitation-Delphi technique conducted in Tanzania to make the tool more appropriate to the country's water supply systems. The research assesses the tool's content validity and further evaluates its applicability and generality in three case studies representing the urban water supply systems within the country. Evaluation results identify the systems' vulnerabilities and examine specific measures to improve the water supply systems resilience to flood hazards. Moreover, the tool's proposed implementation plan facilitates continuous and consistent assessment, ensuring effective implementation of the improvement measures and be able to compare results from resilience assessors—different WSSAs.

1.6 THESIS ORGANIZATION

The current research document is a PhD thesis with publications. The University of Auckland guidelines require the PhD candidate to be the lead author for the published and unpublished publications composing the core of the thesis. This thesis format requires the introduction and conclusion chapters. As such, the thesis encompasses an introduction chapter, eleven core chapters, and a conclusion and recommendations chapter. The core chapters align with the need for achieving the research objectives. The chapters and corresponding articles and manuscripts are listed below. Chapter two and chapter four address the first objective of the research; chapter three is for the general methodologies of the research; chapter five through ten address the second objective of the research; chapter eleven addresses the third objective of the research, whereas chapter twelve addresses the fourth objective of the research, and chapter thirteen is for conclusions and recommendations.

- ❖ **Chapter 2: Conceptualizing Resilience in the Water Supply Sector;** Examines the concepts related to resilience and evaluates factors influencing the resilience of water supply systems globally and in Tanzania.

  Manuscript: Sweya, L. N., Wilkinson, S., & Chang-Richard, A. (2018). Understanding Water Systems Resilience Problems in Tanzania. *Procedia Engineering*, *212*, 488-495. https://doi.org/10.1016/j.proeng.2018.01.063
- ❖ **Chapter 3: Research Approach**
- ❖ **Chapter 4: Evaluating On-ground Resilience Needs for Water Supply Systems in Tanzania;** Identifies on-ground Tanzania water supply systems resilience problems and the needs for resilience improvements

  Manuscript: Sweya, L.N., Wilkinson, S. & Kassenga, G. (2019). *Resilience improvement needs for public water supply systems in Dar Es Salaam.* Contributing Paper to Global Assessment Report "GAR" for Disaster Risk Reduction 2019. Geneva, Switzerland: UNDRR. https://www.undrr.org/publication/resilience-improvement-needs-public-water-supply-systems-dar-es-salaam
- ❖ **Chapter 5: Development of Technical Variables for Measuring the Water Supply Systems Resilience;** Identifies variables/factors that can be used to measure the technical resilience of Tanzania water supply systems

  Manuscript: Sweya L.N., Wilkinson S., Kassenga, G.& Lugomela, G. (2020). Development of a Tool for Measuring Resilience of Water Supply Systems in Tanzania:

Technical Dimension (second version of revised manuscript submitted: Journal of Water Resources Planning and Management-ASCE)

- **Chapter 6: Development of Organizational Variables for Measuring the Water Supply Systems Resilience;** Identifies variables/factors that can be used to measure the organizational resilience of Tanzania water supply system

  Manuscript: Sweya, L. N., Wilkinson, S., Kassenga, G., & Mayunga, J. (2020). Developing a tool to measure the organizational resilience of Tanzania's water supply systems. *Global Business and Organizational Excellence*, 39(2), 6-9 https://doi.org /10.1002/joe. 21985

- **Chapter 7: Development of Environmental Variables for Measuring the Water Supply Systems Resilience;** Identifies variables/factors that can be used to measure the environmental resilience of Tanzania water supply systems

  Manuscript: Sweya, L. N., & Wilkinson, S. (2020). A tool for measuring environmental resilience to floods in Tanzania water supply systems. *Ecological Indicators*, *112*, 106165. https://doi.org/10.1016/j.ecolind.2020.106165

- **Chapter 8: Development of Social Variables for Measuring the Water Supply Systems Resilience;** Identifies variables/factors that can be used to measure the social resilience of Tanzania water supply systems

  Manuscript: Sweya, L. N., Wilkinson, S., Kassenga, G.& Mayunga, J. (2020). A Social Resilience Measurement Tool for Tanzania's Water Supply Systems (Under review: International Journal of Disasters Risk Reduction)

- **Chapter 9: Development of Economic Variables for Measuring the Water Supply Systems Resilience;** Identifies variables/factors that can be used to measure the economic resilience of Tanzania water supply systems

  Manuscript: Sweya, L.N.& Wilkinson, S. (2020). Tool Development to Measure Resilience of Water Supply Systems in Tanzania: Economic Dimension (Under review: Jamba Journal of Disaster Risk Studies)

- **Chapter 10: A Multi-dimensional Tool for Measuring Resilience of Water Supply Systems in Tanzania;** Combines the variables into a multi-dimensional resilience tool to measure the Tanzania water supply systems resilience.

  Manuscript: Sweya, L. N., Wilkinson, S., Mayunga, J., Joseph, A., Lugomela, G., & Victor, J. (2020). Development of a Tool to Measure Resilience against Floods for Water Supply Systems in Tanzania. *Journal of Management in Engineering*, *36*(4), 05020007. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000783

- **Chapter 11: Assessing the Validity of Tanzania Water Supply Systems Resilience Measurement Tool;** Evaluates the content validity of the multi-dimension tool, its applicability and generality in the Tanzania water supply systems

  Manuscript: Sweya, L.N.& Wilkinson, S. (2020). Validity Assessment: An Example of Tanzania Water Supply Resilience Measures. (Under review: Journal of Applied Water Engineering and Research).
- **Chapter 12: Resilience improvement measures and tool implementation plan;** Identifies resilience improvement measures and proposes the implementation plan.
- **Chapter 13: Conclusion and Recommendations**

Chapter 2
Conceptualizing Resilience in the Water Supply Sector

The current chapter is based on the following article:

Sweya, L. N., Wilkinson, S., & Chang-Richard, A. (2018). Understanding Water Systems Resilience Problems in Tanzania. *Procedia Engineering*, *212*, 488-495.

2.1 INTRODUCTION

The current chapter examines the concepts related to resilience and evaluates factors influencing the resilience of water supply systems globally and in Tanzania. Resilience is related to the ability to absorb the effects of a disruptive event, minimize adverse impacts, respond post-event effectively, maintain or recover functionality, and adapt in a way that allows for learning and thriving while mitigating the adverse impacts of future events (Stevenson et al., 2015). The resilience concept intends to prepare for the growing threats of terrorism, natural hazards and other crises (Hwang et al., 2013). For instance, the effect of climate change intensifies the frequency and severity of disasters in which climate change-influenced floods have had severe implications to lifeline infrastructure such as roads, telecommunications, and water supply systems. With their essentiality to provide life-supporting critical services (Brown et al. 2010), water supply systems always need to operate continually.

Nevertheless, the inherent natural complexity of water supply systems exposes them to severe flood risks threats. The systems have a downstream and upstream interdependency with sectors such as transportation, industrial, agriculture, and power. Also, they closely interact with communities and the managing organizations increasing their vulnerability to flooding impacts. As indicated in chapter one, global water supply systems have experienced disaster impacts with significant implications for the water services delivery. Also, Tanzania water supply systems are vulnerable to several disasters (EM-DAT), flooding having a significant effect on the water supply systems, triggering among others, infrastructure failures, and water-related diseases (Paavola, 2008 and URT, 2003) that are linked directly to the lack of water supply systems resilience.

Despite the expectations that climate change will influence the increase in extreme weather impacts such as floods, droughts, cyclones, and tropical storms (Shemsanga, Omambia & Gu, 2010), the examination of water-related issues in the country have received little attention regarding the water supply systems' resilience to disasters. This chapter attempts to explore the principles relevant to water supply systems resilience, assess problems and approaches that can enhance resilience. As the chapter offers a general overview of this thesis' literature, other chapters present more comprehensive and specific literature review.

2.2 WATER SUPPLY SYSTEMS

Water supply systems are critical infrastructures which form the backbone of the community services to sustain life in both regular operations and in times of disasters/emergencies. Communities will fail to survive and recover from disruptions like disasters without the service of water supply systems. Several community operations, including cities, urban and rural settings depend on water supply systems. For instance, water supply systems support hydroelectricity production, agricultural production, livestock production, industrial production, the wellbeing of ecosystems, and human life. Such wide-spread significance underlines their criticality and the value of their continued operations and existence. Water supply systems typically include water sources, water intakes, treatment plants, pumps and pumping stations, transmission mains, reservoirs, distribution networks, and cyber networks (Van Leuven, 2011). Such physical infrastructures require organizations that are responsible for their development, protection, and operations to ensure for the intended goal "water service provision." Also, water consumers, along with funding entities, and the environment, are integral parts of the systems. As such, water supply systems are socio-ecological-technical systems (Newman et al., 2011) in the sense that factors such as technical-physical infrastructures, social-water users, ecological-water sources need to be held in the same bucket for sustainable water service provision. The next section further describes with an example of the Tanzania water supply systems.

2.2.1 Tanzania water supply systems

Tanzania water supply systems play a critical role in public health, environmental wellbeing, agricultural production, industrial production, and the economy. In 1891 the government invested in developing a piped water supply system in Dar Es Salaam (Kjellén, 2000), the system embraced a cost-sharing mechanism. The first President of Tanzania's declaration of "free water for all" then replaced the cost-sharing approach (Rugemalila &

Gibbs, 2015). The economic crisis of the 1970s constrained the "free water for all" policy; in the mid-1980s the government re-adopted the cost-sharing program. Later on, after the establishment of the National Water Policy in 1991, the cost-sharing program was replaced by a focus on full cost recovery and private sector participation.

As shown in **Figure 2.1,** the existing Tanzania water resource is in the form of rivers, lakes, and groundwater, the resource is governed and managed by the water policy of 2002 and the Water Resources Management Act 2009. The latter is preceded by Act no. 10 of 1981, which divided the management of water resources in the country into nine water basins (Sokile, Mwaruvanda & Koppen, 2005). The Regional, District and Township Water Supply and Sanitation Authorities under the Water and Sanitation Act 2009 and its amendment in 2019, manage the water infrastructures. After being formed under the Energy and Water Utilities Regulatory Authority (EWURA) Act 2001 (Kjellén, 2008), the EWURA became active in 2006, with the responsibility for performance monitoring of all commercial-run utilities, including water supply systems. Additionally, the Tanzania Environmental Management Act 2004, is responsible for environmental conservation assisting in protecting the water sources, catchments and recharge areas in the country. Other government institutions which play a role in water management are Prime Minister's Office (Regional Administration and Local Government), Ministry of Finance and Economic Affairs and the Ministry of Health and Social Welfare (AQUASTAT, 2015).

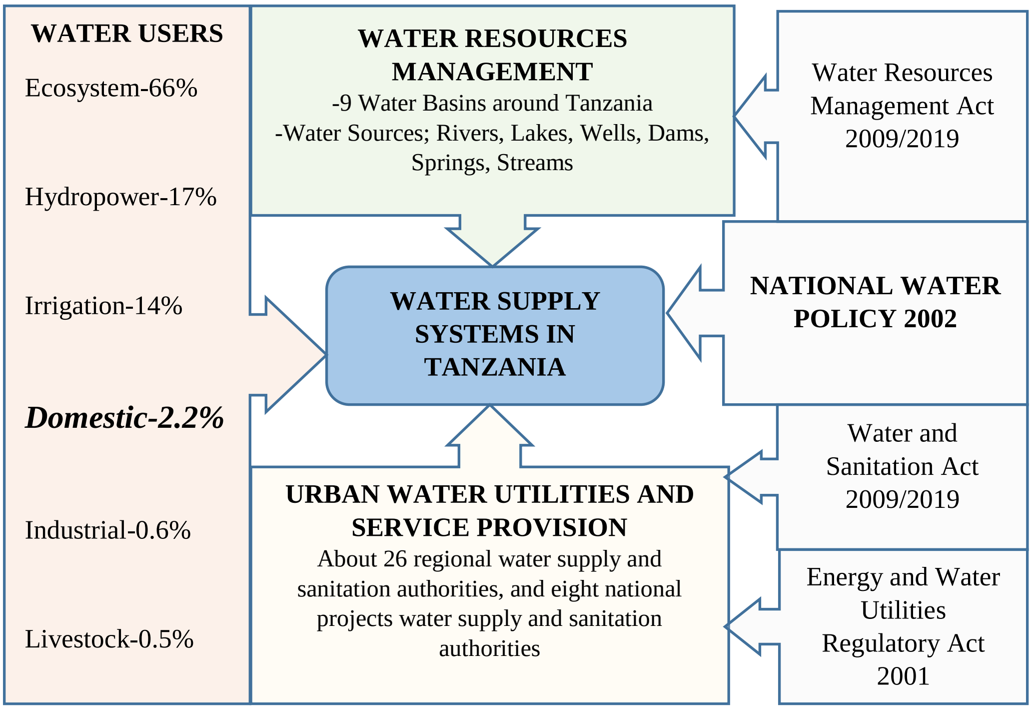


Figure 2.1: Water supply systems in Tanzania

According to URT, (2012b) the Tanzania population is 45 million—nearly 60 million at present—with an annual growth rate of about 3.1% with 70.4% of the total population residing in rural areas. There are currently 26 regional water authorities and eight national project water supply and sanitation authorities in the Mainland serving about 74.2% of the urban population (URT, 2018). There is significant water loss in the country, for instance, for three consecutive production years 2015/16, 2016/17, and 2017/18 about 53.09%, 46.00%, and 46.68% of water was lost in the Dar es Salaam water supply systems (URT, 2018). The water loss leaves a significant number of people without a reliable water supply in urban areas.

The actual estimated total renewable water resource in Tanzania-Mainland is 125,763 million m^3/year, and the total water demand is 76,716 million m^3/year equal to 61%, of which the most significant proportion (66%) is for the replenishment of "ecosystems" environmental demands, 17% is for hydropower, 14% for irrigation and only 2.2% is for domestic purposes (see **Figure 2.2**). The total human-related consumption is about 13,027 million m^3/year dominated by irrigation-about 82%, especially in Rufiji and Pangani water basins both contributing to about 46% of Tanzania's total irrigated area. The percentage of water withdrawn for agriculture shows that Tanzania is reliant on the existing water resources for agricultural production. Agricultural activities such as using fertilizer, and pesticides exact pressure on the water systems ecology. Industrial discharges and emissions also impact the water systems, whereas, a large population "over 80%" uses onsite sanitation generating greenhouse gases and polluting the groundwater (Mato, 2002). The water resources vulnerability index "10%" (Figure 2.2) suggests there are low vulnerabilities in the overall Tanzania water sources, although individual basins such as Wami/Ruvu exhibit high vulnerability due to urbanization and rapid population growth, having consequences to the resilience.

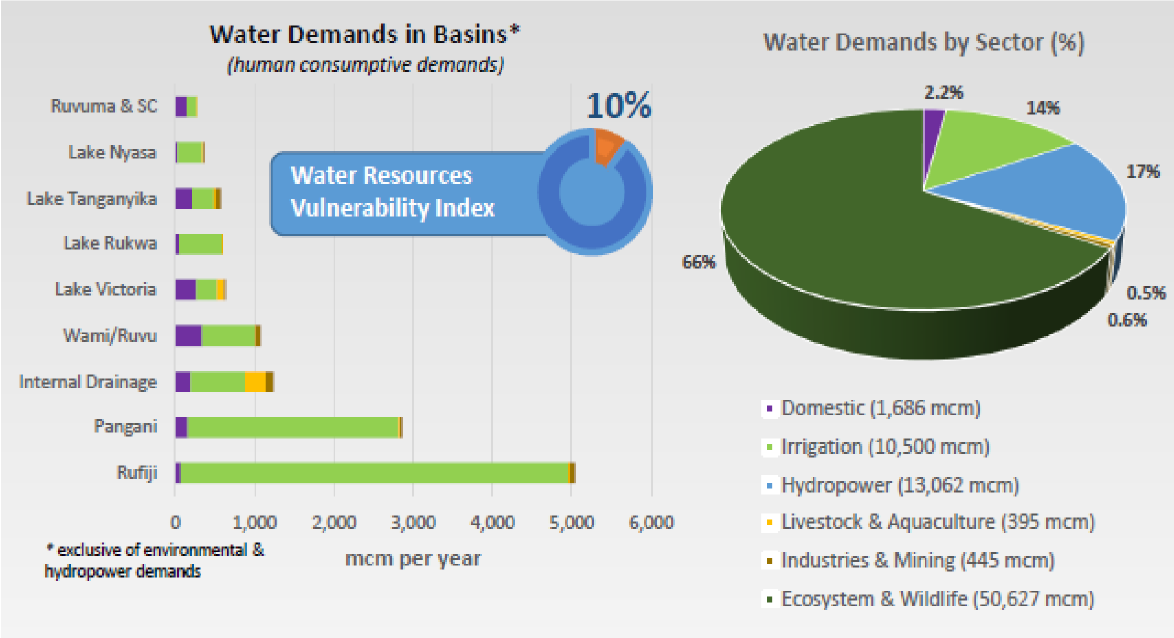


Figure 2.2: Tanzania water demand (Source; MoW-Tanzania Mainland, 2020[3])

Tanzania urban community water service is through public water utilities-Regional Water Supply and Sanitation Authorities (R-WSSAs) and National Projects Water Supply and Sanitation Authorities (NP-WSSAs), Community-based Water Supply Organizations (COWSOs), and privately-owned infrastructures and wells/boreholes. The water sector's privatization initiatives in 2003 (Kjellén, 2008) aiming to improve the water service in the country led to several private companies investing by either building small-scale water infrastructure or by delivering the service through water trucks. Consequently, the price of water increased significantly due to the vending-chain, and the poor population have been the most affected. The country's water sector development program (WSDP) running between 2006-2025 aiming to improve the water service coverage in the country through the construction of new infrastructure, and rehabilitation and replacement of few old infrastructures both in rural and urban areas have seen the service coverage noticeably increasing. For instance, the "access to improved sources of water" increased from 54.5% according to the Tanzania Demographic and Health Survey (TDHS) of 2010 (NBS & ICF Marco 2011) to 61% according to the 2015-2016 Tanzania TDHS and Malaria Indicator Survey (URT, 2016). Such improvements are significant; however, the question remains about the resilience of the systems to be able to provide the water service continuously when disasters occur.

[3] https://www.maji.go.tz/index.php/pages/articles

2.2.2 Vulnerability of the water supply systems

Hughes & Healy (2014) adopting from the UNISDR (2004), defined vulnerability as the propensity of exposed elements such as human beings, their livelihood, and assets to suffer adverse effects when impacted by hazard events. Similarly, the Tanzania Climate Change Strategy (TCCS) (URT, 2012c) with a more specific definition refers to vulnerability to the degree of susceptibility to the adverse effects of climate change. Vulnerability is the function of the hazard to which the system exposes to, as well as sensitivity, and capacity for adaptation (adaptive capacity) (Hughes & Healy, 2014 and URT, 2012c). Based on such descriptions, a hazard according to UNISDR (2004) refers to a potentially damaging physical event, phenomenon or human activity that may cause the loss of life, injury, property damage, social and economic disruptions or environmental degradation. For water supply, hazards that lead to vulnerabilities range from natural to human-made hazards, from short-term to long-term-hazards. Globally, natural and human-made disasters have had significant impacts on the water supply systems leading to failure of functionality and lack of timely delivery of water services to the communities. Earthquakes, floods, landslides, climate change, are among the most pronounced hazards with grave consequences to water supply systems. Such hazards have also affected Tanzania's water supply systems; first, the URT (2012c) vulnerability definition is cognizant of the climate change hazards that are already affecting the country, as some parts of the country are battling drought, others receiving severe rainfall leading to deadly floods. The 2016 earthquake in Kagera region and the recent low magnitude earthquake "April 2020" in the Lake Victoria regions also suggest that there is a high possibility of significant magnitude earthquakes that can affect the water supply systems.

Table 2.1: Summary of the disasters that have affected Tanzania between 1964 to 2019

Disaster type	Disaster subtype	Events count	Total deaths	Total affected	Total damage ('000 US$)
Drought	Drought	10	0	12737483	0
Earthquake	Ground movement	6	26	148592	458000
Earthquake	Tsunami	1	10	0	0
Flood	NA	20	333	748010	7510
Flood	Flash flood	5	69	78246	2000
Flood	Riverine flood	22	431	382347	280
Landslide	Landslide	1	13	150	0
Storm	Convective storm	4	47	6394	0
Storm	Tropical cyclone	2	4	2002500	0

Source: (EM-DAT: Last accessed June 2020)

From **Table 2.1**, of all disasters, floods seem to be of significant concern due to their frequency and the impacts on people's lives. Very few disasters have registered total damages, especially none-have indicated that infrastructures such as water supply were affected; however, floods have been consistent with epidemic diseases such as both claiming lives of people in the same years (see **Table 2.2**). Such diseases are bacterial diseases related to water consumption suggesting that the water supply systems experienced disruptions. Also, studies indicate that, very often, floods have caused infrastructure failures, and water-related diseases (Paavola, 2008 and URT, 2003).

Table 2.2: Floods vs bacterial diseases over the years

Year	Disaster type	Disaster subtype	Total deaths	Total affected
1990	Epidemic	Bacterial disease	200	NA
1990	Flood	NA	6	868
1990	Flood	Riverine flood	183	162000
1997	Epidemic	Bacterial disease	2329	42350
1997	Flood	NA	46	7104
1997	Flood	Riverine flood	37	3028
1998	Epidemic	Bacterial disease	1871	35824
1998	Flood	Flash flood	61	4600
2000	Epidemic	Bacterial disease	16	254
2000	Flood	Riverine flood	36	1817
2001	Epidemic	Bacterial disease	3	103
2001	Flood	Flash flood	5	200
2002	Epidemic	Bacterial disease	9	149
2002	Flood	Riverine flood	9	1200
2009	Epidemic	Bacterial disease	12	600
2009	Flood	Riverine flood	38	50000
2015	Epidemic	Bacterial disease	582	37712
2015	Flood	NA	12	5000

Source: (EM-DAT: Last accessed June 2020)

As indicated in chapter one, the sensitivity of the country's water supply systems is due to several problems/factors such as poor planning, poverty, weak infrastructure, and non-functioning stormwater drainage, whereas section 2.5.1 discusses further sensitivities. About 73% of the urban-WSSAs can generate adequate internal funds to cover their day-to-day operating and maintenance expenses, while they cannot generate funds for depreciation and return on investment. Also, 23% can generate own funds to meet only operational and maintenance costs without covering a particular part of plant electricity costs (URT, 2018), underling their inability to generate appropriate funds for contingency plans and adopt proactive steps to mitigate vulnerabilities in their water supply systems. Chapter four dedicates a discussion on the vulnerability and failure modes of the water supply systems through determining the on-ground impacts of floods on water supply systems.

2.3 DISASTER MANAGEMENT

The United Nations Office of Disaster Risk Reduction, UNDRR, defines a disaster as a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts[4]. The forms in which disasters occur include; natural or human-made, onset or prolonged set that have different degrees and types of physical and social impacts (Brown et al., 2010). Natural disasters are a product of such an event that has a profound effect on properties, lives, economy, or environment, beyond the coping ability of the affected party. They are events that are influenced by the existence of extreme natural events such as earthquakes, floods, and tsunami or due to biotic organisms (Specht, 2006). Natural disasters, whether of meteorological origins such as cyclones, floods, tornadoes, and droughts or of having geological nature such as earthquakes and volcanoes, are well known for their devastating impacts on human life, economy, and environment. With the tropical climate and unstable landforms, coupled with high population density, poverty, illiteracy and lack of infrastructure development, developing countries are more vulnerable to suffer from the damaging potential of such disasters (Jayaraman Chandrasekhar & Rao, 1997 cited in Lin Moe & Pathranarakul, 2006). Tanzania established a Disaster Management Act in 2015. The act indicates that the Prime Minister's Office (PMO)-department of disaster management is the responsible agency for inter-sectoral coordination of disaster management matters in the country. The department is responsible only for policy formulation and provision of guidelines, whereas the responsibility for mitigation of disaster impacts rest with the sectors, local government authorities, and other technical institutions. That said, such activities in the water sector rest on the Ministry of Water

[4] https://www.undrr.org/terminology/disaster

and its organs, including the water supply and sanitation authorities (Disaster Management Act, 2015).

2.2.1 Disaster management and Disaster risk management

The field of disaster management originates from the Cold War when planning for nuclear war where the building of bomb shelters was encouraged; once the threat of a nuclear war withdrew, concerns turned towards responding to natural disasters (Pearce, 2003). The focus was to reduce the risk posed by actual and potential hazards (Alexander, 2002). In that sense, proper management seeks to minimize the impacts of a disaster, not by day to day or year to year activities, but through responding to exceptional circumstances (Specht, 2006). The management involves five generic phases—prediction, warning, emergency relief, rehabilitation, and reconstruction (Jayaraman et al., 1997) thus, is based upon four distinct components—*mitigation, preparedness, response, and recovery* (Coppola, 2006). With the increase of risks due to development activities and inadequacy of traditional disaster management to address them, calls for a new approach "disaster risk management" (de Guzman, 2003) comprising of all forms of activities to avoid (prevent) or to limit (mitigation and preparedness) adverse effects of hazards (UNISDR, 2004).

Comfort, Boin & Demchak, (2010) and Coppola, (2006) indicate that no nation, regardless of its wealth or influence, is so far advanced as to be entirely immune of disasters' adverse effects. Comfort et al. (2010) suggest further that if we cannot predict or foresee the urgent threats we face, prevention and preparedness—related to disaster risk management—become difficult thus, the concept of resilience holds the promise of an answer. Besides, Boin & McConnell (2007) suggest that administrative and societal capacities can be enhanced to cope with those conditions by introducing a complementary strategy-promotion of resilience. Resilience points to the qualities that are central to disaster management, namely the ability to restore or sustain required operations by responding in the situation by being prepared when the disturbance happens and finally by using the lessons learned to rearrange or restructure how it works (Masys, 2015). As such, effective response during immediate aftermath critically depends on the resilience of citizens, first-line responders, and operational commanders (Boin & McConnell, 2007). Also, resilient systems reduce the probability of failure; the consequences of failure, and the time of recovery (Tierney & Bruneau, 2007) leading to enhanced capacity of the communities to survive disaster risks.

2.4 RESILIENCE PERSPECTIVE

Chapter one has indicated that the magnitude and frequency of weather-related disasters are increasing due to the failure of climate change mitigation and adaptation measures. Particularly, communities living in urban areas comprising of complex networks of societal systems and critical infrastructures are at high risk. Lacking the ability to predict the future climate change patterns contributes to the need for building resilience so that to equip communities to cope with future disaster impacts. The Hyogo Framework of Action (HFA) 2005-2015 assisted the efforts of nations and communities to become more resilient and to cope better with the hazards threatening their developments (UNISDR, 2005). Indicating that disaster risk reduction should be part of our everyday decision from how people educate their children to how they plan their cities and that each decision can make us either more vulnerable or more resilient. Preceded by the HFA, Sendai Framework of Disaster Risk Reduction (SFDRR) advocates the sustainable reduction of disaster damage to infrastructure and disruption of basic services including developing resilience and investing in disaster risk reduction for resilience (UNISDR, 2015). The SFDRR aligns with the Sustainable Development Goals (SDG-9) suggesting having resilient infrastructures that are capable of surviving disaster risks.

Initiatives such as the “City Resilience Framework (2014)” funded by the Rockefeller Foundation and developed by Arup International Development indicate that cities rely on a complex web of interconnected institutions, infrastructure and information (Silva & Morera, 2014). They are places where stress accumulates, or sudden shocks occur that may result in social breakdown, physical collapse or economic deprivation. The number of people is influencing the scale of urban risks, and risks are increasingly unpredictable due to complexity. Such arguments underpin the need for more resilient systems that are reflective, robust, redundant, flexible, resourceful, inclusive and integrated. Among others, the framework advocates the reduction of physical vulnerability and continuity of the critical services through diverse provisions and active management, maintenance of ecosystems and infrastructure, and contingency planning. The framework emphasizes the embedment of resilient critical infrastructures to enhance the overall cities resilience, such as improving the cities’ community’s capacity to respond and recover from potential disasters. A more specific initiative to water supply systems “the City Water Resilience Approach (CWRA)” was developed in collaboration with ARUP, The Stockholm International Water Institute, 100 Resilient Cities, and Organization for Economic Cooperation and Development. The CWRA responds to a demand for innovative approaches and tools that help cities build water resilience at the urban scale. The approach details five steps to guide cities through initial stakeholders’ engagement and baseline assessment, through action planning, implementation and monitoring of new initiatives that build water resilience.

2.4.1 Local policies related to resilience building in the country

National Adaptation Program of Action (NAPA) 2007

Developed to align with the United Nations Framework Convention on Climate Change (UNFCCC) (1992), Tanzania’s NAPA (URT, 2007) vision is to identify immediate and urgent actions for climate change adaptation that are robust enough to lead to long-term sustainable development in a changing environment. Among others, NAPA aims to identify and develop immediate and urgent activities to adapt to climate change and climate variability and protect life and livelihood of people, infrastructure, biodiversity and environment. NAPA indicates that vulnerabilities such as decreased/increased runoff in river basins, encroachment into stream ecosystems, water pollution, water logging due to increased water flow are already occurring in the water sector. To address the vulnerabilities, NAPA suggests potential adaptation activities such as developing alternative water storage programs and water harvesting technologies for communities, strengthening integrated water resources management, and developing both surface and subsurface water reservoirs. Also, promoting community-based catchments conservation and management programs, promoting new water serving technologies in irrigation, developing recycle and reuse facility in the industrial sector and potentially in households, developing early warning systems, and desalinizing and defluoridating water in areas with saline and fluoride content.

National Climate Change Strategy 2012

The goal of the National Climate Change Strategy (URT, 2012c) is to enable Tanzania to effectively adapt to climate change and participate in global effort to mitigate climate change with a view of achieving sustainable development in line with the Five Years National Development Plan; The Development Vision 2025, as well as national sectoral policies. The strategy expects to reduce vulnerability and enhance resilience to the impacts of climate change. The implementation of the strategy enables the country to put in place measures to adapt to climate change and mitigate GHG emissions in order to achieve sustainable development through climate pathways.

Among others, the strategy' specific objectives include building the capacity of Tanzania to adapt to climate change impacts and enhancing the resilience of ecosystems to the challenges posed by climate change. The strategy indicates that the projected effects of climate change could have significant effects on the nation's infrastructure system, including water supply. As infrastructure assets have long operational lifetimes, they are sensitive not only on the existing climate at the time of their construction but also to climate variations over the decades of their use. Preparedness, in planning and managing the impacts of climate change is unavoidable to increase the resilience of both new and existing infrastructure. As such, the goal is to have an infrastructure system that is resilient to climate change through-mainstreaming climate change aspects into infrastructure initiating designing and development and promoting the deployment of appropriate technology in infrastructure designing and development. The strategy leads to strategic actions such as, promoting and enhancing the use of climate change-adaptive building codes and standards, promoting coordinated planning in infrastructure designing, development and using suitable technologies, promoting the construction and rehabilitation of relevant infrastructure, and promoting infrastructures insurance schemes.

National Water Policy 2002

The National Water Policy (URT, 2002) develops a comprehensive framework for sustainable development and management of the nation's water resource, in which effective legal and institutional framework for implementation are put in place ensuring that beneficiaries participate fully in planning, construction, operation, maintenance, and management of the community-based domestic water supply schemes. The policy addresses three sub-sector issues; *Water Resources Management*-providing a comprehensive framework for promoting optimal, sustainable and equitable development and use of water resources for the benefit of the present and the future generation; *Rural Water Supply*-improving the health and alleviating poverty of the population through improved access to adequate and safe water; *Urban Water Supply and Sewerage*-achieving an efficient development and management of urban water supply and sewerage services. The general emphasis is on sustainable water development, implying that the actions of the present generation to develop and use water resources should ensure that the future generation enjoys the benefit of the resource. As such, it entails taking into consideration things such as; maintaining water quality to meet the agreed objectives and standards, and that human actions do not impair the long-term availability of freshwater stocks. Also, instituting integrated water resources management, putting in place effective and sustainable strategies to address natural and human-made water resources problems.

The integrated water resources management adapted by the policy aligns with the Dublin Statement on water, and sustainable development (1992) and the UN Conference on Environment Development, Rio de Janeiro, 1992 Agenda 21, chapter 18, suggesting that water is a finite and vulnerable resource, and water management and development should base on a participatory approach involving users, planners, and policy-makers. As such water resources management among others aims to promote the management of water quality and conservation, improve the management and conservation of ecosystems and wetlands, promote integrated planning and management of water resources, and raise public awareness and broaden stakeholder participation in the planning and management of water resources. Also, the policy acknowledges the need for flood mitigation plans to address the floods that have been occurring in the country in the form of runoff processes and landslides-mudflow causing losses of property and life and damage to infrastructure. However, disaster management practices have focused on remedial actions rather than *preventive approaches*, underlining vulnerabilities that contribute to loss to life and property when major floods occur.

There are several policy issues related to urban water supply and sanitation services, the policy's goal is to have improved infrastructure for sustainable and efficient water supply to address the already aging and poorly functioning infrastructure to cope with the increased demand and emergencies. The policy recommends pursuance of *Urban-specific strategies dealing with emergencies such as floods in order to guarantee water supply during such emergencies*. As such, urban water utilities are responsible for developing contingency plans and establish financing mechanisms and develop measures to deal with flood emergencies. The policy puts in place mechanisms for the protection of water sources from the encroachment of activities leading to pollution from wastewater disposal, agro-chemicals, and sedimentation to address the impact of pollution of water sources due to encroachment. The policy emphasizes the *demand-driven approach* for designing water supply systems, whereas among others promote staff training as part of capacity building in order to improve the performance of entities ensuring water supply meets the standards. Notably, urban water demand is increasing at a higher rate compared to the rate of infrastructure expansion due to high rate of population growth and urbanization. Such increase needs a water demand management approach to prevent wasteful water use and control leakages while prioritizing the low-income groups and communities by providing appropriate water supply services and having an efficient urban water supply services through private sector participation (PSP). Moreover, the policy promotes applied research and technological development through collaboration with sector stakeholders, local and international research institutions, and encourage local researchers' initiatives. In all cases, the policy focuses on sustainability lacking resilience mechanisms that would enhance the functionality of water supply systems during disasters. The reliance on demand-driven design approach emphasized by the policy, underlines the inadequacy of resilience-based approaches for improving the systems.

National Water Sector Development Strategy (NWSDS) 2006-2015

The National Water Sector Development Strategy (URT, 2008a) sets out how the Ministry responsible for water implements the National Water Policy to achieve the National Strategy for Growth and Reduction of Poverty (NSGRP) targets. Also, guides the Ministry's formulation of the harmonized National Water sector Development Plan and Water Sector Development Program as inputs into the financial planning Framework for Medium-Term Expenditure. While acknowledging that disaster management in the country relies on the intersectoral coordination placed "only for policy formulation and provision of guidelines" under the Prime Minister's Office-Disaster Management Department, the response for mitigation of disaster impacts rests with the sectors, local government authorities, and other technical institutions. As such water-related disasters have been managed based on limited inter-sectoral coordination, inadequate early warning systems, and inadequate enforcement of preventive measures underlining disaster mitigation actions focusing on remedial rather than preventive approaches. Intending to provide advanced warning of possible disasters, including those related to long term climate change, and contingency plans and resources available to minimize the impact of natural and other disasters, the strategy for disaster management embraces, among other things, instituting contingency plans, adaptation and mitigation measures, and procedures for minimizing the impact of droughts, floods, climate change, accidental chemical pollution and other disasters

National Water Sector Development Program (NWSDP) 2006

The National Water Sector Development Strategy (URT, 2008a) sets out a strategy for National Water Policy implementation and in effect directs the formulation of the sub-sectoral investment programs, including the water resources management program and the urban water and sewerage program as inputs to the WSDP (URT, 2006a). The water sector development challenges include water insecurity as there is inadequate investment in constructed water storage and other water sources infrastructure to buffer against the impacts of floods (climate variability) and inadequate investment in pollution control, investment in costly but unreliable infrastructure, and inadequate investment in water resources management systems. Few water supply and sanitation authorities are replacing aging facilities while depending on donor assistance or grants from the Ministry of Water (MoW) for major renovations, justifying their approaches to maintaining and repairing visible leakage distribution networks due to inadequate leakage detection technology. Also, several issues are related to the stakeholder and private sector involvement. There is relatively weak private sector active participation in the water sector needing resources for capacity building and quality assurance. The government retaining the role of decision-making *undermines real community involvement in project* planning and ownership—a natural bias for schemes to favor the more powerful and better off at the expense of the poor. Also, inadequate management experience for those entrusted to manage the newly established community water supply entities indicates a certain level of inability to enhance continuous water service including in disaster times

The overall WSDP objective is alleviating poverty through improvements in the governance of water resources management (WRM) and the *sustainable delivery of water supply services.* In the WSDP context, WRM seeks to establish and implement a robust monitoring and pollution control program for water quality and to assess the water resources and prepare IWRM plans and mitigation against floods and droughts. Specifically, flood interventions are proposed, such as planning and agreement on disaster response organizational structure, preparation, financing and implementation of disaster early warning systems, development of contingency plans and procedures and staff training in their use, and development of dam-safety measures to *mitigate the impacts of floods and identifying and conducting studies on climate change responses*. For urban water supply, the NWSDP aims to improve and sustain quality and quantity of drinking water from 74% to 90% by 2010 and 100% by 2025 through upgrading and expanding the water supply systems while having UWSAs responsible for operating and maintaining their works including replacing aging facilities and using revenue from the sale of water. As the results of the WSDP, the water service coverage has increased to about 80% of the urban population and about 70% of the rural populations

Guidelines for the Preparation of Water Safety Plans (WSP) - Resilient to Climate Change for Urban Water Supply Utilities

Other initiatives such as the guidelines for preparing water safety plans-resilient to climate change for urban water supply utilities (URT, 2015) exist showing that Tanzania is attempting to adopt resilience-based mechanisms in the water sector. In particular, the Water Safety Plan (WSP) intends to enable operators and managers of the urban water supply systems to know the systems thoroughly, identify where and how problems could arise. Also, put multiple barriers and management systems in place to stop the problems before they happen and making all the parts of the system work to ensure the safety of intended water for human consumption and other domestic uses in adequate quantity. The WSP further intends to play a vital role as tools for comprehensive risk assessment and risk management that will encompass all steps in the water supply system from catchment to consumption. The introduction chapter briefly discussed a few more initiatives in terms of projects-related to resilience building in the water sector, showing that the country is already taking some measures to enhance resilience in the water sector, yet failing to fully-operationalize the concept due to lacking appropriate measurement instruments

2.4.2 The position of resilience in relation to other concepts

It is therefore evident that policies, strategies, and programs reveal the awareness of the presence of "most pronounced" disaster risks in the country, especially climate change-related risks such as floods and drought. By drawing common concepts from the earlier discussions, the research draws few themes from the policies, programs, and strategies and guidelines; 1. risks affecting Tanzania water supply systems, 2. measures for ensuring water supply availability during disasters, and 3. interactions of Integrated Water Resources Management (IWRM), sustainability, risk management, vulnerability, and resilience

Risks affecting Tanzania water supply systems

Water insecurity is the major threat for Tanzania water supply systems. Water insecurity relates to lacking the access to adequate quantity of water and acceptable quality for human use and the environment. Also, it involves the lack of enough water to meet all critical water needs as well as the inability to adapt to major water disasters (Habiba, Abedin, & Shaw, 2013). Such disasters as drought, floods, landslides, and climate change are the main drivers towards water insecurity in the country. As such, water supply systems are unable to adequately and continuously support the community’s functionality in terms of acceptable quantity and quality of water. Acknowledging such risks in the policies, programs, and strategies underline the awareness of the responsible organization of the potential impacts to the community because of lacking adequate water service in terms of acceptable quantity and quality. With the main goal for the water supply systems to providing water service to the community and the environment, the country has strategized several measures to ensure that the service is available. Nevertheless, the National Water Policy is reliant on demand-based planning and designing for water supply infrastructure focusing on coverage “water for all” which may not adequately prepare the systems to withstand the impacts of disasters such as floods.

Measures for ensuring water availability during disasters

There are several measures from the policies, programs, and strategies to ensure continued availability of the water service. In all cases, there are few measures related to responding to disruption with more emphasis on traditional disaster management and risk management approaches. Such measures are usually ineffective and do not adequately prepare the water supply systems to survive the sudden shocks or impacts of disasters. They are more tailored to enhance sustainability rather than resilience. About 18 different measures are evident, most of which situate in the first two phases of disaster management which are pertinent to disaster risk management. For instance, mitigating the impacts of floods, replacing aging infrastructures, promoting management of water quality and conservation, improving community-based catchment conservation and management programs, and adapting to climate change and mitigating GHG emissions, maintaining and repairing distribution networks, and preparedness. Perhaps most of such measures are even focused on the water resources management rather than the water supply infrastructure. On the second phase of disaster management, contingency plans, promoting infrastructure insurance systems, and disaster response are present although in general, the measures are not resilience-based and could easily be ineffective in the face of disasters. Moreover, all such mitigation response measures are supposed to be carried out by the sectoral ministry; more so in the water supply systems, the water supply and sanitation authorities are responsible. With their financial incapacities leading to inability to develop contingency plans and funding mechanisms to deal with emergencies, they are not able to effectively implement the measures, thus focusing on remedial actions. Also, the agencies dealing with water supply have inadequate capacity for disaster risk management and resilience building, needing support from organizations specialized in those areas.

Integrated Water Resources Management (IWRM), sustainability, risk management, vulnerability, and resilience

The emphasis is on using the IWRM approach throughout the water policy, strategy and programs to ensure that the utilization of the water resource is proper to achieve sustainability. IWRM is a framework designed to improve the management of water resources based on four fundamental principles adopted at the January 1992 Dublin International Conference on Water and Environment, and the June 1992 Rio de Janeiro Earth Summit. The principles include;

1. freshwater is finite and vulnerable resource essential to sustain life, development and the environment;
2. water development and management should rely on a participatory approach, involving users, planners, and policy-makers at all levels;
3. women play a central part in the position, management, and safeguarding of water; and
4. water has an economic value in all its competing uses; thus, it is an economic good (White, 2014).

Such principles align with the principles of sustainability, risk management, and resilience. For instance, the first principle acknowledges the vulnerability of the water resource which is consistent with the exposure to different risks, leading to the need for risk management activities to avoid (prevent) or to limit (mitigation and preparedness) adverse effects of hazards (UNISDR, 2004) to the water supply systems. Also, the IWRM principles lead to sustainable water resources through efficient use and protection of the resource to suffice the current and future generation of users. Sustainability is significant throughout the national water policy, strategy, and the program, aiming to reduce or eliminate environmental impacts to enhance the quality of the life of the communities. As such, the water resource utilization and functionality of the water supply systems aim to provide sustainable water supply services to the communities and the environment. A further suggestion is that sustainability focuses on increasing the quality of life with respect to the environment, social, and economic considerations in both present and future generation (Collier et al., 2013) perhaps increasing the quality of life concerning water supply services considerations in both present and future generation for the current study. On the other hand, resilience's primary goal is to have cities, structures, systems, or resources that are able to make it through disasters or sudden changes. Resilience focuses on the response of systems (including environmental, social, economic) to both extreme disturbances and persistent stress (Marchese et al., 2018). Both sustainability and resilience refer to a state of a system over time, focusing on the persistence of the system under normal conditions, and in response to disturbances (Fiksel et al., 2014). The way sustainability and resilience interact when used concurrently is significantly important since given their similarities, they are separate and distinct concepts that are subject to misuse if neglecting their differences. Literature has prominently discussed three categories of frameworks to understand the rationale of such differences.

The first approach regards resilience and sustainability as separate objectives-in this approach, resilience and sustainability are concepts with separate objectives that lack hierarchical structure and that complement and compete with each other. Resilience in this aspect does not contribute to sustainability; neither does sustainability contribute to resilience. This approach is prevalent in civil infrastructures, although they potentially lead to conflicts and underperformance in both efforts (Marchese et al., 2018). The second approach views sustainability as the component of resilience-in this case, resilience "aiming to maintain some primary goal of critical functionality during and after disturbances" is the ultimate objective of the system with sustainability proposed as a contributing factor to resilience. As such, increasing sustainability makes the system resilient whereas, increasing resilience does not necessarily make the system sustainable (Marchese et al., 2018). The third approach considers resilience as a component of sustainability-this approach operates with the notion that increasing the resilience of a system makes the system sustainable but increasing sustainability does not necessarily make the system more resilient (Marchese et al., 2018). Also, without resilience, a system can only possess fragile sustainability (Ahern, 2013). In this approach resilience concepts are used to meet the systems sustainability objectives, i.e. in order to be sustainable, the system design processes need to consider the vulnerabilities to disturbances (Marchese et al., 2018).

There is a significant opportunity to develop sustainability practices that are more consistent with resilience methods. An example of such approach is to set sustainability as a critical function of the project, policy, or system to maintain during and after disturbances; here the emphasis is put on evaluating and building resilience for sustainable components of the system (Marchese et al., 2018). The Tanzania Water Policy's emphasis, as indicated earlier is on sustainability, so is the strategy and both programs I and II indicating that there is already a certain level of sustainability in the water supply systems. Building on that and acknowledging the ever-increasing impacts of climate change and its influence on the frequency and magnitude of floods, embedding resilience methods to enhance sustainability in both normal conditions and during disturbances is crucial. Such methods will also assist the implementation of NAPA, and its strategies to ensure the country's water supply resources and infrastructures can better cope with climate change and its impacts such as floods.

Likewise, vulnerability can be a component of resilience and vice versa. Although, Hughes and Healy (2014) suggest that, vulnerability is a deficit concept; thus, resilience and vulnerability are two ends of the continuum with resilience as a positive measure. Such argument is consistent with Folke et al. (2002) cited in Hughes and Healy (2014), indicating that vulnerability is the opposite side of resilience. As such, a resilient system is less vulnerable than a non-resilient system. The current research embraces such a fact, viewing resilience as a positive end of vulnerability; thus, by improving the resilience of water supply system will imply a reduction of the vulnerabilities.

2.4.3 Defining resilience

The resilience concept originates from a Latin word *resilio,* meaning 'to jump back' (Klein, Nicholls, & Thomalla, 2003). In that case, a resilient system has certain recovery characteristics to the original state (Proag, 2016), capable of withstanding short-term disruptions, overcoming disruptions, and being built or building itself after damage (Hwang, Forrester, and Lansey, 2013). Resilience has no accepted standard interpretation (Barnes et al., 2012), it is dynamic and undergoing several evolutions of prolonged refreshment and redefinition (Prior, 2015) because the concept applies to many disciplines (Agarwal, 2015; Perry 2013; Manyena 2006; Hughes & Healy, 2014). It was first introduced by Holling (1973) towards "Resilience and Stability of Ecological Systems," and got its prominence in 2005 after the hit of Hurricane Katrina (Tierney & Bruneau, 2007). Since then, several scholars have expressed varying views regarding the concept of resilience.

There are many resilience definitions in literature; for instance, infrastructure systems resilience is related to the system's ability to reduce the chances of a shock, absorb the shock and to recover quickly after a shock (Bruneau et al., 2003). In ecological and environmental aspects, resilience refers to the ability to absorb disturbances and reorganize itself into a better configuration while still retaining its fundamental characteristics (Walker et al., 2004). In social aspects, resilience is the ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change (Adger, 2000). For organizations, resilience concerns the ability to adapt, the need to detect the drift toward failure or weak signals, the organization's preoccupation with failure, and the level of organizational reliability (Lee et al., 2013). Furthermore, the ability of an economy or a local community to absorb and adapt to the negative effects of economic shock and move towards pre-disaster equilibrium or stability (Bastaminia et al., 2017) for economic aspects.

In all cases, resilience definitions contain features which are very similar to one another. Literature analysis for 32 definitions revealed that resilience contains such features as *anticipate, resist, reduce, withstand, recover, bounce on, adapt, organize itself, and timely recovery.* The commonest features include absorb/withstand, adapt, and recover indicated in 53%, 44%, and 41% respectively of all the assessed definitions, and others include resist (16%) and organize itself (19%). The critical characteristic is stability (Barnes et al., 2012); therefore, an efficient, resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and rapidly recover from a potentially disruptive event (Soldi et al., 2015). Such features align with The National Science Challenge definition by Stevenson et al., (2015) comprehensively developed by analyzing 120 definitions existing in literature " The ability to absorb the effects of a disruptive event, minimize adverse impacts, respond effectively post-event, maintain or recover functionality, and adapt in a way that allows for learning and thriving, while mitigating the adverse impacts of future events." The definition is as general, such as to acknowledge both engineering resilience-the system returning to a single equilibrium after a disaster, and the ecological resilience-the possibility of the system to adapt to one of the multiple equilibriums. The definition draws together many features—such as absorbing the effects of disruptive events, minimizing adverse impacts, and mitigating future impacts—that are consistent with the IWRM, vulnerability, risk management, and sustainability. Such features form an appealing benchmark for understanding the concept of resilience especially for multi-dimensional systems such as water supply.

2.4.4 Measuring resilience

Resilience remains a theoretical concept unless there is the ability to measure (Prior, 2015). Resilience can be measured based on the functionality of the system and recovery time to pre-disaster state (Tierney & Bruneau, 2007; Moteff, 2012; Vugrin et al. 2010). The assessment can be hazard-based, or consequence based. However, Hughes & Healy (2014) suggest that applying a holistic approach that considers non-specific hazards should be a priority for organizations against the emphasis on common hazards. Bruneau et al. (2003) developed a conceptual framework with four dimensions: Technical, Organizational, Social, Economic, for measuring community resilience. The framework's emphasis is on a holistic approach looking beyond physical and organizational systems to the impacts of social and economic networks (Tierney & Bruneau, 2007). With the same dimensions, different performance measures such as *robustness, redundancy, resourcefulness,* and *rapidity* are requisite depending on the system in the analysis.

For instance, for infrastructure, a robust system is strong enough to withstand impacts during adverse events by continually delivering an essential service. Robustness alone is not enough to render the system resilient, the system needs redundancy, such that the system has alternative components to substitute damaged components at the time of extreme events. Besides, a resilient system should easily and quickly recover from a potential disaster. Redundancy contributes to robustness (Agarwal, 2015). Other properties such as resourcefulness and rapidity relate to each other as rapidity is the speed of disaster recovery when resources are available, the recovery speed is high, and time is shorter than in situations of scarce resources. More details related to organizational, social, economic, and ecological aspects are in the respective chapters.

Why measure resilience?

Technological, natural and social systems' vulnerabilities are not predictable, whereas the ability to accommodate change without catastrophic failure is critical. Besides, people and properties fare better in resilient cities when struck by disasters as fewer buildings collapse, less power outage occur, fewer businesses become at risk, and fewer deaths and injuries occur. Moreover, the complex interdependencies and more complex and interconnected modern infrastructures lead to the need for an approach to thoroughly analyze where vulnerability lies and where resilience can be improved (Hughes & Healy, 2014). As such, resilience measures aim to;

- ❖ Deepen the understanding of resilience, shifting from abstract construct to concrete phenomenon
- ❖ Serve critical communication roles, provide people with a shared language and the means to enlist others in the common aim of improving resilience to disasters.
- ❖ Provide strategic and decision-making assistance by helping to identify where to begin work and apply the limited resources (Monica Schoch-Spana et al., 2019)
- ❖ Characterize resilience through the articulation of resilience constituents

- ❖ Raise awareness-using the measurement results as a method of communicating the need for resilience. Assisted by observable measures, it helps managers to direct resilience-related information to the entities whose resilience is low.
- ❖ Allocate resources for resilience
- ❖ Build resilience through detection and management of disruptions and their effects on low resilience entities, thereby helping risk management agencies to direct their assistance measures adequately.
- ❖ Monitor policy performance by assessing the effectiveness of resilience-building policies through longitudinal comparisons of resilience in those entities targeted by the policy (Prior & Hagmann, 2014)

The complexity of measuring resilience

As indicated earlier, resilience is a theoretical concept with ambiguous definitions, such that, the gap between theory and application can be closed by the ability to undertake its measurement. Just as there is no standard definition of resilience, also, there is no standard measure too (Willis, 2015). Measuring resilience is complicated due to the number of factors such as physical, social, organizational, and cultural (Prior, 2015) and needs a better understanding of unpredictable events (Hughes & Healy, 2014).

Resilience is inherently complex, and with increasing complexity comes greater difficulties in establishing measures to interpret the results (Prior & Hagmann, 2014). Developing a tool that meets the important interpretations while capturing the complexity of the concept as a policy-relevant phenomenon can be time-consuming and expensive. In the quest to simplify the issue, there is the need to understand about 1. absolute evaluation vs relative evaluation, 2. indicators of arbitrariness and weighting, 3. data quality, availability and sustainability, 4. context, place and threat specificity, and 5. fit for the purpose. An index is a way of simplifying the complexity, and many variables used to denote the phenomenon are the proximal representation of the actual subject of measurement and only assumed to be representative, suggesting that most indices only reflect *relative* measures than an *absolute* measure. The *relative* measure comparing between places, entities, or overtime, is useful only if someone wants a relational understanding of resilience (e.g. for allocating resilience development funds). It will not tell if a riverside community can be resilient to major flooding, only whether it is better than the neighboring riverside community. Literature also indicates the presence of *arbitrary* or *subjective* indicators, suggesting that it is almost impossible to identify/choose indicators that are measurable on the same scale; thus, transformation is necessary. Besides, *data quality, data availability,* and *data sustainability* may limit the resilience assessment process, for instance, since indicators are proxies, data may be accessible but not directly relevant to the measure. Moreover, it is challenging to develop a generic and direct measure of resilience, due to the enormous variety of proposed measures and theoretical conception in literature, whereas, precise framing of resilience to avoid vagueness is needed including-a sound definition, explicit policy linked to the definition, and explicit articulation of scale and context (Prior & Hagmann, 2014).

Resilience of what? and Resilience to what?

When dealing with resilience, a common question like "resilience to what?" is essential to specify the specific system configuration to be assessed. In previous sections, The National Water Policy (URT, 2002) has indicated that the Tanzania water sector experience three sub-sector issues; water resources management, rural water supply, and urban water supply and sewerage services. The current study focuses on the urban water supply part of the urban water supply and sewerage services. Due to the broad nature of aspects influencing the water supply services, the study also encompasses the water resources management issues pertinent to respective urban water supply systems. As such, the water supply system in the current study includes the physical infrastructures of the urban water supply systems, the organizations that operate the physical infrastructures, urban water users, economic aspects and the respective water resources-the environment. The Water and Sanitation Act 2009 indicates that the primary function of the urban water supply is to provide water services to the community through the lawful organizations-Water Supply and Sanitation Authorities (WSSAs). Such organizations are responsible for the functionality of the urban water infrastructures and the respective water sources. As such, the study assesses the *resilience of* urban water supply systems for all aspects of functionality and the wellbeing of the environments where the water sources exist.

The *resilience to what?* attempts to respond to the type of disturbance of interest (Hughes & Healy, 2014). It describes the potential resilience threats to the system of concern "water supply and its dimensions" (Liu, 2014). Previous sections have indicated that there is a wide range of hazards that can have significant consequences to water supply systems. However, Hughes& Healy (2014) suggest that a resilience assessment also requires an awareness that the hazard itself may be unpredictable and that the organization may require to think beyond the typical disaster scenarios. As such, the consequence scenario that directly relates to the loss of service as well as, other impacts is important to apply. Nevertheless, such consideration should not write-off an assessment of known hazards. Having said that, Tanzania—as indicated in section 2.2.2—is frequently exposed to flood hazards more than other hazards that have impacts on the water supply systems thus, the current study attempts to evaluate the *resilience to* flood hazards for the water supply systems.

Resilience assessment approaches

Bottom-up vs top-down

Assessing resilience encompasses two approaches; bottom-up approaches, also known as *ideographic* (Cutter, 2016) usually employing qualitative data and input from experts and non-experts (Monica Schoch-Spana et al., 2019); using community surveys and stakeholders' interviews to derive indicators directly and assess resilience (Parsons et al., 2016). Cutter (2016) suggests that such measures are locally generated and customized to a particular place through engaging communities or experts to develop resilience goals and to increase their capacity to achieve them. Top-down approaches, also known as *nomothetic* (Cutter 2016) are the products of an organization outside the community intended for use by oversight or expert-driven body and reliant upon standardized and centralized data to quantify resilience (Monica Schoch-Spana et al., 2019). They use existing secondary data, such as census or economic data to indirectly derive proxy indicators in assessing resilience (Parsons et al., 2016). Cox & Hamlen (2015) suggest further that top-down approaches involve an initial extensive literature review to identify common principles that can guide the resilience assessment process. The process establishes dimensions of resilience, which then allow an indicators identification process. Subsequently, experts are involved in identifying indicators that practitioners and policy-makers consider essential.

Formative vs summative

Top-down and bottom-up resilience assessment approaches can be formative or summative; Sharifi (2016) indicates that formative assessment is related to ex-ante "accounting for future uncertainty/based on forecasts" evaluation and continuous monitoring of the condition from early stages of the planning process. It is a process-based methodology aiming at enhancing adaptive capacity through the incremental improvement of the conditions. The assessment provides opportunities for learning and, given its iterative nature, it can be suitable for dynamic issues. On the other hand, summative assessments base on ex-post "actual" measures of the effectiveness of interventions; they are outcome-based, helping communities understand where they stand based in terms of resilience providing evidence needed for deciding about the necessity of modifying intervention strategies.

Standard assessment vs context-specific assessment

Further categories of assessment approaches include standard and context-specific (see **Figure 2.3**). Standard approaches are generic, taking into account key resilience characteristics without specific contextual attributes. Such assessment as all-hazard assessments falling under this category are high-level assessment looking at resilience measures in response to all hazards Hughes & Healy 2014). Context-specific, are tailor-made assessments to specific hazards, specific to different community levels and specific to different geographical settings (Saja et al., 2019). For instance, hazard-specific are more detailed assessments focusing on a certain hazard; therefore, such assessments might be more appropriate for certain critical assets (Hughes & Healy, 2014).

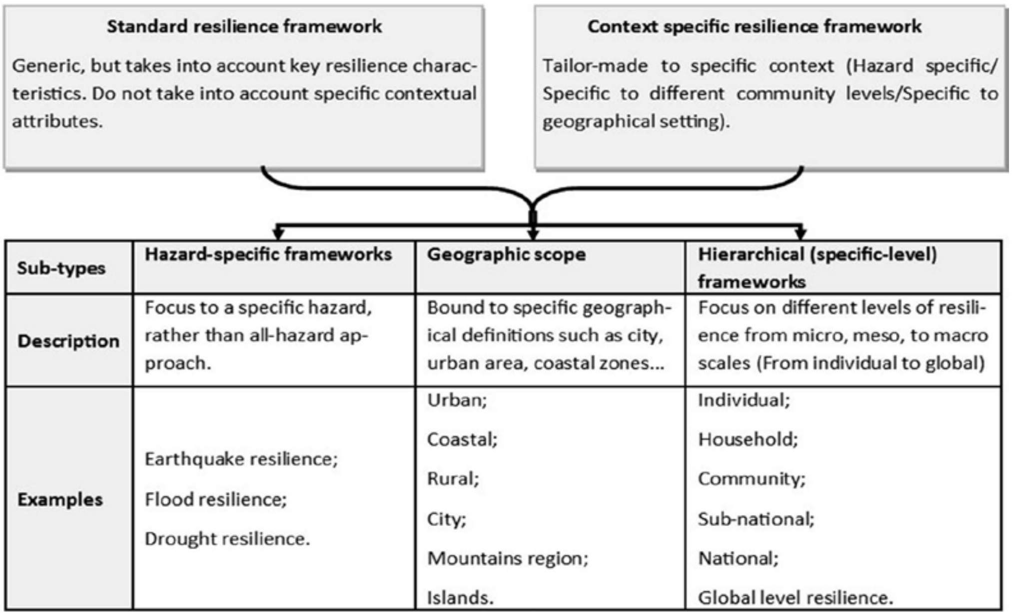


Figure 2.3: Examples of standard and context-specific assessments (Adapted from Saja et al. 2019)

In all cases. Sharifi (2016) suggests that the assessments can be conducted against baseline conditions, against thresholds that reflect the program objectives, against principals of good resilience, against peer (benchmarking), and based on the speed of the recovery. Throughout, qualitative and quantitative methods are useful as principle methods for measuring resilience; discussion of such methods is in the next “methodology” chapter. Results of the assessment of resilience are useful in identifying appropriate measures to enhance resilience; the next section describes approaches used to identify measures for enhancing resilience.

2.5 APPROACHES FOR IDENTIFYING RESILIENCE IMPROVEMENT MEASURES

Vugrin et al. (2010) adopting a mixed assessment method approach, their framework featured a qualitative analysis component to explain the results of quantitative measurements or can take the place of the quantitative results when data are unavailable. The qualitative portion of the framework uses three fundamental system capacities “absorptive, adaptive, and restorative,” providing insights and direction of potential improvements. They suggest further that the qualitative part of the framework containing the three capacities are useful in identifying improvements to enhance the system resilience. In their study towards “Reliable, resilient and sustainable water management: The Safe & SuRe approach” Butler et al. (2017) developed an intervention framework including four capacities that align with Vugrin et al. (2010); mitigation, adaptation, coping, and learning capacities. To better understand the intervention measures, problems affecting the water supply systems are first identified and then intervention measures later discussed in terms of the capacities.

2.5.1 Resilience problems for water supply systems

This section identifies the common problems across technical, organizational, social, economic, and environmental dimensions which directly influence the resilience of water supply systems. **Figure 2.4** shows the summary of global water system resilience problems across technical, organizational, social, economic and environmental dimensions. Generally speaking, resilience problems affecting water systems in a global perspective also affect Tanzania; this could be due to similarities concerning water supply systems aspects and the threats that are exposed. Any discrepancy could be due to the limited literature consulted and lack of adequate information about Tanzania’s water supply systems’ resilience.

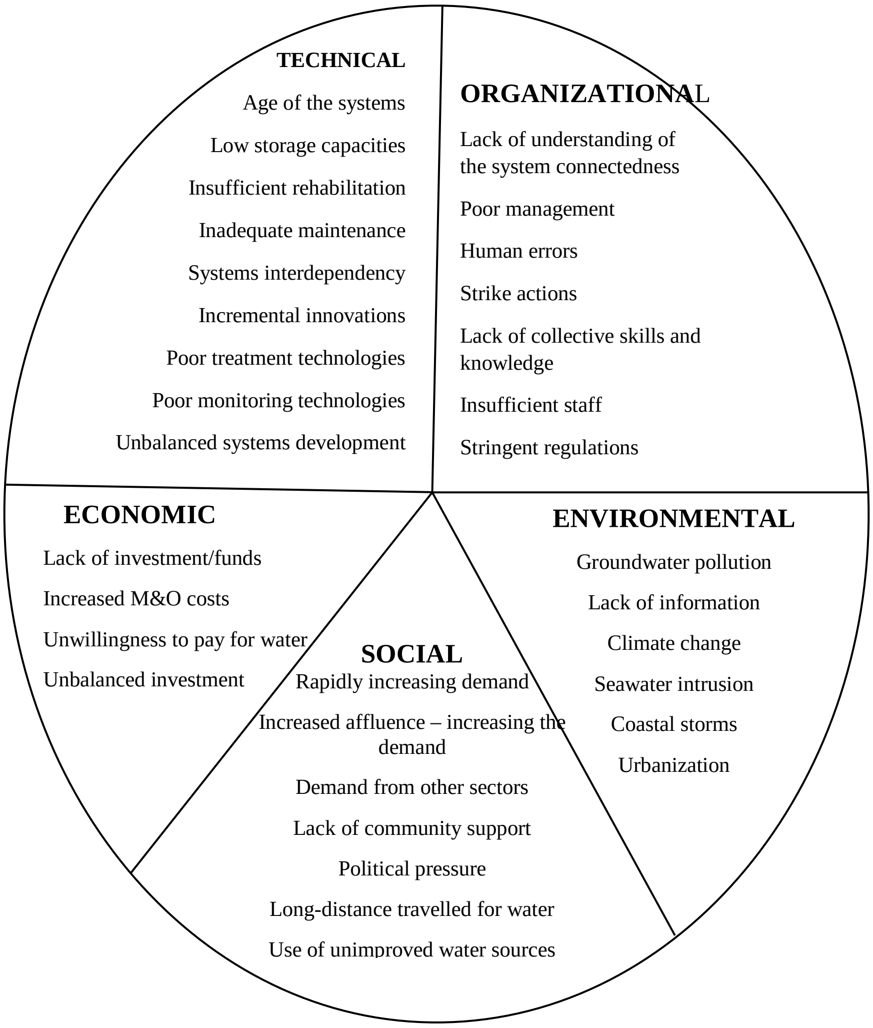


Figure 2.4: Summary of global problems that affect the water systems resilience

Aging infrastructures, insufficient rehabilitation and maintenance, and interdependencies are the technical difficulties that exist globally and for the case of Tanzania. Part of Tanzania's water system is aging and lacks proper rehabilitation and maintenance, and is thus vulnerable to bursts, vandalism, and leakage (Rugemalila & Gibbs, 2015 and Kjellén, 2008). The interdependent complexity of the water supply systems on power and road infrastructures (Kanza & Ndesamburo, 1996 and Smiley, 2016) exacerbates the situation as most of the urban areas experience a shortage of piped water during power outages, while poor roads affect the peri-urban zones where supply is through water trucks. Such arguments agree with Brown, (2012) and Butler et al. (2017) whose studies are on a global scale and indicate that these problems affect the water supply systems' resilience. For unbalanced systems development, Kjellén (2008) indicates that investment in the primary water network is significant while the secondary distribution networks remain poorly developed. Thus, house connections are made from distant points “sometimes” without qualified personnel affecting the resilience of the systems. Also, poor treatment and monitoring technologies, low storage capacities (Brown, 2012) are global water resilience problems that are likely affecting Tanzania water supply systems resilience.

Organizational problems, such as limited community involvement in planning and decision-making, lead to governance failure. The community is consulted at later stages of the projects normally near construction, resulting in the lack of commitment to the community (Rugemalila & Gibbs, 2015). The continuous alternate in the water sector including frequent changes of the Water Ministry from one government to another affects the implementation of plans and policies (Rugemalila & Gibbs, 2015 and Kanza & Ndesamburo, 1996). Lacking coordination between different authorities responsible for water management affects the water management activities within the country (Gondwe, 1990). Such problems are related to poor management aligning with Butler et al. (2017) suggesting that poor management leads to poor water supply systems resilience. Inadequate understanding of the connectedness of the systems (Proag, 2016), human errors, strike actions, inadequate collective skills and knowledge, insufficient staffs, and stringent regulations (Butler et al., 2017) are further problems that affect the water supply systems resilience globally and may also have significant implications to Tanzania.

Tanzania’s population grew three times in the period from 1967 to 2012 (URT, 2012b) and equally increased the water demand at nearly the same rate. Such rapid population growth influences the water demand aligning with Butler et al. (2017) and Howard & Bartram (2010) whose studies indicate that rapid increase in water demand overwhelms the existing aging and slowly expanding infrastructures. As a result of insufficient water, people in rural areas and peri-urban areas spend more time —often by women, placing extra burden on top of heavy household works—travelling a long distance to fetch water instead of doing other income-generating activities (Rugemalila & Gibbs, 2015). Also, piped water is costly, and those who use alternative sources 54.64% are unimproved. Other social problems include demand from other sectors, lack of community support and political pressure, these are consistent with Brown (2012), and Howard & Bartram (2010).

Inadequate funds for investing in the water supply systems is an economic problem that is affecting the Tanzania water supply systems. According to Kjellén (2000), and Rugemalila & Gibbs (2015), poor billing and collections, and politically established tariffs contribute to the lack of funds, thus affecting the financial capacity of the organizations to invest in infrastructure development. Insufficiency of funds is consistent with Brown (2012) suggesting that aging infrastructures, and increasing costs for water collection, treating and delivery has led to more water systems authorities seek for more funds which are not readily securable and hardly accessible if available. Kjellén (2008) further shows that Tanzania water supply systems are experiencing unbalanced investment where well-constructed infrastructure lacks proper connection to consumers; thus, the majority lack piped water. Due to the limited involvement in planning and decision-making processes which is also the case for Tanzania (Rugemalila & Gibbs, 2015) unwillingness to pay for water as reported by Brown (2012) could be related to lack of commitment.

Seawater intrusion and urbanization appear to be the common environmental problems affecting the resilience of water supply systems. Urbanization, among others, has contributed to climate change leading to severe floods and droughts with significant impacts. Such problems align with Butler et al. (2017) who argue further that urban creep exacerbates the consequences of climate change, putting more pressure on the resilience of water systems. Sappa et al. (2015) suggest that Tanzania coastal areas are already facing seawater intrusion, rendering groundwater unsuitable for consumption. The problem is aggravated by pollution from onsite sanitation facilities which make up more than 80% of Tanzania's sanitation system (Mato, 2002). Moreover, lacking information such as water abstraction and recharge (Kjellén, 2000) affects water management activities and systems' predictability of their capacity to survive during disasters.

2.5.2 Resilience improvement measures for water supply systems

General improvement measures for improving water systems resilience in Tanzania appear in **Table 2.3**; this section discusses these measures according to *absorptive, adaptive, coping,* and *learning approaches*. *Absorptive capacity* is related to mitigation, which is any physical or nonphysical action taken to reduce the frequency, magnitude, or duration of a specific threat (Butler et al. 2017), and most of the measures fall under this approach. Development of the secondary distribution network is one of the actions that can connect many prospective water consumers to the water network. At the same time, assets replacement (Butler et al. 2017) appears to be the right solution for addressing the age, and insufficient rehabilitation and maintenance of water systems in Tanzania. Demand management, improving cooperation among authorities, advocating permanent ministry, and enforcing plans and policies are in line with Brown (2012); Gondwe (1990) and Howard & Bartram (2010) respectively whose studies suggest that these practices can enhance better water management.

The authorities must deploy boil water advisories to avoid health risks due to the use of unimproved and polluted water sources—this is in line with Brown (2012) whose study shows that immediate communication to the public will save it from such risks. Systematic billing and revenue collection would increase the water authorities' internal funds; thus, build their financial capacity to operate and expand the systems. Others are, reduction of greenhouse gas emissions, and documentation of abstraction and recharge and other data which can address environmental problems; the former is the result of controlled urbanization and would drastically attenuate the impacts of climate change (Butler et al., 2017).

Table 2.3: Improvement measures for water systems resilience in Tanzania

Dimension	Resilience problems	Improvement measures
TECHNICAL	Age of systems Insufficient rehabilitation & Maintenance	Acceleration of assets replacement
	Unbalanced systems development	Development of secondary network
	Systems interdependency	Use of alternative power supply
ORGANIZATIONAL	Poor management	Best practices for water management 1. Community involvement in planning and decision-making 2. Enforcement of plans and policies 3. Improve cooperation among authorities 4. Advocate permanent water ministry 5. Develop emergency plans and preparedness
SOCIAL	Increase in demand due to rapid population growth	1. Demand management 2. Use of RWH and water serving technologies
	Long-distance travelled	Promoting water projects in rural areas and use of RWH
	Use of unimproved sources	1. Awareness creation 2. Boil water advisories
ECONOMIC	Lack of funds	Systematic billing and revenue collection, and grants
	Unbalanced investment	Investing in the secondary distribution networks
ENVIRONMENTAL	Groundwater pollution	Promote the use of off-site sanitation systems
	Lack of information	Improve documentation of abstraction and recharge monitoring and other data
	Seawater intrusion	Control groundwater abstraction
	Urbanisation	Enforce planning controls
	Climate change	Reduce greenhouse gas emissions

Adaptive capacity is in the form of modification of a particular element or property of the system to enhance the ability to deliver the same level of service in variable conditions continuously. It is defined by Mao et al. (2017) as "the systemic capability to respond to stresses from shifting environment by adjustment and alterations." Measures that fall under this approach include, the introduction of new technologies (Howard & Bartram, 2010) such as the use of alternative power supply and water serving technologies, these would address the interdependency and increased water demand respectively. Others are, involving the community in planning and decision-making, and developing emergency and preparedness plans; these are consistent with Brown (2012) and Proag (2016) respectively who suggest that these measures would enhance the resilience of water systems. Additionally, promoting the use of off-site sanitation systems would reduce the pollution loads from onsite sanitation facilities to the groundwater.

The insufficiency of mitigative and adaptive measures to restore the required service level calls for *coping measures* described by Butler et al. (2017) as "any preparation or action taken to reduce the frequency, magnitude or duration of the effect of an impact or recipient." Coping measures that can increase water systems resilience in Tanzania include, the use of rainwater harvesting—although not popular it is practiced in the country. The technology aligns with Ward & Butler (2016) whose study suggest that such a measure can supplement the existing sources which are under pressure. The measure can also save people from groundwater exploitation and utilization of unimproved sources. Creating awareness to the public on water supply issues, and boiling water for consumption align with Butler et al. (2017) and could be applied to enhance water systems resilience in the case of Tanzania.

Moreover, *learning* is the "embedment of experience and new knowledge in the best practice" (Butler et al., 2017). Since absorption, adaptation, and coping cannot completely eradicate all resilience problems, it is essential for Tanzania water managers to continually improve water resilience through different learning approaches cutting across all dimensions. Learning can take place in certain ways, such as learning from the past events, developing pilot schemes to generate knowledge for best practice, learning from others, collecting the right data and efficient communication strategies (Ferguson, Brown & Deletic, 2013).

2.6 CONCLUSION

The chapter has revealed that water supply systems are critical infrastructures providing critical services to support the life of the communities. They are a combination of several aspects entailing the need for a multi-dimensional approach to ensure its management. Tanzania, like other countries, consists of such systems encompassing similar aspects, including physical infrastructures, water users, organizations, water sources-environment, and funding entities. Given the strides made in increasing the coverage of the water services following the implementation of the WSDP I & II, resilience is however inadequately attended, making the systems vulnerable when disasters occur. The systems are subject to several hazards, although the most significant is flood-climate related disasters. Evident floods are associated with bacterial infections suggesting that water supply systems failed to provide adequate quality water to the community. Disaster management activities such as mitigation, preparedness and response rest on the—Ministry of water and its organs in the current research—sectors. However, authorities are failing to execute adequate mitigation and preparedness due to lacking adequate funding for contingency planning, as funds generated only cover for typical operation and maintenance (O&M) purposes. Recognition of disaster risks in policies, strategies, programs and guidelines underlines the need to incorporate resilience-based mechanisms to ensure water service provision to the community at all times. Such mechanisms will enhance IWRM, improve risk reduction, reduce vulnerabilities, and enhance sustainability.

The adoption of the National Science Challenge definition is pertinent to the understanding of the complexity of the resilience concept. Such a definition will help understand the multi-dimensional nature of the water supply system involving technical, organizational, social, economic, and environmental dimensions. Measuring resilience implies bridging the gap between theory and operationalization, but it is complicated as there are several factors involved. Also, measuring entails many benefits such as allocating resources for resilience, raise resilience awareness, deepen the understanding of the concept. Relative measures are useful in simplifying the measurement complexity offering the relative resilience value for the system, however, need close evaluation of the availability, quality, and sustainability of data. The current research measures the *resilience of* water supply systems encompassing the urban water supply and their respective water resources and their aspects to be able to provide continued water services to the communities. The research also assesses *resilience to* flood hazards adopting a top-down approach, formative, and context-specific which is profitable to areas that face data issues and the knowledge base is relatively low. Such approaches align with four capacities “absorptive, adaptive, cooping, and learning,” to identify measures for improving the water supply systems resilience in the country.

Chapter 3
Research Approach

3.1 INTRODUCTION

This thesis intends to develop a measurement tool that can assist in the development of the improve the resilience of water supply systems. The previous chapter has indicated that the thesis will develop measures against the impacts of flood hazards. Given the inadequate awareness of the resilience concept and its measures, the thesis adopts a top-down approach-starting with an extensive literature review to identify common concepts and their proxies and involve experts in making the measures more appropriate to the country's water supply systems. Such an approach is formative focusing on the evaluation and continuous monitoring of the conditions from early stages of planning processes and enhances the adaptive capacity through the incremental improvement of the conditions. Also, the approach is context specific focusing on flood hazards and to Tanzania's water supply systems. Such approaches can be achieved through quantitative or qualitative methods, as discussed in the current chapter. This chapter presents the general methodology as applied in conducting the research. The chapter employs a literature review to describe both qualitative and quantitative methods for measuring resilience, the use of the mixed methods—quantitative and qualitative or semi-quantitative, and the selection of the appropriate method. It discusses the rationale of using Delphi techniques in the assessment measures development processes and articulates the case studies used for evaluating the tool showing how it works, its applicability, and generality. The chapter also encompasses the research design—it introduces the general concepts and methods used during the study, whereas more specific methodologies are in each chapter of this thesis.

3.2 METHODS FOR MEASURING RESILIENCE

Resilience measurement has occurred in many ways, and the technique or techniques used depend on the measure's requirement and the characteristics of the system of interest (Prior & Hagmann, 2014). In general, resilience evaluation encompasses two major categories: quantitative and qualitative methods (Hossein et al., 2015). Such categories are compatible with several studies such as Hughes and Healy (2014), which indicate that most studies have fallen into these categorical methods of resilience assessment.

3.2.1 Quantitative methods

Quantitative methods involve resilience measurements of specific networks leading "in most cases" to indices resulting from the modelling of networks and possible failure modes (Hughes & Healy, 2014). Hossein et al. (2015) suggest that such quantitative methods fall within two sub-categories; general resilience methods, and structural-based modelling methods. *General resilience methods* encompass techniques that offer domain-agnostic measures to quantify resilience across applications (Hossein et al., 2015). The methods base on numerical data (Sharifi, 2016). They produce quantitative means to assess resilience by measuring system performance regardless of the structures of the systems. Such methods develop quantitative metrics through more detailed analysis or modelling (Hughes & Healy, 2014). They can be classified further into deterministic-performance based approaches which do not incorporate uncertainties and stochastic-approaches that capture the stochasticity associated with the system behavior (Hossein et al., 2015). Examples include the Enhanced Critical Infrastructure Program (Fisher & Norman, 2010; Petit et al., 2011) sponsored by US Department of Homeland Security (DHS) focusing on developing several quantitative indices designed for risk management of critical infrastructures. Such indices as Protective Measure Index (PMI), Resilience Index (RI), and Critical Index (CI) intend to apply as part of the DHS's enhanced critical Infrastructure Protection program (Prior & Hagmann, 2014). *Structural-based modelling approaches* entail techniques that model domain-specific representations of the components of resilience (Hossein et al., 2015). These techniques examine how the structure of the system impacts resilience. As such, observation of the system's behavior is a must, and characterization must be modelled or simulated. Further classifications are optimization models (e.g. Vugrin et al. 2014; Khaled et al. 2015), simulation models (e.g. Carvalho et al. 2012), and fuzzy logic models (e.g. Muller 2012).

3.2.2 Qualitative methods

Qualitative methods are top-down, starting big and then draw conclusions on small components (Juan-Garcia et al., 2017). Qualitative methods tend to assess resilience without numerical descriptions (Hossein et al., 2015). They rely on public perceptions and the experts' judgement for evaluating performances (Sharifi, 2016). In a few instances, qualitative methods complement well quantitative resilience studies, achieving a more beautiful grain in the descriptions and coping phenomenon. The limited resources quantitatively seem to require the switch of horses midstream and look more closely at differences between individuals (Unger, 2003). Unger (2003) suggests further that qualitative methods are composed of aspects such as "discovery of unnamed processes," "contextual specificity," "the power of marginalized voices," "transferability," and "researcher standpoint bias." Prolonged contact with participants, files, or organizations brings the researcher close enough to his or her data to detect trends which may not otherwise be apparent. The assessment focuses on contexts, highlighting the highly individual and contextual specificity risk solutions that communities use to cope with high-risk environments. Since it aims to describe a concept centered on experiences of the communities, studies strive to affirm the transferability of their results, not the generality. The specificity of the qualitative approaches in which participants and researchers participate in the process of dialogical reciprocity enables many truths claims to rise by co-construction of the meaning. Giving voice to those who are otherwise marginalized in knowledge production contributes to a deeper understanding of the localized resistance discourse which permeates oppressed communities. The provision of a forum for the expression of these minority voices through research also encourages tolerance for localized construction and avoids generalization of findings. The researcher is the research instrument when using qualitative methods, and as such, must deconstruct his or her relationship with participants and data in order to minimize subjectivity. Qualitative methods consist of conceptual frameworks, and semi-quantitative indices (Hossein et al., 2015)

Conceptual frameworks constitute most of the qualitative methods for assessing the resilience of the systems by offering best practices (Hossein et al., 2015). In this case, conceptual frameworks development is by setting out principles to measure the resilience (Hughes & Healy, 2014). For instance, the DROP model (Cutter et al., 2008; Cutter, Burton & Emrich, 2010) is a conceptual framework using several dimensions such as social, economic, institutional, community, and infrastructure for measuring the community disaster resilience (Prior & Hagmann, 2014). Other examples are Speranza et al. (2014); Labaka et al. (2015) and Vugrin et al. (2011).

For *semi-quantitative methods*-Unger (2003) indicates that both qualitative and quantitative approaches form a beneficial relationship in which some combinations of the two may produce the most informed findings—the arbitrariness and contextual problems of resilience researchers resolve through using qualitative approaches. Integrating both qualitative and quantitative methods, research yield reliable findings at each site that account for how local communities perceive resilience. Also, Juan-Garcia et al. (2017) suggest that in order to take into account the whole set of properties of a resilient system, it is necessary to use both quantitative and qualitative methods. As such, *semi-quantitative* refer to resilience assessment methods with mixed qualitative and quantitative techniques (Hossein et al., 2015). The method is particularly applicable to the assessment of community resilience and the social interaction between communities and their environments and the structural aspects on which they depend. As many authors argue that the complexity of the concepts like resilience is best explainable qualitatively, such methods explore the human elements of exposure to threat and the way the elements interacts with the structural features of the social systems (Prior & Hagmann, 2014). They are usually constructed with a set of questions designed to assess different resilience-based system characteristics (e.g. redundancy and resourcefulness) on a Likert scale (0-10) or percentage scale (0-100) (Hossein et al., 2015; Clarke et al., 2016). The assessments of the system characteristics from experts' opinions aggregate in some ways to produce an index of resilience (Hossein et al., 2015; Clarke et al., 2016) outlining the resilience domains or aspects of the investigated system where resilience improvement could be specified (Clarke et al., 2016). For instance, Cutter (2008); first identified 36 resilience variables of communities to natural disasters, including redundancy, resourcefulness, and robustness. Each variable was then scored between 0-100 according to the data observed from the government source. The 36 variables were grouped into five dimensions. The score of each sub-index was calculated using the unweighted average of each variable, and the total score was calculated by using the unweighted average of all sub-indices scores. Others are Petit et al. (2010) and Shirali et al. (2013). Clarke et al. (2016) suggest that the DROP model by Cutter et al. (2008) also fall under this category.

Semi-quantitative tools can be useful for quantifying and evaluating critical infrastructure resilience since such an approach offers a tangible operational measure that critical infrastructures operators can recognize and used as a benchmark for further resilience strategies (Clarke et al., 2016). Furthermore, they note that, unlike the sole use of qualitative or quantitative methods, the application of such a hybrid method makes it possible to tackle important soft societal, organizational, and infrastructure aspects of critical infrastructure operations that are difficult to quantify as well as physical/technical and economic dimensions affecting the overall resilience of the critical infrastructure systems.

3.2.3 Why qualitative methods?

Sharifi (2016) indicates that there are several reasons for the importance of employing qualitative methods based on normative judgements; among others, the methods are useful for circumstances where data availability is a problem. Also, resilience is a value-laden concept, influenced by factors such as preference, attitudes, and perceptions; community members have a better knowledge of needs, vulnerabilities, and coping capacities of their community, and qualitative assessment is needed to understand the opinion of the people. By comparing quantitative and qualitative methods (see **Table 3.1**), Hughes & Healy (2014) suggest that qualitative methods are flexible, encompass none/minimum computational requirements, ease to implement, can be applied with complete or incomplete data sets, and useful in wider organizational resilience assessments, and useful in assessing physical networks asset resilience. Such advantages are consistent with water supply systems containing several aspects of physical, organizational, social, economic and environmental nature. More so, they align with the situations in developing countries such as Tanzania that face difficulties in data availability. In such countries, resilience is still a theoretical concept, as very few studies exist for measuring resilience, thus needing such a method as qualitative that is easy to implement. By adopting the qualitative methods of assessment, the current research is specifically applying the semi-quantitative method that is highly advantageous to multi-dimensional systems such as water supply systems encompassing aspects ranging from physical systems, organizational, environmental, economic, to social systems.

Table 3.1: Comparison of the qualitative and quantitative measurement approaches

Criteria	Qualitative method	Quantitative method
Flexibility	Provides a flexible approach adaptable to a range of situations, scales, and conditions	Is typically applied only at a smaller geographical scale and at a more detailed level.
Data requirements	Can be applied with complete or incomplete data sets. Relies on subjective assessments in many cases	Typically requires large, accurate data sets
Computational requirements	None/minimal	Requires significant computational effort
Results	A relative, subjectivity assessment-often using a ranking scale	Typically delivers a discrete resilience index or measure by way of network modelling or fuzzy logic modelling
Ease of implementation	Simple	Difficult
Use in targeting resilience improvements	Useful; however, is very much related to the design of the framework, how it is implemented, and subjectivity of the scores given	Can be accurate for the network analyzed
Useful in wider organizational resilience assessments and engagement	Yes	No
Useful in assessing physical network asset resilience	Yes	Yes

Source: Hughes & Healy (2014)

3.2.4 Types of measures

Based on qualitative and quantitative methods, the following are the major types of measures used throughout the assessments of resilience. *Scorecards* are useful in obtaining values for performance against each criterion in the resilience assessment tool. Values could be in various forms such as answers to dichotomous or multiple-choice questions, calculated statistical values, e.g. counts, percentages, median, means, rates or judgements/perceptions. When using judgement, scaled questions always apply to quantify the qualitative feedback, for instance, using questionnaire surveys, degree of meeting the resilience criteria can be assessed on a 1-5 level scale with 5 being the complete compliance (Sharifi, 2016). *Indices* usually use (weighted) average or (weighted) sum of scores obtained for all criteria in the assessment tool (Sharifi, 2016); therefore, they mainly rely on quantitative data for generating index value (Cutter, 2016). Since relative significance can vary depending on contextual and temporal factors, some tool developers assign weights to selected criteria via an analytical hierarchy process (AHP) by experts' opinions. The index value is useful for assigning an overall rating to the performance of the system (e.g. outstanding, and excellent) (Sharifi, 2016). *Models* are used to deal with complex relationships between various risk and resilience related factors and resolve uncertainties and limitations associated with predicting future events and their consequences. Examples are probabilistic models and models for estimating losses and recovery (Sharifi, 2016). *Toolkits* have broader scopes and establish procedures for assessing resilience using one or a combination of the former three approaches (Cutter, 2016). In addition to providing instructions on how to carry out assessments, toolkits may also outline processes for identifying assessment criteria, collecting required data, assigning weights, conducting assessments, and suggesting interventions based on the assessment results, and monitoring implementation of action plans (Sharifi, 2016). The objective of the current research is more suited to this "toolkit" measure as encompasses the assessment tool, improvement measures and implementation plan.

3.2.5 Resilience Measurement in Relation to Water Supply Systems (With Examples)

Previous resilience assessments have often measured performance using abstract indices or more qualitative approaches by relating the impact directly to the level of service measures used in the water sector (Butler et al., 2017). Wang & Blackmore (2009) indicate that since the 1960s, several studies have developed quantitative measures for the resilience of water resources systems. Quantitative assessments for water systems such as Hashimoto et al.

(1982) developed indices related to how systems would recover from short-term supply shortages. The study is frequently cited as the first attempt upon which other studies have developed resilience indices for water supply systems. In most cases, the indices have been applied only to specific external hazards such as flooding or particular system attribute such as pipe internal energy dispersion (Perry, 2013). As indicated earlier, most of such quantitative methods are focused on small systems, typically certain parts of the water supply systems. To address the multi-dimensional resilience for water supply systems needs the application of qualitative methods-particularly semi-quantitative. For instance, Davis, Mostafavi, & Wang (2018) qualitative study had the purpose of providing information useful for creating and maintaining resilient utility lifeline systems, including water supply. In their study, 17 characteristics, each with indicators, were grouped into technical, organizational, social, and economic domains for assessing resilience, whereas, resilience was estimated as the aggregate of the domains.

The City Water Resilience Framework (CWRF) guides cities evaluating the current areas of strength and weakness in their urban water systems (ARUP & SIWI, 2019). The framework helps guide cities to build resilience in four dimensions which are broken down into eight goals and detailed further in 53 sub-goals. Indicators for each sub-goal allow cities to measure performance and assess the overall resilience of their current water system. The Resilience Measurement Index (RMI) developed by Argonne National Laboratories is for critical infrastructures, including water aiming to support decision making for risk management, disaster response, and business continuity. The Index's input includes qualitative and quantitative answers, leading to weighted aggregations for levels from five to one; each element at each level supporting the decision making (Fisher et al., 2010). Perry (2013) developed and tested a qualitative method of assessing water services resilience. He first explored a set of principles "attributes and features of a resilient system", then developed a simple scoring method against each feature. The number of scoring options was kept minimum to reduce subjectivity.

3.2.6 The use of Delphi techniques

As indicated earlier, the use of experts' judgement elicitation when using qualitative methods is evident and important. Delphi is applied in the current research because it is a widely used and accepted method for developing consensus on real-world knowledge solicited from experts within a certain topic area (Hsu & Sandford 2007) including water supply (Ward et al. 2019). Besides, Delphi is common in developing resilience tools; for example, Zhong et al. (2015) used the technique to develop key indicators for hospital resilience whereas Yang et al. (2019) applied the technique in developing a framework for resilient infrastructure asset management including water supply systems. Furthermore, Ward et al. (2019) applied the method to explore international perceptions between data, models and decision making in the water sector.

The method is characterized by iterative processes where participants respond to a questionnaire in a series of rounds. The first round begins with open-ended questionnaires to allow free opinions from the participants. The information is collected, analyzed and translated into a structured questionnaire allowing participants to rate or rank-order of items in the successive rounds. The selection of experts is an unclear process; however, there are some noteworthy recommendations in the literature; for instance, Pill (1971) quoted in Hsu & Sandford (2007) indicates that candidates are suitable if they have a relatively similar background and experienced, can make useful contributions, and are ready to revisit their previous voting. The first two align with Ward et al. (2019) suggesting experts with publications, teaching relevant courses in universities, and professionals in the studied topic. The optimum number of experts is also uncertain, although it is preferable to use less than 50, whereas most Delphi studies have used 15 to 20 respondents as too small sample size, could not provide representative judgement while too large sample size could lead to low response rates (Hsu & Sandford, 2007). Moreover, qualitative analyses are applied in the first round, whereas, in the subsequent rounds, descriptive statistical analyses apply to measure the central tendency in terms of mean ratings (MRs), median ratings (MeRs), modes (MDs) and standard deviations (SDs) to assess the collective judgements of the respondents (Hasson, Keeney, & McKenna, 2000).

3.4 DESCRIPTION OF THE CASE STUDY

This research addresses issues of Tanzania water supply systems’ resilience to flood hazards. The study is conducted in Tanzania due to the country’s successive exposure to flood hazards leading to impacts on the water supply systems. For instance, in October 2017, floods across Mbezi River in Dar es Salaam broke a 30” water transmission main leaving people stranded without access to safe water in some areas of the city. In 2018, 2019, 2020, there have been floods in different areas of the country, and water supply systems were affected. In line with the existing efforts to address water-related issues, developing a measurement tool would help to understand the current resilience position, the vulnerabilities, and improvement measures ensuring the service is always available. The tool is designed for Tanzania and evaluated in three water supply systems, including Dar es Salaam City water supply system, Morogoro Municipality water supply system, and Lindi Municipality water supply system. These are flood-prone areas, and their water supply systems contain unique features differing from one another regarding demand, size of the networks, types of sources, and production representing about 26 urban water supply systems in Tanzania mainland.

3.4.1 Case I: Dar es Salaam City water supply

Dar es Salaam is the major city of Tanzania with a total population of 4,364,541 (URT, 2012b) approximately six million at present having a total water demand of 450,000m^3/d. The case situates in the coastal areas of the Indian Ocean in Tanzania. Water supply is in the form of piped water from surface water sources and groundwaters ranging from shallow wells to deep boreholes. Piped water is managed by Dar es Salaam Water Supply and Sewerage Authority (DAWASA)-the primary water service provider in the city. According to Section 6(1) of the Water Supply Regulations 2013[5], URT (2018) regards the WSSA as category A service provider based on its financial capability. That means the utility has service coverage of more than 75% and meets all operation, maintenance and depreciation costs. Piped water is from sources such as rivers and boreholes as deep as 400m. Over 2000 other boreholes belong to Community Owned Water Supply Organizations (COWSOs), private companies, and individuals. Additional supply is from water vendors, ranging from pushcarts, water trucks to small networks owners. The only reliable service is piped water. During floods sometimes, the city experiences power blackout affecting the water supply service. Besides, some pipes are defective especially river crossing pipes, leading to contamination while the low-income population seeks alternative water services from other sources such as traditional wells, and lowland waters some of which are saline and contaminated.

3.4.2 Case II: Morogoro Municipal water supply

Morogoro Municipal is about 200km away from Dar es Salaam with a population 315,866 (URT, 2012b) approximately 400,000 at present and total water demand of 40,755m^3/day. The primary water supply service provider in the municipality is a WSSA

[5] http://extwprlegs1.fao.org/docs/pdf/tan171056.pdf

producing about 24,000m^3/day equivalent to 85% of the total water supply in the municipality. Similarly, the utility is grouped as category A service provider based on its financial capability (URT, 2018). Other sources are 5% from residents' own sources, while 10% is directly from streams, rivers, and traditional wells of which are susceptible to pollutions, especially on flood occasions. The water production is from various sources; a dam is the primary water source contributing up to 81% of the total production, water from the dam gets to service areas through a pumped scheme, whereas 19% flows from gravity sources from within the municipality. Floods tend to destruct the water supply systems by breaking pipes and contaminating sources leaving the communities without access to safe water.

3.4.3 Case III: Lindi Municipal water supply

Lindi is a municipality with a population of about 78,841 (URT, 2012b). The case is in the south coast of the Indian Ocean in Tanzania. There is a WSSA that is responsible for water supply services in the municipality. The total water demand is approximately 4,800m^3/d. The water utility is category C, with service coverage below 65%, and meets operating and maintenance costs except for plant electricity (URT, 2018). The municipality had long suffered from water scarcity "portable water" as most residents used saline water from boreholes which is still prominent in few areas to date. The water supply system comprises of several sources ranging from springs to boreholes, most of them decentralized to provide service in their localities. A reliable source to the center of the municipality was from an island that had to pass a few kilometers across the Indian ocean. Very often, the transmission main was broken during high tides, and the municipality could go short of reliable water for a considerable number of days. Floods are also frequent, and springs have been affected due to siltation leading to poor water quality in the rainy season and extremely low water quantity during summer. A recently commissioned source is groundwater with eight boreholes having a production capacity of 7500m^3/d. Although such production can suffice the demand, resilience issues to floods of the whole water supply system still need a close check.

3.5 RESEARCH DESIGN AND METHODS

The study adopts a mixed approach of qualitative and quantitative designs for data collection, analysis, and interpretation due to the objectives and technical, social, and ecological nature of water supply systems with a methodological pattern that integrates both approaches as indicated in previous sections. In achieving the research's objectives, the methods are applied through four-stage processes each addressing a particular objective including initial research and scoping, development of a practical and appropriate multi-dimensional resilience measurement tool, evaluation of the tool in selected Tanzania water supply systems, and identification of resilience enhancement measures for the water supply systems in the country (see **Figure 3.1**).

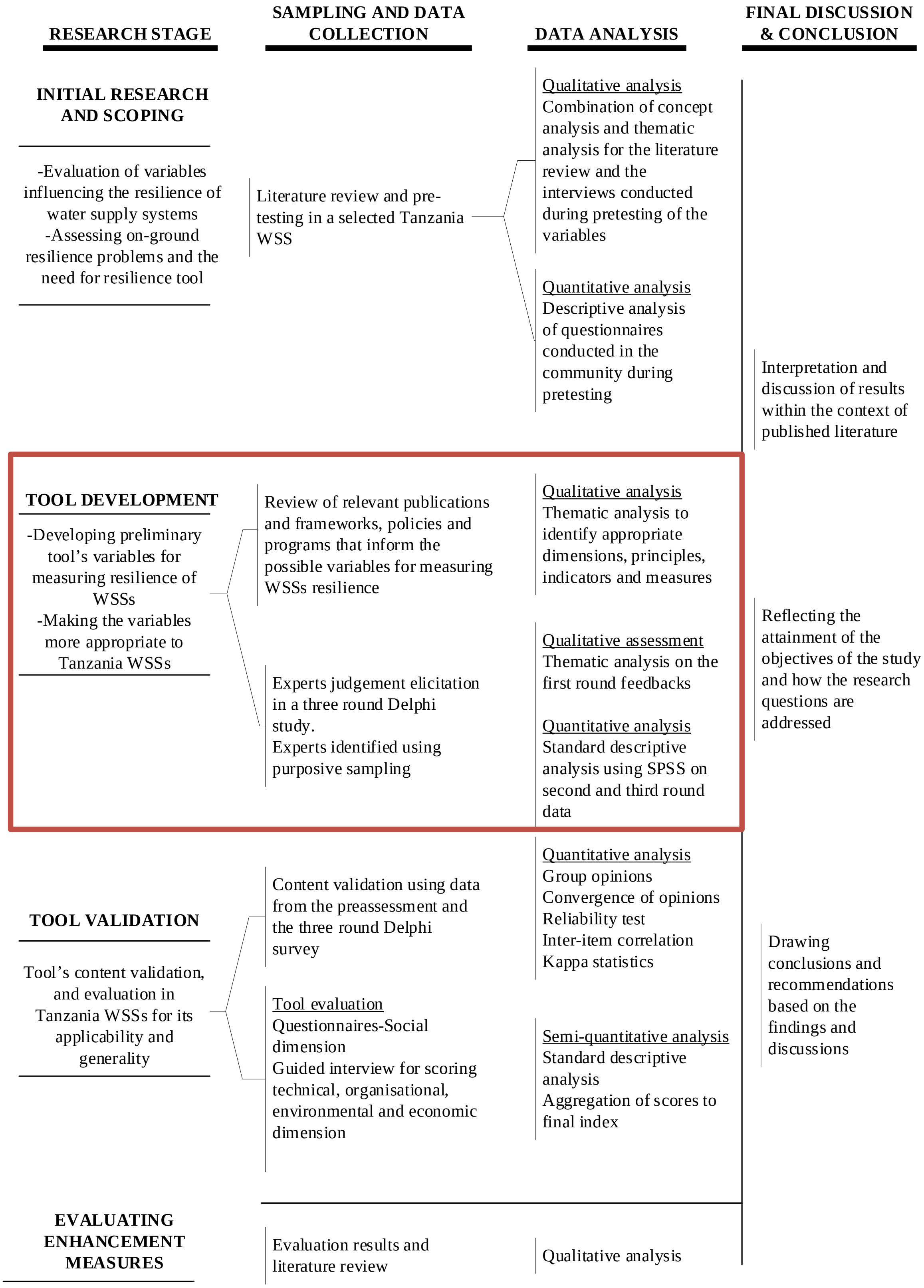


Figure 3.1: Summary of the research design and methods

3.5.1 Sampling and data collection

Stage 1: Initial research and scoping

Objective 1: 1. To evaluate the concepts related to resilience, determine factors affecting resilience in the context of water supply systems and apply them to assess the problems affecting Tanzania water supply systems and the need for developing a resilience measurement tool

Qualitative approach encompassing systematic analysis of existing resilience-related publications, policies, acts, programs and projects reports was used to evaluate the concept of resilience in the context of water supply systems in Tanzania. The review evaluated the factors influencing the resilience of the systems having the potential to inform the systems' capacity to survive the impacts of flooding. The factors/variables having pretested in Tanzania—through questionnaires administration to the water users, and interviews to the water supply organizations—were further used to examine the on-ground problems affecting the resilience of water supply systems in the country consequently, help identify the need for the resilience improvement needs and the tool development needs.

Stage 2: Tool development

Objective 2: To develop a tool for measuring the water supply systems resilience to floods in Tanzania

The processes involved in sampling and data collection in the tool development stage are further detailed in **Figure 3.2** and **Table 3.2.** Developing a measurement tool involved consulting numerous publications at an initial stage to hypothesize the essential tool's variables used to measure the resilience of water supply systems. Proposed variables were then subjected in a pre-assessment process to assess their relevance to the Tanzania water supply systems resilience to flood. Pre-assessment involved ten Tanzania water and environmental experts with disaster resilience experience. As indicated in stage 1, the variables were further pretested in a Dar es Salaam water supply to first evaluate their preliminary applicability and examine the on-ground problems affecting the resilience of the water supply systems.

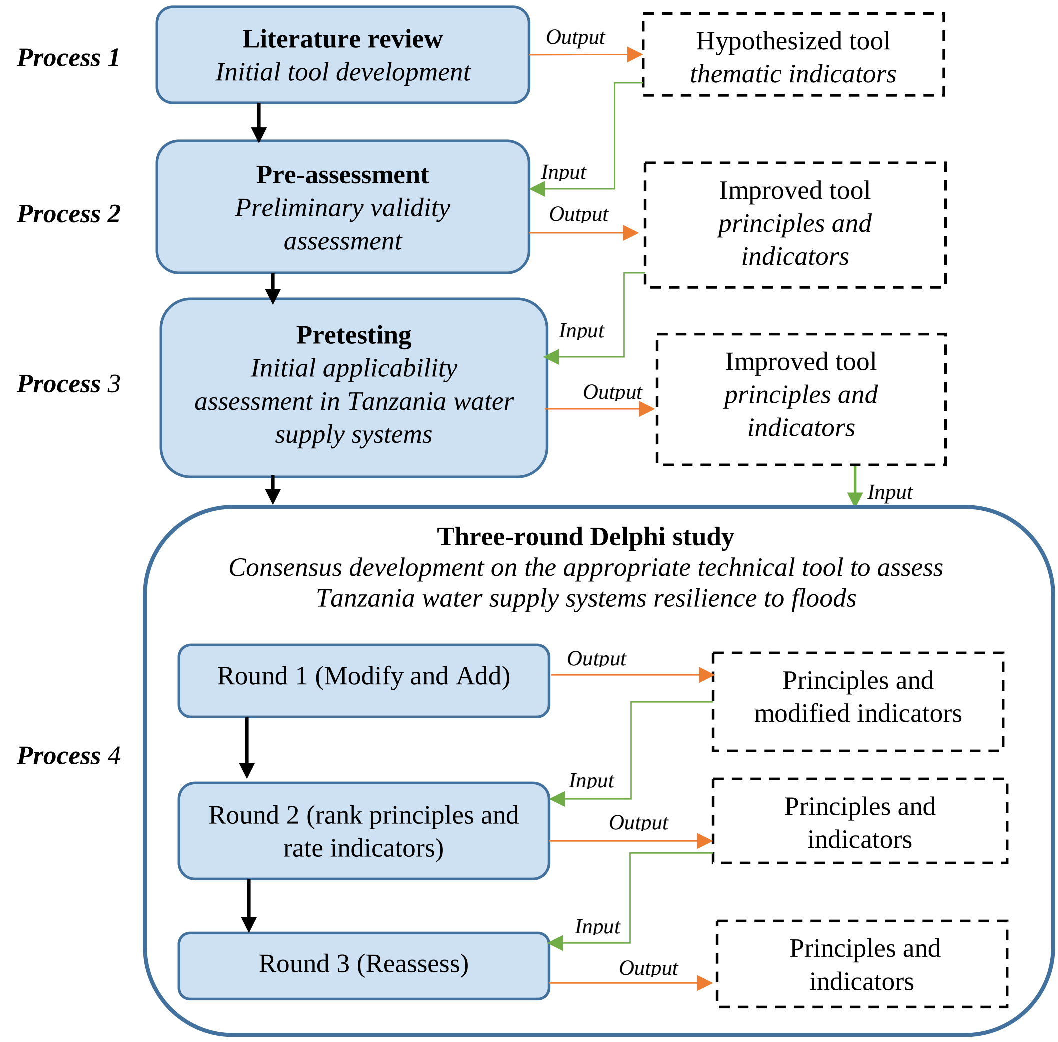


Figure 3.2: Detailed processes for the tool development stage

Improved variables from the pre-assessment and pretesting processes were subjected to a three-round Delphi survey to render them more appropriate to the Tanzania water supply systems. Experts selection relied on the relevance of their professionalism to the water sector, their educational background “at least a bachelor’s degree,” their experience in the water sector and exposure to disaster management-resilience issues, and their willingness to proceed with the Delphi survey in the progressive rounds (see **Table 3.2**). In Tanzania, the level of expertise on disaster resilience is relatively low, more so, resilience is a new concept, posing difficulties in finding experts with relevant experience. Such experts in Table 3.2 are among the few who possess the right expertise on urban water supply and the environment integrated with disaster resilience.

Table 3.2: Qualification of the experts during the three-round Delphi survey

Items	Categories	1st round feedback		2nd round feedback		3rd round feedback	
		N	**P (%)**	**N**	**P (%)**	**N**	**P (%)**
Education background	PhD	5	31.25	3	25	3	25
	Master	8	50	7	58.33	7	58.33
	Bachelor	3	18.75	2	16.67	2	16.67
Professional Rank	Senior professional	8	50	6	50	6	50
	Associate senior professional	8	50	6	50	6	50
Workplace	Water supply authorities	3	18.75	3	25	3	25
	Academic institutions	4	25	3	25	3	25
	Centre for Disaster Management	1	6.25	1	8.33	1	8.33
	Regulatory authority	1	6.25	1	8.33	1	8.33
	NEMC	2	12.5	1	8.33	1	8.33
	Consultancy and Contractors	2	12.5	1	8.33	1	8.33
	LGA	1	6.25	1	8.33	1	8.33
	Ministry of water	2	12.5	1	8.33	1	8.33
Disaster experience	Yes	11	68.75	9	75	9	75
	No experience	5	31.25	3	25	3	25
Total		16	100	12	100	12	100

Initially, the Delphi study involved 22 experts with diverse experiences and areas of expertise from government organizations that run and administer the water supply systems, academic institutions, and private companies, including consultancy firms and contractors. The experts modified and refined the tool's variables—narrowing the scope (Holey et al., 2007) of agreed domains, indicators, and measures, indicating the convergence of opinion for achieved consensus. The experts were involved systematically in consensus development and prioritization of the tool's variables in the three-rounds survey. In the first round, the experts were provided with the background of the study and asked to comment or modify the domains and principles, and comment, modify or add more indicators and measures. In the second and third rounds, they were asked to rate the importance of each dimension, principle, and indicator using five points Likert scale from 1-strongly disagree, 2-disagree, 3-neither agree nor disagree, 4-agree, 5-strongly agree (see **Figure 3.3**).

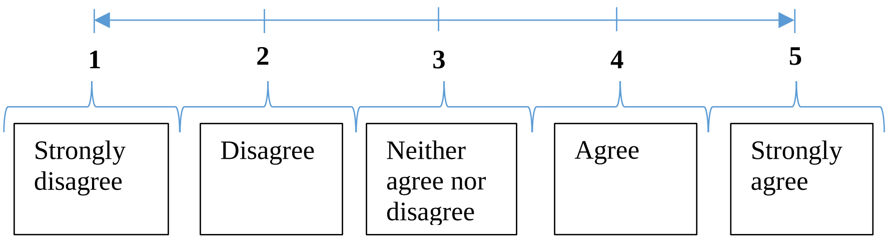


Figure 3.3: Five-point Likert scale for assessing the components of the tool

The rating process was assisted using six key attributes—relevance, affordability, availability, simplicity, transparency as guidelines commonly used in literature for assessing the importance of indicators (see **Table 3.3**)

Table 3.3: Key attributes for assessing the validity of indicators

Key attribute	Description	Reference
Relevance	The degree to which indicators are appropriate or related to this study	Balaei et al., 2018
Affordability	Data accessible/generated for reasonable cost/level of effort	Morley, 2012 from Villagran's 2006
Availability	Easy to collect and measure	Morley, 2012 from Villagran's 2006
Reliability	Consistent over time	Morley, 2012 from Villagran's 2006
Simplicity	Ease of understanding by decision-makers	Morley, 2012 from Villagran's 2006; Cutter, 2014
Transparency	Can the data be reproduced and verified?	Morley, 2012 from Villagran's 2006; Cutter, 2014

Stage 3: Tool validation

Objective 3: To evaluate the validity of the measurement tool including testing its applicability and generality in selected Tanzania water supply systems

The experts' ratings from pre-assessment and the Delphi survey were used to assess the content validity of the tool. The information was useful in the validation as the group of experts involved is the most appropriate and showed interest to continue working with the tool. Such experts with experience in urban water supply and disaster resilience are rare in the country, such as establishing another group of experts would be impractical. To assess the applicability and generality of the tool, an evaluation was carried out involving administering of semi-structured questionnaires to a randomly selected sample population of water users who reside in flood-prone areas and who are direct victims of the water supply systems failure due to flood hazards. The information was used to assess the social dimension of the water supply systems. Besides, interviews consisting of guided questions were conducted to the selected water supply systems officials to obtain initial scores for evaluating the resilience for the technical, organizational, environmental, and economic dimensions of the water supply systems.

Stage 4: Evaluating enhancement measures

Objective 4: To evaluate measures for improving Tanzania water supply systems resilience and propose an appropriate implementation plan.

Tool testing and evaluation in the selected "case studies" Tanzania water supply systems portrayed the vulnerabilities of the systems in the different dimensions, and the need for improvements. The level of resilience in the indicators, principles, and dimensions indicated the needs for improving the systems resilience. Such information allowed for an opportunity to identify the resilience improvement measures. The information was used in line with the literature review and the experience of the researcher to propose measures to improve the resilience of the water supply systems. The assessment for the appropriate measures took place based on the needs to enhance the absorptive capacity, adaptive capacity, coping capacity, and learning capacity (AACL). The AACL measures applied in addressing the problems towards enhancing the overall water supply systems resilience. Assisted with a literature review, a further implementation plan was proposed to ensure consistent application of the assessment tool.

3.5.2 Data analysis

Stage 1: Initial research and scoping

Objective 1: 1. To evaluate the concepts related to resilience, determine factors affecting resilience in the context of water supply systems and apply them to assess the problems affecting Tanzania water supply systems and the need for developing a resilience measurement tool

The concept analysis approach (Walker & Avant, 2004) was used to determine the important attributes that help understand and describe the concept of resilience and its relation to water supply systems globally and in the case of Tanzania. Describing the resilience involved searching for the cluster of attributes that most frequently associated with the concept. Determining the attributes was in line with assessing the resilience problems for water supply systems. The attributes were further pretested in the Tanzania water supply systems to examine the on-ground problems affecting the resilience of the systems in the country, and their need for improvements. Quantitative analysis applied for the data from questionnaire administration, whereas, qualitative analysis was used for interview data from the water organizations.

Stage 2: Tool development

Objective 2: To develop a tool for measuring the water supply systems resilience to floods in Tanzania

As indicated in **Figure 3.2**, different types of literature concerning measuring of resilience were initially studied to analyze and develop a hypothetical water supply systems resilience measurement tool using thematic analysis methodology of Luborsky (1994). The analysis consisted of defining the type of system to be assessed, identifying the dimensions of the system, selecting the resilience assessment approach and nature of assessment, identifying the performance measures, and defining the indicators and measures. Besides, the thematic analysis was used to analyze the first-round Delphi survey feedbacks whereas, standard descriptive statistical analysis using Statistical Package for Social Sciences, IBM SPSS Statistics 25 was used during the second and third rounds of the Delphi study. Comments from experts were accommodated and used to improve the tool's variables in each round. The importance of the proposed variables was rated based on a five-point Likert scale, and the agreement was defined as at least 70% of the respondents agreeing or strongly agreeing to the inclusion of the variables with (SD) less than 0.998 (Zhong et al., 2015). The (MSs), SDs, and p-values and kappa values were used to describe the importance rating, describe the convergence of the importance rating, and compare the level of agreement between rounds, respectively.

Stage 3: Tool validation

Objective 3: To evaluate the validity of the measurement tool including testing its applicability and generality in selected Tanzania water supply systems

The tool's content validation followed a five-stage analysis process: 1. Group opinions assessment, 2. The convergence of opinions assessment, 3. Reliability analysis, 4. Inter-items correlations assessment, 5. Level of agreements assessment. The analysis of the evaluation results was in the framework of the developed tool for measuring the resilience of Tanzania water supply systems. It included a semi-quantitative analysis approach involving aggregation of the initial scores into a semi-quantitative index (Hossein, Barker, & Ramirez-Marquez, 2016). The initial scores for the measures relied on Likert values of 1 to 5: 1 for the poor level of resilience, and 5 for the high level of resilience (see **Table 3.4**). The MSs and weighted means were calculated for each measure of each indicator, then aggregated to the principle resilience, dimension resilience, and the final overall system resilience index —using equations derived based on the weighting and aggregation principles (Morley, 2012).

Table 3.4: Description of the final resilience scores (Modified from Hughes & Healy, 2014 and Morley 2012)

Scale	Performance level	Description
1	Very low resilience	Very poor performance and extensive improvement measures required
2	Low resilience	Poor performance and improvements required
3	Moderate resilience	Less than desirable performance and specific improvements should be prioritized
4	High resilience	Acceptable performance in relation to a measure (s) some improvements could be made
5	Very high resilience	Meets all requirements

Stage 4: Evaluating enhancement measures

Objective 4: To evaluate measures for improving Tanzania water supply systems resilience and propose an appropriate implementation plan.

This part of the research involved a qualitative analysis encompassing the researcher's experience and literature review and using the tool evaluation results to provide insight and direction for potential improvement measures. As indicated earlier, the identification of resilience improvement measures relied on the need for enhancing the absorptive, adaptive, coping, and learning capacities across all the dimensions of the water supply systems resilience. The measures, indicators, principles, and dimensions that scored between 1 to 3 (see **Table 3.4**) suggested that their resilience was wanting and needed improvement. The improvement in this case meant to improve a measure, indicator, principle, or dimension to performance level 5-very high resilience. Thus, the development of the improved measures was consistent with suggesting features that would up the resilience to level-5.

3.5.3 Final discussion and conclusion

The final discussion of the results was conducted within the context of published literature in water supply systems resilience and disaster management. The discussion reflected the attainment of the primary objective of the study while answering the research questions. Finally, the conclusion and recommendations of the investigation were drawn based on the findings and discussion.

3.6 ETHICS CONSIDERATIONS

All relevant ethical aspects of the research were considered, an application was submitted to the University of Auckland's Human Participants Ethics Committee for the direct interview and the anonymous surveys of the research. The committee approved the application on 18th August 2017, for three years with reference number 019619. The decision for approval instructed the use of Participants Information Sheets (PIS) and Consent Forms (CF) designed for the participants involved in the study. As such, three types of such documents (i.e. PIS and CF) were approved; the PIS and CFs for organizations, PIS and CFs for experts, and PIS and CFs for community members. During the study, the participants took part voluntarily based on their understanding of this research, after PISs supplied and CFs signed accordingly. All ethics documents, including the approval letter are included in **Appendix 1** of this thesis.

3.7 CONCLUSION

The research methodology adopts a top-down approach for developing a multi-dimensional resilience assessment tool that is qualitative. The tool development encompasses semi-quantitative features, including both quantitative and qualitative methods designed to involve experts at later stages to make the tool more appropriate to Tanzania water supply systems. Experts are involved in the study in a three-round Delphi survey conducted in Tanzania, leading to a toolkit including the resilience assessment measures validated through evaluation in selected Tanzania water supply systems, and the measures for improving resilience and the implementation plan. As indicated earlier in this chapter, more specific methodologies are presented in each chapter of this thesis.

Chapter 4
Evaluating On-ground Resilience Needs for Water Supply Systems in Tanzania

The current chapter is based on the following article.

Sweya, L.N.; Wilkinson, S. and Kassenga, G. (2019). *Resilience improvement needs for public water supply systems in Dar Es Salaam*. Contributing Paper to Global Assessment Report (GAR) 2019. Geneva, Switzerland: UNDRR.

4.1 INTRODUCTION

This chapter evaluates the on-ground problems affecting the resilience of Tanzania water supply systems. Dar es Salaam water supply system applies as a case study. Environmental-related risks such as extreme weather events and failure of climate change mitigation and adaptation as well as water crises have emerged as consistently central features of the Global Risks Perception Survey (GRPS) risk landscape, strongly interconnected with many other risks for the past decade: the risks are in the top 5 list of global risks in terms of likelihood and impacts (World Economic Forum, 2017). Natural hazards like floods are extreme weather events which are exacerbated by climate change (URT, 2003 & IPCC, 2014). Floods have diverse impacts on people, buildings, and infrastructures, such as water supply systems are particularly at risk (Arrighi, 2017). Floods damages to water infrastructure are classified as direct and indirect depending on the occurrence of the event either in space or time and can cause cascading effects. The flood risks for water supply systems include water contamination, pipelines breakdowns, infrastructure disruption, water shortage, and the collapse of the entire system (Pan American Health Organization, 1998). As such, systems resilience is needful to ensure that the service is continuous.

As seen before, resilience is an integrating concept that allows multiple risks, shocks and stresses and their impacts on ecosystems and vulnerable people to be considered together in the context of development programming (Mitchell & Harris, 2012). If flood risks are managed, there will be an increased chance of enhancing resilience and reduce the chances of failures in the water supply systems. Risk management requires a holistic strategy that encompasses mitigation, preparedness, response and recovery (Sinisi & Aertgeerts, 2011), also representing the four key phases of managing disasters (Rubin, 1991). The best time to act is in the first phase of the cycle when preventive and mitigation measures can strengthen a system by reducing its vulnerability (Pan American Health Organization, 1998). Among the mitigation activities, identification of hazards and comprehensive vulnerability analysis are cognizant as pre-eminent (Arrighi et al. 2017). This is fundamental support for decision making because it increases awareness and foster adoption of mitigation strategies.

The current chapter relies on Dar es Salaam City, Tanzania. In recent years, flood hazards have been Tanzania's most destructive events,[6] particularly in Dar es Salaam, resulting in widespread diseases, and infrastructure destruction. In October 2017, flooding water in Mbezi River dragged a 30" water transmission main while other small distribution pipes were also affected. As a result, the quality and availability of public water were compromised in the areas served by the water transmission main. During these periods, alternative sources such as wells become flooded and unsuitable for consumption, and boreholes from shallow aquifers are unreliable due to direct recharge from flooded onsite sanitation facilities and floodwater from crude/unofficial dumping sites.

Such conditions indicate that Tanzania water supply systems are facing common resilience problems that exist elsewhere in the world (Sweya et al., 2018), leading to the need for immediate interventions to improve the resilience. The current chapter assesses the factors that affect the resilience of water supply systems and identify on-ground problems that intensify the impacts of flood risks to the systems in Dar es Salaam. The findings could be fundamental support for decision-makers because it increases awareness and foster adoption of the mitigation strategies for improving the country's water supply systems resilience to floods.

4.2 METHODOLOGY

The study was conducted in Dar es Salaam, the major city of Tanzania to identify on-ground problems that escalate the flood risks to water supply systems in the city and the needs for improvement. Identification of problems was based on the factors that affect the resilience of infrastructure systems (see **Table 4.1**). Households were sampled in Vingunguti, Tandale, and Jangwani wards to represent the Dar es Salaam population living in low-lying areas that are vulnerable to floods: the information was used to evaluate the problems facing the Dar es Salaam community in surviving the impacts of flooding on the water supply systems. Interviews were conducted to three water supply institutions namely DAWASA, DAWASCO,

[6] EM-DAT: The Emergency Events Database - Universite catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium

and Wami/Ruvu basin water office, to identify the problems facing the infrastructure and the environment within which water sources, catchments and recharge areas exist.

Table 4.1: Factors that can affect the resilience of water supply systems

S/N	FACTOR AFFECTING RESILIENCE	REFERENCE
1	Population composition in terms of education level, employment status and house ownership	Sharifi, 2016
2	Likeliness of being affected by floods	***
3	Flood experience	Sharifi, 2016
4	Effects of floods on water supply systems	***
5	Alternative water supply	***
6	Preparedness for future floods	Jovanovic et al. 2016
7	Additional system capacity	Mugume et al. 2015
8	System exposure to flood hazards	Hughes & Healy, 2014
9	Water losses	***
10	System redundancy	Hughes & Healy, 2014
11	System upstream interdependencies	Hughes & Healy, 2014
12	Use of local knowledge and native species	Sharifi, 2016
13	Soil erosion protection	Sharifi, 2016
14	Availability and accessibility of water	Sharifi, 2016
15	Pollution stresses in the ecosystem	Sharifi, 2016
16	Human encroachment in catchment areas	Brenkert & Malone, 2005
17	Water withdrawal	Brenkert & Malone, 2005
18	Natural flood buffers	Sharifi, 2016; Cuter et al. 2014

*** Factors added by Researchers

One hundred and six (106) semi-structured questionnaires were administered in three wards: Vingunguti, Tandale, and Jangwani to assess the problems and resilience needs for the water users (communities). The target population was the households that are highly vulnerable to floods. For Vingunguti the target population was selected along the Msimbazi River valley, for Jangwani in the Msimbazi River floodplain, and Tandale along the Ng'ombe River. A total of 140 houses were targeted in the three wards: 65 in Vingunguti, 40 in Tandale and 35 in Jangwani. The difference in the target population reflected the general population in the respective wards: 106,946 for Vingunguti 54,781 for Tandale, and 17,647 for Jangwani (URT, 2012b). The sample size (106) was determined based on the confidence level (CL) of 95%, Z-score of 1.96, and the margin of error of 8% (see **Table 4.2**). In that regard, 45 households in Vingunguti, 32 in Tandale and 29 in Jangwani were studied.

Table 4.2: Sample size determination

Ward	Target population	Confidence level (%)	Margin of error (%)	Z-score	Sample size
Vingunguti	65	95	8	1.96	45
Tandale	40	95	8	1.96	32
Jangwani	35	95	8	1.96	29

Random sampling was adopted to identify the participants. Heads of households were particularly the main targets. Questionnaires were administered in Kiswahili to the heads of households after obtaining their consent to participate in the study. In addition, three interviews were conducted. Two at the Dar es Salaam Water Supply and Sewerage Authority (DAWASA), and Dar es Salaam Water Supply and Sewerage Cooperation (DAWASCO) to assess the problems and resilience needs facing the water infrastructure and one interview at the Wami/Ruvu basin water office to assess the resilience improvement needs in the water sources, recharge and catchment areas. The interviewees were asked for their consent to recording the interviews.

A standard descriptive analysis using the Statistical Package for Social Sciences (SPSS), IBM SPSS Statistics 25, was used to describe information obtained from the questionnaires. The percentages were calculated to assess the problems and resilience improvement needs for the water users of the water supply system. Recorded interviews were transcribed by the researcher and a thematic approach (Luborsky, 1994) was used to analyze the information. The emerging themes were studied to assess the on-ground problems and needs for improving resilience for the infrastructure and the environment.

4.3 RESULTS

This section of the chapter presents the results obtained from the questionnaire survey and interviews: it entails the resilience problems that exacerbate flood risks in water supply systems in Dar es Salaam. The problems were assessed in three aspects of the resilience of water supply systems including the infrastructure, the environment and the water consumers (communities); the following sections present the results;

4.3.1 Resilience problems that escalate flood risks to water supply systems

On-ground infrastructure problems

Dar es Salaam total water demand is approximately 195.24 million m^3/year equivalents to 545,000m^3/day (URT, 2017a) while the combined production following the 2011-2015 upgrade of the public water utility is 488,000m^3/day (see **Figure 4.1**). The water produced serves almost 75% of Dar es Salaam and parts of the coastal region[7]. That means the utility is short of additional capacity to serve in times of failure or abrupt demand increases.

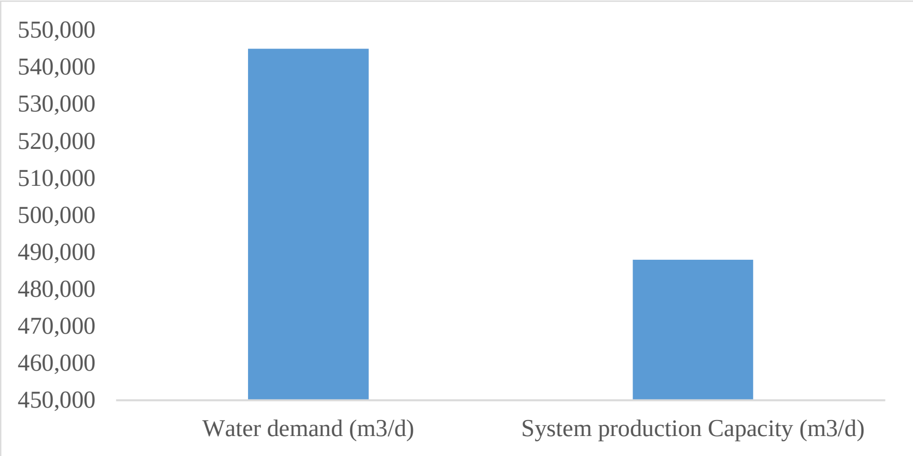


Figure 4.1: Water demand vs system production for Dar es Salaam city

In each pumping station, there is one standby pump, and transmission mains are partially looped with alternative pipes running parallel to each other. The system is also partially interconnected between the Upper and Lower Ruvu networks only along Mandela Road. Results show that some of the critical assets such as the intakes, pumping system for the Mtoni network, and all the transmission mains are exposed to flood hazards, and do not have alternative facilities or routes during flooding (see **Figure 4.2** & **Table 4.3**). That also includes several distribution pipes that cross rivers within the city.

[7] http://www.dawasco.go.tz/waterservices.html

Figure 4.2: Water transmission (30” diameter) dragged away by flooding water across Mbezi River in October 2017

Table 4.3: Alternative facilities for critical assets

Facility	System	Flooding Hazards	Alternative
Intake	Mtoni	Affected	No alternative facility
	Lower Ruvu	Affected	No alternative facility
	Upper Ruvu	Affected	No alternative facility
Water Treatment Plant	Mtoni	Not affected	
	Lower Ruvu	Not affected	
	Upper Ruvu	Not affected	
Pumping system	Mtoni	Affected	No alternative facility
	Lower Ruvu	Not affected	
	Upper Ruvu	Not affected	
Transmission Mains	Mtoni	Affected	No alternative routes
	Lower Ruvu	Affected	No alternative routes
	Upper Ruvu	Affected	No alternative routes
Reservoirs	Mtoni, Lower Ruvu, and Upper Ruvu	Not affected	

The system suffered water losses (see **Figure 4.3**) in terms of average non-revenue water (NRW) per month ranging from 33.28% to 57.44% between 2015/2016 and 2016/2017 operation years (see **Figure 4.4**). The highest values are 57.44% in May and 55.62% in June for the 2015/2016 and 2016/2017 production years respectively, such results concur with the fact that in Tanzania, May and June are preceded by the rainy season, the period which more destructions of pipes occur due to flooding. Also, in such rainy seasons, NRW goes unnoticed because the demand from a public water utility is low, as some people use rainwater and other sources.

Figure 4.3: Structural leakages that contribute to water losses in Dar es Salaam

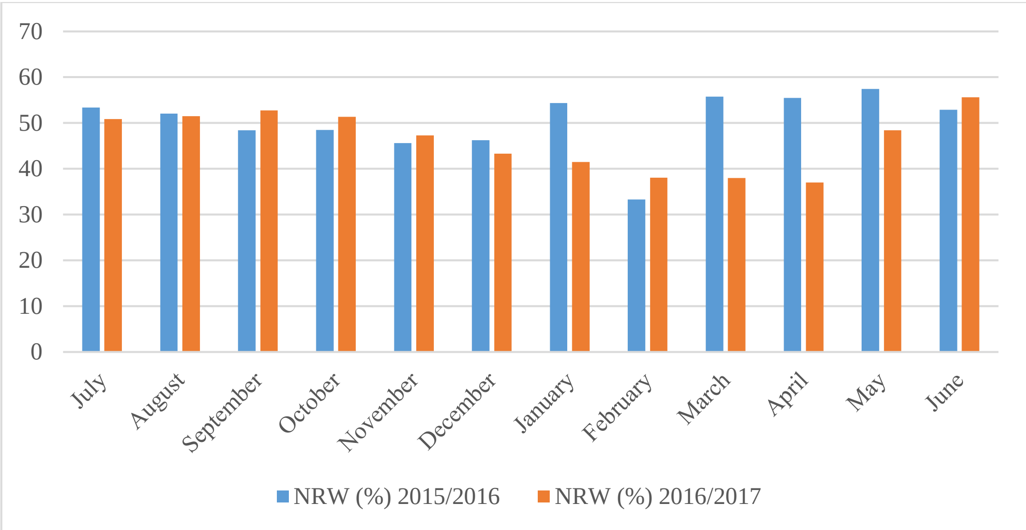


Figure 4.4: Non-Revenue-Water (NRW) in the city of Dar es Salaam (*Source: DAWASCO)*

Water production for Dar es Salaam public water utility depends entirely on the power supply from the Tanzania Electric Supply Company Limited (TANESCO). The available standby generators are mainly for lighting and cannot support production. Besides, there is a high chemical demand for water purification during floods; thus, water production is low because some pumps are stopped to minimize production costs and reduce the risk of damaging the system.

On-ground problems for the water sources, recharge and catchment areas

Ruvu River is the main source of water for the city of Dar es Salaam found in the Wami/Ruvu basin: the basin has seven sub-catchments namely Kinyasungwe, Mkondoa, Wami, Upper Ruvu, Ngerengere, Lower Ruvu and Coastal rivers. Of the seven sub-catchments, only Ngerengere sub-catchments seem to have significant natural vegetation especially, in the Uluguru highlands. It is only in these highlands, traditional practices for water management exist. Most other areas have become potentially suitable for agricultural activities and grazing. Thus, the use of local knowledge and natural species in many areas is diminishing.

The basin has experienced severe erosion due to inadequate soil protection measures against activities such as sand-cement block making, agriculture, overgrazing, sand quarrying, and mining. Soil erosion in the upstream of the Ruvu River source, for example, has resulted in severe deposition downstream at Kidongozero. The deposition has widened the river at that location, changing its regime and affecting the water availability further downstream where the two Ruvu water treatment plants are located.

Surface water-the main water source for the city is insufficient and affected by management concerns due to a large number of unregistered water users. Groundwater is the second most used source in the city, and its quality is still unpredictable due to susceptible discharge from uncontrolled waste disposal sites and onsite sanitation systems such as Vingunguti un-engineered dumpsite that also receives waste from the nearby abattoir (see **Figure 4.5**) and several onsite sanitation setups in the city. Some recharge areas are affected by urbanization, whereas the groundwater source is also at risk of seawater intrusion due to over-pumping. Moreover, rainwater is rarely used as a sustainable alternative source of water in the city as most residents lack enough storage facilities to store water for a long time.

Figure 4.5: Vingunguti un-engineered dumpsite

Human encroachment has put the surface water source at risk from industrial, domestic, and mining pollutions. Both industrial and domestic effluents discharged in water bodies such as rivers have contributed to the pollution of the water. Besides, there are mining activities conducted along and within rivers especially in the Ngerengere sub-catchment of the Ruvu River, whereas “the biggest concern is the susceptible pollution from mercury, if it is used as one of the chemicals for extracting gold” (Research Participant).

Water balance and withdrawal monitoring are rarely conducted. Most infrastructure projects are built first, and the permits applied afterwards; thus, it becomes difficult to reject the applications. “For example, there are five projects right now, e.g. the Mkulazi sugarcane production started the project, but then the sugarcanes started to dry due to lack of water, there was no choice but to grant a permit to abstract water from the Wami River," (Research Participant). Also, Inadequacy of water users information has impaired the withdrawal monitoring leading to inability to conduct consistent water balance activities.

On-ground problems relating to water users

Results from the questionnaire survey show that more than 80% of the respondents are unemployed (see **Figure 4.6a**), whereas the highest education level for more than 80% is a primary school (see **Figure 4.6b**).

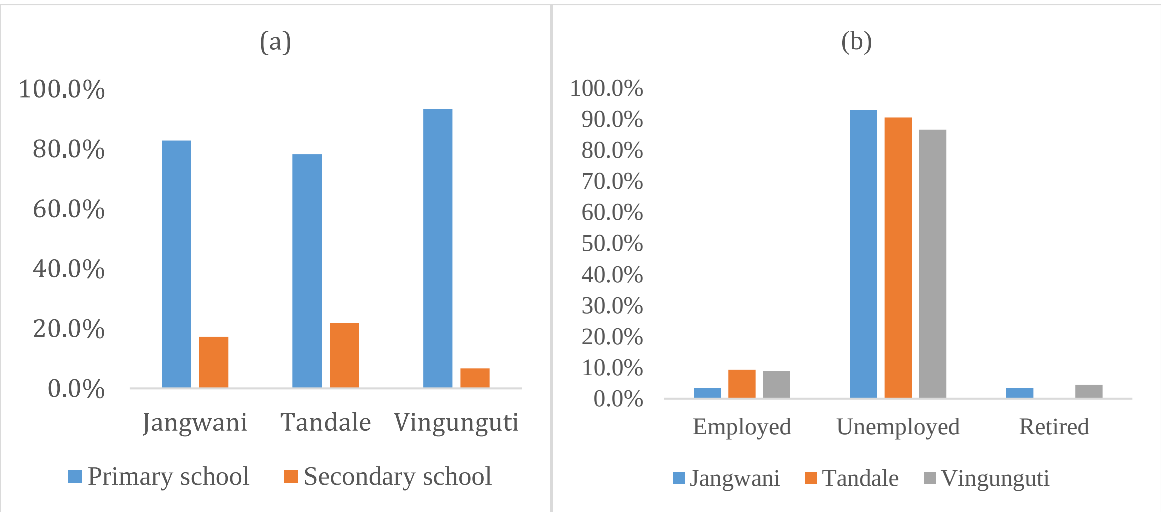


Figure 4.6: (a) education level of respondents **(b)** employment status of the respondents

Above 50% of the respondents in Tandale own the houses they live in, similar results were observed in Vingunguti, while in Jangwani more than 50% are tenants. Besides, 3.4%, 6.3%, and 6.7% of the respondents from Jangwani, Tandale, and Vingunguti, respectively, inherited the houses they live in, while about 3.4% in Jangwani alone live in temporary shelters or neighbors’ houses during floods, (see **Figure 4.7**) and all the houses are not insured.

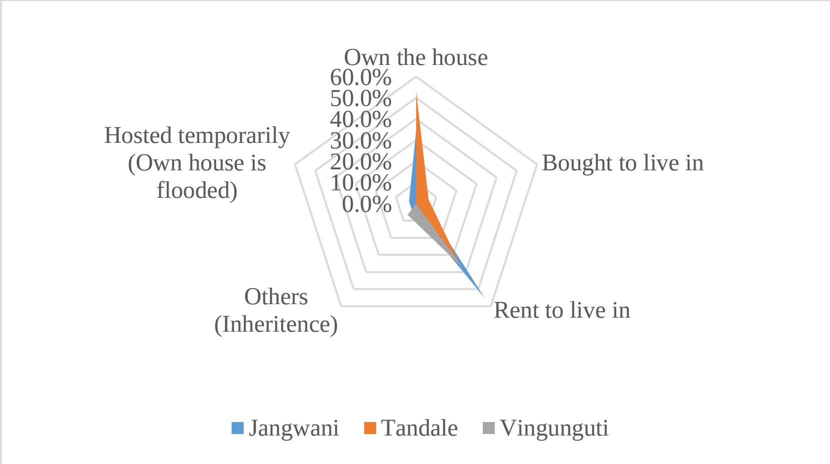


Figure 4.7: House ownership

Flood is the only natural hazard that is likely to occur in the city of Dar es Salaam. The average of 63.2% of the respondents are highly likely affected whereas, 36.4% are quite likely affected by floods (see **Figure 4.8a**). In line with such observation, the average of 88.7% of the respondents has experienced previous floods, implying that most of the respondents are exposed to the impacts of floods (see **Figure 4.8b**).

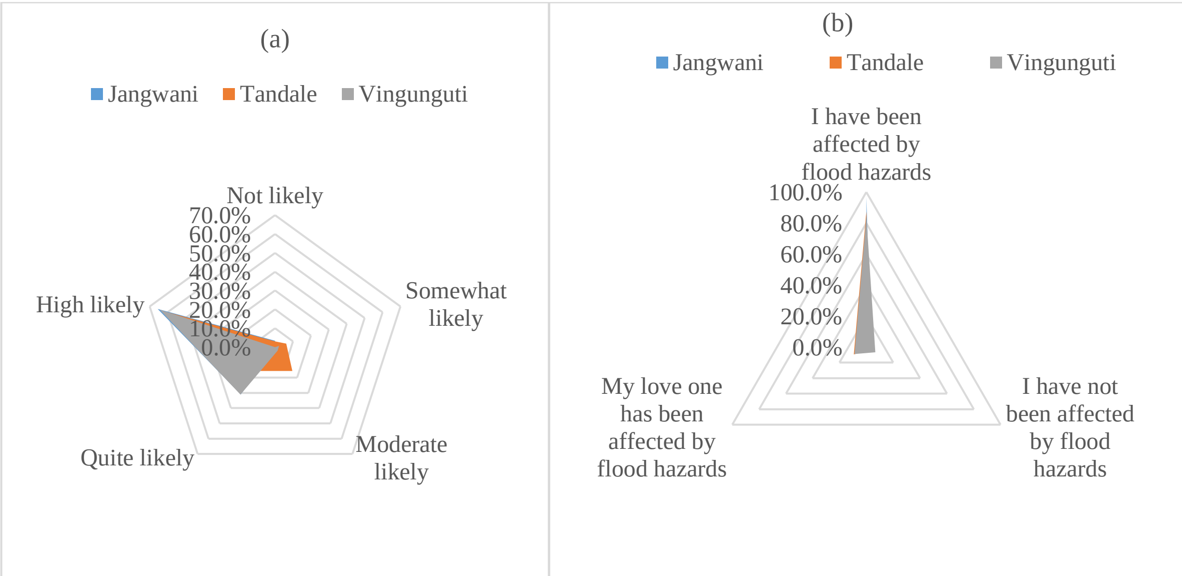


Figure 4.8: (a) Possibility of being affected by floods **(b)** experience with flood hazards

As shown in **Table 4.4 through 4.6,** the average of 34.5%, 40.2%, and 45.6% of the respondents indicated that the water quality, quantity, and services, respectively are highly likely affected during flooding. Also, 53.9%, 40.7%, and 38.4% said the water quality, quantity, and services respectively are quite likely affected by flooding. In all cases, the combined result "over 90%" for respondents from Vingunguti is between quite likely and highly likely, suggesting that, the water quality, quantity, and services in the ward are at risk than in Jangwani and Tandale wards.

Table 4.4: Effect of floods on water quality

	Not likely	Somewhat likely	Moderate likely	Quite likely	High likely
Jangwani	6.9%	3.4%	0.0%	65.5%	24.1%
Tandale	9.4%	0.0%	6.3%	40.6%	43.8%
Vingunguti	0.0%	0.0%	8.9%	55.6%	35.6%
Average	**5.4%**	**1.1%**	**5.0%**	**53.9%**	**34.5%**

Table 4.5: Effects of floods on water quantity

	Not likely	Somewhat likely	Moderate likely	Quite likely	High likely
Jangwani	13.8%	3.4%	3.4%	48.3%	31.0%
Tandale	6.3%	0.0%	28.1%	25.0%	40.6%
Vingunguti	0.0%	0.0%	2.2%	48.9%	48.9%
Average	**6.7%**	**1.1%**	**11.3%**	**40.7%**	**40.2%**

Table 4.6: Effects of floods on the water service

	Not likely	Somewhat likely	Moderate likely	Quite likely	High likely
Jangwani	10.3%	6.9%	3.4%	41.4%	37.9%
Tandale	6.3%	0.0%	18.8%	25.0%	50.0%
Vingunguti	0.0%	0.0%	2.2%	48.9%	48.9%
Average	**5.5%**	**2.3%**	**8.1%**	**38.4%**	**45.6%**

More than ten alternative water supply options are used when the quality, quantity, and service of water from the public utility are affected by flooding emergencies. Few responses are such as; "There is no water service at all," "We find it very difficult to find water because all infrastructures are being destructed including electricity," "We buy bottled water because other waters become mixed with wastewater," and "We buy saline water from wells." Notably, 23.6% of the respondents said it is very hard to get water, 19.8% said they have no alternative water supply, and 15.1% said there is no service at all during flooding. The three responses form a combined result of 58.5%, suggesting that the majority suffer from the impacts of flooding on the water supply system. The most preferred alternative is buying reserved water from vendors which accounts for 13.2% of the respondents. Other alternatives are; getting water from neighbors, in-house storage, and travelling long distances to get water from vendors. There are also situations where other respondents buy bottled water, use water from traditional wells, use rainwater, get water from lowlands, and vacate their houses until the flood recedes (see **Table 4.7**).

Table 4.7: Alternative water supply during flood emergencies

Alternative	Jangwani		Tandale		Vingunguti		Overall results	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
None	5	17.2	10	31.3	6	13.3	21	19.8
Get water from the neighborhood	2	6.9	1	3.1	0	0	3	2.8
Get water from neighbors	3	10.3	0	0	2	4.4	5	4.7
In-house water storage buckets/facilities	2	6.9	0	0	2	4.4	4	3.8
Buy reserved water from vendors	0	0	6	18.8	8	17.8	14	13.2
No service at all	2	6.9	7	21.9	7	15.6	16	15.1
It is very hard to get water	9	31	5	15.6	11	24.4	25	23.6
Buy bottled water	2	6.9	0	0	1	2.2	3	2.8
Buy from water trucks vendors	0	0	0	0	1	2.2	1	0.9
Vacate the house and return when the flood recedes	1	3.4	0	0	1	2.2	2	1.9
Use well waters	0	0	0	0	3	6.7	3	2.8
Use rainwater	0	0	0	0	1	2.2	1	0.9
Travel long distance to get water from vendors	3	10.3	2	6.3	1	2.2	6	5.7
Search water from lowlands (valleys)	0	0	1	3.1	0	0	1	0.9
Use water from unimproved wells	0	0	0	0	1	2.2	1	0.9
	29	**100**	**32**	**100**	**45**	**100**	**106**	**100.0**

Furthermore, about 71.7% of respondents had taken no actions to prepare for the future impacts of floods on water supply system, some respondents said, “We are not prepared because if we reserve the water, it can also be contaminated,” and “Because of the economic situation, I have not done anything.” Reserving water for use during floods was the only significant action reported to prepare for future floods, accounting to overall 10.4% of the respondents. Also, few respondents, especially in Tandale and Vingunguti, were willing to be relocated if the government compensates them. In the same wards, some respondents called for the government to build houses for the victims. Other actions include pre-flooding moving to safer places, the use of rainwater, and the use of household water treatment chemicals (see **Table 4.8**).

Table 4.8: Actions taken for self-preparation regarding future floods

	Jangwani		Tandale		Vingunguti		Overall results	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
No actions	27	93.1	18	56.3	31	68.9	76	71.7
To have reserved water	1	3.4	8	25	2	4.4	11	10.4
To use water guard chemicals	1	3.4	0	0	1	2.2	2	1.9
Use rainwater	0	0	0	0	2	4.4	2	1.9
Vacate to a safe place after being informed	0	0	1	3.1	3	6.7	4	3.8
Asking the government to build houses for victims	0	0	2	6.3	2	4.4	4	3.8
Asking the government for relocation, after compensation	0	0	0	0	1	2.2	1	0.9
Have been told by the government to vacate yet not compensated	0	0	2	6.3	2	4.4	4	3.8
No money	0	0	1	3.1	0	0	1	0.9
Water is always available	0	0	0	0	1	2.2	1	0.9
	29	**100**	**32**	**100**	**45**	**100**	**106**	**100.0**

4.3.2 Interplay of the problems between the infrastructure, environmental, and water users' aspects

There is a strong relationship between the infrastructure, environment, and water users due to the way the problems interact across them. All types of water consumers are the major source of pollution stresses and degradation of the environment. For instance, polluted and degraded environment aggravates climate change impacts, thereby increasing the exposure of the water supply infrastructure to more intense risks such as floods. The polluted environment also affects water sources and consequently the water users pay back due to lack of reliable public water supply, therefore, consuming water from alternative sources which are highly likely contaminated. Water users also weaken the infrastructures through actions such as vandalization and illegal connections that also contribute to high water losses (see **Figure 4.9**) and raise the vulnerability of the system to flood risks.

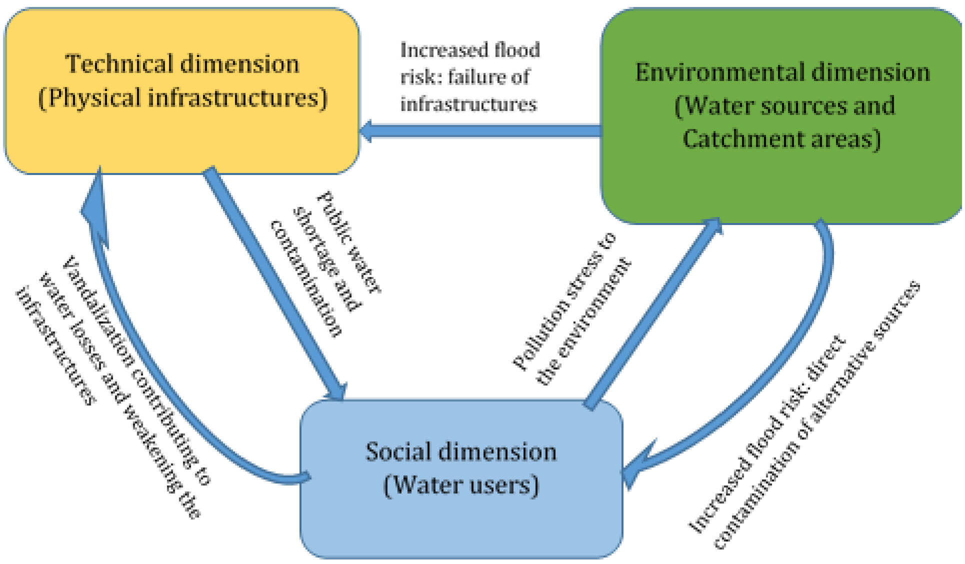


Figure 4.9: Relationship between infrastructure, the environment and the community

4.3.3 Flood risk implications for the water supply systems

Flood risks to water supply systems lead to direct and indirect effects: direct effects are such as degradation of the water sources through soil erosion and deposition, contamination of the water sources, and failure of the water infrastructures. For instance, water sources degradation has affected the Ruvu River at Kidongozero, affecting the water quantity downstream to the Upper and Lower Ruvu treatment plants. Degradation causes indirect effects such as public water scarcity leading to the use of unreliable water sources or spending too much money on buying water and consequently increasing the chance of water-related diseases and economic losses to the people. Contamination is for both main and alternative sources. Contamination of main sources is both primary and post-contamination, primary contamination contributes to cascade effects such as an increase of water treatment expenses impacting the WSSA's economy, whereas post-contamination triggers secondary effects of contaminating the water in the distribution networks, thus raising the possibility of water-related diseases. Failure of the infrastructure leads to three secondary effects, such as public water scarcity, public water contamination, and demands for repair and maintenance or recovery should the system face high magnitude flood impacts. The first two increase the chances of water-related diseases, while the latter leads to the WSSA's economic losses (see **Figure 4.10**).

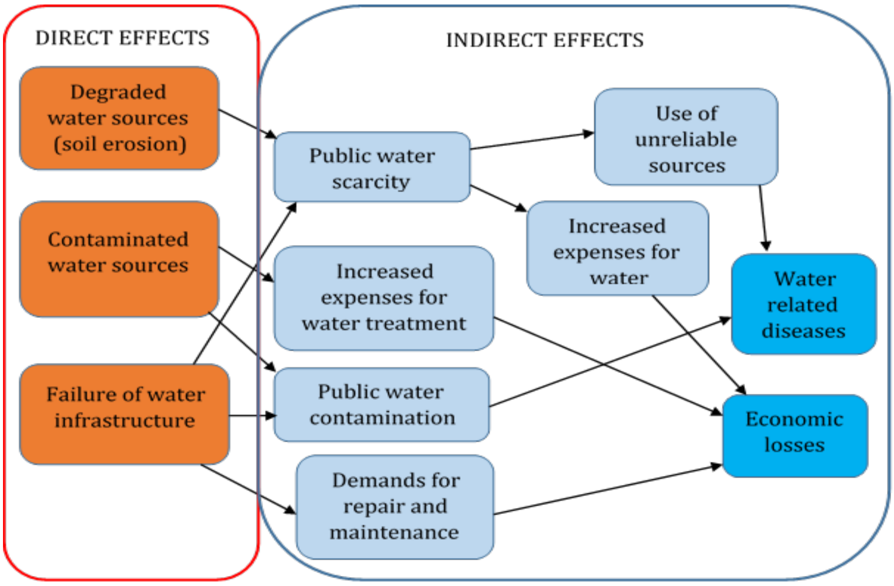


Figure 4.10: Impacts of flood risks to water supply systems

4.4 DISCUSSION

4.4.1 Infrastructure resilience issues affecting the water supply systems

The chapter is about assessing the on-ground problems affecting the resilience of Tanzania water supply systems focusing on the infrastructure, the environment and the water users or the communities. The three water schemes in Dar es Salaam: Mtoni, Lower Ruvu, and Upper Ruvu are partially interconnected. The only interconnection is between Lower Ruvu and Upper Ruvu in the areas along Mandela Road. That means the schemes divide into service zones, and the failure of one scheme means the served areas/zones face an interruption of public water supply services. This is evident from DAWASCO adverts regarding water shortage of up to 48hours on 23/24th January 2015[8] due to installation of interconnection between an old pipe and a new pipe at the Lower Ruvu water treatment plant. All customers served by the scheme starting from Bagamoyo district in the Coastal region, about 31 wards in Dar es Salaam, and the Muhimbili National Hospital lacked public water service. According to Proag (2016), lack of connectedness/linkage of the water schemes suggests that the system has low redundancy which affects the resilience of water supply systems against disasters.

Other redundancy issues include lack of additional capacities in the critical assets and inadequate alternative facilities for some critical assets. Although the Ruvu treatment plants' expansion doubled their capacities by 2015, the whole public water system can only serve 75%

[8] http://www.tanzaniatoday.co.tz/news/dawasco-yatangaza-kukosekana-huduma-ya-maji-kwa-siku-mbili-jijini-dar

of the total demand at present[9]. That means there is a shortage of about 25% of the total demand, and that the system cannot accommodate any shock related to abrupt water demand increase or disruptive events such as floods. Critical facilities such as water intakes in all schemes, a pumping station for Mtoni scheme, and the water transmission mains in all schemes are exposed to floods and lack alternative facilities or routes in case of supply interruption due to flood events.

The system has experienced a monthly average NRW of 50.29% and 46.31% in 2015/2016 and 2016/2017 production years respectively suggesting the loss of approximately half of the water produced, leaving the majority water users "who rely on the system" without enough water. The water loss is associated with structural leakages (Kjellen, 2008) because of ageing infrastructures, illegal connections, and bursting of pipes along roads due to traffic and insufficient soil cover. Water loss is also associated with water pressure caused by unbalanced system development. For instance, in 2011-2015, the Ruvu water schemes were upgraded to double their capacities from 82,000m^3/d to 196,000m^3/d and 180,000m^3/d to 270,000m^3/d for Upper Ruvu and Lower Ruvu respectively[10]. While the upgrade enhanced the capacity of the treatment plants and transmission mains, the sizes of the distribution networks remained the same. Thus, water with high-pressure from the production sites flows into smaller size distribution pipes leading to pipe bursts in some areas. Although there are current efforts to upgrade the distribution systems, this area needs immediate improvement to enhance the robustness of the system.

Water production in the three schemes depends entirely on the power supply from the national electricity grid. It is not uncommon for power supply to be interrupted during heavy downpours, where production processes are affected. The Ruvu schemes have a power substation connecting to both the Coastal region and Dar es Salaam City electricity networks to dampen failures. The interdependency on the national power grid aligns with Proag (2016) who identified a similar problem affecting the resilience of the water supply systems in Mauritius. Despite the availability of back-up generators at the production sites, only lighting and supporting other small loads uses. Furthermore, during flooding where water at the intakes is highly turbid, water production is lowered to avoid massive consumption of chemicals leading to a shortage of water supply in the city.

[9] http://www.dawasco.go.tz/waterservices.html
[10] http://dawasa.go.tz/facilities

4.4.2 Environmental effects on the resilience of the water supply systems

Catchment and recharge areas for the water sources in Dar es Salaam are within the Wami/Ruvu basin. Their management is one of the overarching problems for Dar es Salaam water managers. The use of local knowledge and native species has the potential to support management activities (Watts, 2012). However, the local knowledge has received little recognition; thus, the practices and values previously passed down through generations are diminishing except for a few areas in the highlands of Uluguru. Despite the potential of native vegetation on increasing rainfall interception by trees and the litter layer which stores water and allow time for a greater degree of infiltration, there is a decline in the native vegetation cover within the basin encompassing an increase in flash floods, drying up of springs, and increase in turbidity in rivers. The *miombo* woodlands amidst savanna grassland in the basin's lowlands have degraded by 43% from 1970 to 1990s the trend that continues (GLOWS-FIU, 2014). The Eastern Arc Mountains in the basin's uplands, dwindled by 60% to 90%, slowing down to 6% towards the end of the 20th century due to reserve status and distance from the city (GLOWS-FIU, 2014). The removal of native vegetation cover "deforestation" has spread out from the city due to urbanization, agriculture, and demands for charcoal and low to high-value timber leading to immediate runoff, soil erosion, flash floods, and low groundwater recharge during rainfall. Besides, lowlands deforestation has thinned out the canopy cover with significant effects on water and soil resources.

Ecosystem sensitivity for water resources includes the management of catchments and recharge areas. "Encroachment of human activities in these areas is evident and severe" (Research Participant). Also, the Minister for water and irrigation while addressing the audience during the water week on 20th March 2018 mentioned the importance of deploying strategies to tackle the ongoing pollution in different catchments within the country[11]. There are several income generating activities taking place in the catchment areas. Parts of the catchments and recharge areas have become potential areas for human settlements. The areas are also fertile and wet throughout the year, thus, have attracted agricultural activities. The abundance of appropriate tree species has attracted people to produce charcoal and timber. Other activities include sand-cement block making, sand quarrying, grazing, and mining. Such activities along the river banks and loss of riparian vegetation have contributed to the erosion

[11] https://issamichuzi.blogspot.co.nz/2018/03/waziri-wa-maji-azungumzia-umuhimu-wa.html

of river banks, changes in river morphology, and deterioration of the water quality, especially during flooding.

Human encroachment has affected the natural buffers within the basin. Natural buffers in the form of wetlands and floodplains are capable of regulating hydrology by storing rainwater and surface runoff during the wet season and discharging it into rivers during the dry season. However, natural ways for flood management which involving a whole catchment approach to manage floodwater through managing soil, wetlands, woodlands, and floodplains seems to be in jeopardy. According to Hirji, Davis and Brown (2009), major wetlands in the Ruvu system found in the southeast of the Uluguru Mountains have been affected by human activities such as agriculture, land conversion, water abstraction, brick making and pollution. Also, the wetlands for saline water in the estuaries of the Ruvu River comprising of the mangrove forests have been affected by deforestation due to land clearing for other uses like panning, and tree felling for firewood and charcoal making (JICA, 2013). Similar effects are in the estuary of the Kizinga River, which in addition is at risk due to urbanization (Hirji, Davis and Brown, 2009). Furthermore, the rivers are polluted and face severe erosion due to the rare existence of riparian vegetation. Such finding aligns with the river health analysis report which indicates that most of the rivers in the Wami/Ruvu basin are devoid of Macrophytes, hence they have bare riverbanks (UTD, 2017b).

The water sources management is at risk due to insufficient information about water users. According to the research participant, the number of unregistered water users, including domestic, agricultural and industrial is higher than the registered users. JICA, (2013) revealed that even registered users hardly conduct monitoring of abstraction volumes, as many intake facilities do not have flow measuring devices. That means, the total water withdrawal monitoring is rarely in practice, and the sensitivity of the water resources is partially known. Besides, no systematic water balance assessment since 2012 when the same was conducted by JICA (2013), meaning that there is no clear trend on the efficient use of water within the basin. The water balance conducted for the entire Wami/Ruvu basin by JICA (2013) cited in Schaefer & Dietrich (2015) showed that the risk of groundwater over-exploitation is significant, and the surface water deficit will rise in the basin within the next two decades despite stable rainfall levels. The problem is exacerbated by flooding as the stress shifts from water scarcity alone to water scarcity and contamination, and more people become vulnerable.

4.4.3 Issues related to water consumers

The highest education level of more than 80% of the people residing in the study area and are vulnerable to floods is the primary school, most of which have no formal employment. The majority “about 60%” are either small-scale entrepreneurs or food vendors. These findings agree with Douglas et al. (2008); Independent Evaluation group (2006); Rashid (2000); Chaudhry & Ruysschaert (2007); and Proag (2016) suggesting that the poorest in the low-income countries have no choice but to locate themselves in unsafe settings and consequently they are most vulnerable to disasters. More than 50% of such residents in Tandale and Vingunguti own the houses they live in. In Jangwani, over 50% rented the houses they live in; the area attracts more low-income tenants due to its prominence for urban agriculture (Pallela, 2000) and proximity to the city center and “Kariakoo” the main business area in Dar es Salaam with affordable housing (Limbumba & Ngware, 2016). The three wards have developed to be potential business areas in Dar es Salaam, and probably that is the main reason people do not want to leave despite the areas’ vulnerability to floods. The houses in these areas are not insured, such that the owners incur total losses when their houses are affected by floods. As the areas are in the floodplains of the Msimbazi River, there is severe deposition in some locations; thus, water distribution pipes and standpipes became utterly buried in sediments.

Over 90% of the respondents revealed that water quality, quantity, and services are affected by flooding. Such results concur with previous sections indicating that the leaking and broken water distribution pipes are likely to reduce the quantity of water and allow floodwater to enter the potable water pipes during the interruption, and low-pressure times. A research participant indicated further that, during flooding, water at the intakes is highly turbid and contains a lot of suspended matters such that the production cost increases due to the need for frequent removal of screenings, and more chemical to address the turbidity at the treatment plants. In that regard, operators lower the water production to avoid the likely extra production costs and damages of the screens. Besides, pumping stations at the Mtoni treatment plants are usually stopped due to the effects of the flooding water, while the transmission mains are currently at risk, as they cross rivers, thus affecting both quality and availability of the water within the city.

When the public water supply is affected by flooding, the residents have different alternatives used to secure the service. The majority “58.5%” of the respondents experience hardship on securing water supply during flooding. Few people store bulk water in buckets for emergencies, thereby minimizing their consumption so that they do not completely run short of water. The findings are in line with Bayliss (2011) whose study shows that, in water scarcity areas such as Vingunguti in Dar es Salaam, households have already reduced the consumption of piped water to a bare minimum in normal periods suggesting that further minimization occurs in emergencies. Although buying water is the only significant alternative, it is expensive and almost unaffordable to the majority. Bayliss (2011) indicates that the most expensive water originates from the public taps: vendors transport the water such that the long supply chain translates into substantial mark-up prices and most people already use more than 5% of their income (acceptable poverty threshold) for water, while the quality also remains questionable due to post-contamination and lacking effective monitoring programs. Borehole waters are largely described as salty while other alternative water supplies such as from lowlands and traditional wells are susceptible to pollution.

There were some signs of preparedness for future flooding, and a few respondents showed dependence on the government claiming to be ready to leave the vulnerable areas if they get compensation from the government. Also, few people who claimed that they are prepared to vacate temporarily to a safer place and return when floods recede. Others indicated the desire to reserve water in their houses for use during a crisis, use of rainwater, and use of domestic water treatment chemical agents. The majority "over 60%" indicated that they are no prepared at all, one of the reasons being inadequate finances suggesting that the poor are the most affected.

4.4.4 Implication of the findings

The problems that intensify flood risks in the water infrastructure are partly related to inadequate asset management. High water loss measured in terms of NRW is due to vandalization and illegal tapping resulted from inadequate protection of the system and enforcement of the DAWASA Act 2001 sect. 18.4[12] which acknowledges these actions as offences. Other reasons include broken pipes due to traffic, intentionally defected pipes to get free water and improper construction methods in some areas. Also, parts of the distribution network and the oldest scheme of 1951 are aged, whereas there are inadequate measures for renewal; thus, remain weak and vulnerable to flood risks. Several distribution pipes are exposed to the ground due to soil erosion which is attributable to insufficient soil cover as a result of ineffective use of guidelines during construction, especially for small projects. Moreover, the current design guidelines (i.e. Design Manual for Water Supply and Wastewater Disposal,

[12] https://www.maji.go.tz/pages/water-legislation

(URT, 2009) contain very limited information embracing resilience-based approaches in planning, designing and construction of critical assets in or across flood risk areas.

Most of the environmental issues are associated with inadequate enforcement of measures for pollution control stipulated in the Environmental Management Act (EMA) 2004, and the water resources management including enforcing effluent discharge permits, water abstraction, withdrawal monitoring and water balance, and restricting human activities within 60m from the water sources (Water Resources Management Act-WRMA, 2009). There is also a sense that political influence plays a big role in slowing down enforcement of the regulations. It is not uncommon in Tanzania for the technical officials to have different views with political leaders and more pressure prevails during electoral campaigns where officials are discouraged from reporting issues (McCrickard et al., 2017). The two National Environment Management Council taken to court over corruption in 2013[13], and the five officials charged with several economic crimes related to offences in 2018[14] show further that, there are ethical and professional issues that need to be resolved within the government agencies to ensure that enforcement is successful.

People at high risk live in low-lying areas close to urban rivers, the majority of which are poor and unable to secure land in safer areas or rent in safer residents. Poverty is deepened by what is referred by Pavlova (2016) as a simple demolition of houses in restricted areas rather than applying a phasic relocation program to places with needed services. The National Water Policy (URT, 2002) emphasizes on the public-private partnership, which is also one of the objectives of the Water and Sanitation Act 2009 and its amendment. The most famous attempt to implement the objective was the establishment of a partnership between DAWASA and a private operator—City Water Services, ending prematurely in 2005 due misunderstanding among the three key-players—government, financiers, and private actors (WaterAid, 2008). The existing public-private partnership involves small private networks, most of which are unregulated, and vendors whose water cost more than tap water (Kassenga et al. 2009) due to the long vending chain. The most popular is the public-public partnership between DAWASCO and the existing Community Water Supply Organizations (COWSOs) which operate in remote areas from the main networks. Some COWSOs are middlemen, tapping water from the main water supply; thus, they offer a little alternative when the main network suffers from flood hazards. The human rights in the water sector, on the other hand, is still a pending problem in

[13] www.dailynews.co.tz/news/two-nemc-officials-in-court-over-bribery-charges.aspx)

[14] www.thecitizen.co.tz/News/Five-NEMC-officials-charged/1840340-4831472-14b4pt3z/index.html

the city. Although the Water Policy 2002 acknowledges that every citizen has an equal right to access and use the water, there is an uneven supply of water (Smiley 2016): some receive regular water supply, some have pipes but receive an intermittent supply, and some do not receive piped water at all. Under this scenario, the poorest residents of the city suffer the most.

4.5 CONCLUSION

The Dar es Salaam water supply system experiences inadequate redundancy, due to lack of alternative facilities for critical assets and connectedness of the schemes. The system is also suffering significant water losses affecting the ability of the authority to generate sufficient income for critical activities such as renewal, operation, and maintenance. Despite the efforts invested by the Government through the ministry of water, DAWASA, and DAWASCO to extend the water supply service to a large population, Dar es Salaam public water supply can only suffice 75% of the total population, leaving about 25% of residents most of them being poor without access to potable water. The highest value of NRW, 57.44%, means that at certain times even those who are connected to the public water supply system can only get less than half of their demand. The water sources are at risk of pollution due to the encroachment of human activities in the catchments and recharge areas. The poor population is the main victim of the impacts of floods on public water supply systems—during flooding, the majority are unable to access water from the system. In some instances, when the water is available, usually it becomes costly due to the vending chain.

Furthermore, most of the respondents are already spending more than 5% of their income on the water in normal periods. Thus, they are unable to prepare for the future impacts of floods on water supply systems. These findings suggest that improving the physical infrastructure would have a strong influence on the wellbeing of the water users in relation to water issues. Also, environmental degradation has implications on the integrity of water sources in Dar es Salaam. Therefore, there is a need for improving the resilience of the system altogether to ensure that there is a continued supply during flood emergencies. In addition, justice, rights for water, effective enforcement of policies and regulations, and a well-coordinated public-private partnership calls for proper organization and effective management assisted with economic stability to foster the continuity of public water supply in the city. The findings serve as a benchmark for other systems in the country as the city’s system is the most problematic and highly invested for the past many years. The next chapters attempt to develop tools to measure the resilience of the water supply systems and determine appropriate measures for improving resilience.

Chapter 5
Development of Technical Variables for Measuring the Resilience

The current chapter is based on the following article:

Sweya L.N., Wilkinson S., Kassenga, G., Lugomela, G. (2020). Development of a Tool for Measuring Resilience of Water Supply Systems in Tanzania: Technical Dimension (Accepted: Journal of Water Resources Planning and Management-ASCE)

5.1 INTRODUCTION

The current chapter develops variables to measure the technical resilience for Tanzania water supply systems. As indicated earlier, water supply systems are lifeline infrastructure because they provide essential services that support community life (Brown et al., 2010). Ageing infrastructure, inadequate redundancy, interdependency, inadequate preparedness and political influence on water development projects and billing systems affect the resilience in most developing countries (Sweya et al. 2018). Other factors are related to environmental conservation (Odada et al., 2004), water governance (Rugemalila & Gibbs, 2015 and Smiley, 2016), funding systems and competition between water consumers (Maganga et al., 2002), and public involvement in water management projects (Kyessi, 2007 and Dungumaro & Madulu, 2003). Such problems aggravate floods risk affecting the community water supply services.

Flood hazards will intensify due to climate change (URT, 2003 & IPCC, 2014), rapid urbanization, dysfunctioning drainage systems, and poor planning (Sakijege, Lupala & Sheuya, 2012; Kebede & Nicolls, 2011) leading to more severe risks on water supply systems. The physical infrastructures are particularly susceptible in flood-prone countries like Tanzania and other developing countries such as Mozambique, which was affected by Cyclone Idai in March 2019, and Mauritius (Proag, 2016) whose infrastructures are continually vulnerable to cyclonic events or torrential downpours. Sweya et al. (2019) categorize water supply systems flood risks as *direct*—causing “structural failure” and *indirect*—those cascading after structural failure, e.g. water contamination. Both risks affect the community water supply services leading to the need to improve the water supply systems resilience to better cope with future impacts.

Ability to measure resilience supports the decision on appropriate resilience improvement interventions (D'Lima & Medda, 2015). There is, however, a lack of a universal metric for application in all systems (Willis, 2015). Also, many components for measuring resilience are complex (Prior, 2015) such that careful assessment is required to customize them for application in Tanzania water supply systems as the majority are from other countries facing a different set of issues (Bruneau et al., 2003; Vugrin et al. 2010; Perry, 2013; Morley, 2012; Hughes & Healy, 2014; Balaei et al., 2018 and Butler et al., 2017). The objective of the current study is to develop a technical resilience tool to measure Tanzania water supply systems resilience. The objective of the current chapter is to develop a qualitative technical resilience tool to gauge the water supply systems resilience. The chapter embraces a five-stage process, including literature review, pre-assessment, pretesting, a Delphi survey, and tool evaluation. The tool is primarily intended to portray the current technical resilience performance for urban water supply systems and identify areas needing improvements to enhance informed decision making on appropriate resilience interventions. Future expectations are that the tool can be used in the WSSAs' planning processes and budgeting to improve overall resilience, leading to overall policy changes regarding resilience issues in the water sector.

5.2 TECHNICAL RESILIENCE

The concept of resilience is from the Latin word *resilio,* meaning 'to jump back' (Klein et al., 2003). A resilient system has some characteristics enabling a return to the original state (Proag, 2016), withstanding short-term disturbances, overcoming disruptions and being built or building itself after damage (Hwang et al., 2013). Resilience has no universally accepted standard interpretation (Barnes et al., 2012) and, as such, is dynamic and undergoes several evolutions of prolonged refreshment and redefinition (Prior, 2015). An efficient and resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and rapidly recover from a potentially disruptive event (Soldi et al., 2015). Stevenson et al. (2015) defined resilience as *"The ability to absorb the effects of a disruptive event, minimize adverse impacts, respond effectively post-event, maintain or recover functionality, and adapt in a way that allows for learning and thriving, while mitigating the adverse impacts of future events."* Such a definition aligns with Marchese et al. (2020) and Khatavkar & Mays (2019) suggesting that resilience encompasses the system's ability to either prevent or minimize the effects of disruptions that arise and rapidly recover or adapt to changing conditions associated with emerging threats. Both studies entail useful information for improving water supply systems resilience.

Measuring resilience is based on systems' functionality and recovery time to pre-disaster state (Tierney & Bruneau, 2007 and Moteff, 2012). The measurement can take place before or after disasters through *quantitative approaches*—using numerical descriptions like detailed analyses and modelling leading to resilience indices, and *qualitative approaches*—using a set of principles from which to assess resilience (Hughes & Healy, 2014). Qualitative approaches lead to conceptual frameworks and semi-quantitative indices where sets of principles, the mechanisms and behaviors for measuring resilience, are scaled up and aggregated to indices. Broad qualitative approaches would lead to more practical and flexible frameworks in terms of data requirement, computational requirement, results, ease of implementation, use in targeting resilience improvements, useful in broader organizational resilience assessments and engagement, as well as in assessing physical network asset resilience (Hughes & Healy 2014).

Bruneau et al. (2003) developed a four-dimension conceptual framework (technical, organizational, social, economic, (TOSE)), for measuring community resilience. The framework emphasized on a holistic approach looking beyond physical and organizational systems to the impacts of social and economic networks (Tierney & Bruneau, 2007). Various modifications exist upon TOSE, including measuring resilience for eight different infrastructures (Vugrin et al. 2010), transport infrastructure (Hughes & Healy, 2014), and water supply systems (Balaei et al. 2018). Particularly, Balaei et al. (2018) developed a five-dimensional framework (technical, organizational, social, economic, and environmental), to assess water supply system resilience against earthquake impacts.

Most frameworks regard technical resilience as the most important —referring to the ability of physical systems "including components, their interconnections and interactions, and entire systems" to perform to acceptable standards (Bruneau et al., 2003). Different principles can be defined, describing the ability of the physical system to withstand forces and quickly recover from the disasters' impacts. The principles of technical resilience vary depending on the nature of the infrastructure in question. **Table 5.1** shows a list of principles that are significant in enhancing technical resilience.

Table 5.1: Factors affecting technical resilience

Author(s)	Target system	Factors/Principle(s)
Bruneau et al. 2003	Community resilience	Robustness, Redundancy, Resourcefulness, Rapidity
Hughes & Healy 2014	Transport resilience	Robustness, Redundancy, Safe-to-fail
Proag 2016	Water supply systems	Robustness, Redundancy, Reliability, Resourcefulness, Rapidity
Mugume 2015	Urban water systems	Flexibility, Redundancy
de Bruijn et al. 2017	Societies	Remain-functioning
Karamouz et al. 2019	Building infrastructure	Redundancy, adaptive hazard mitigation practices
Khatavkar & Mays 2019	Water distribution system	Redundancy, Robustness
Basupi & Kapelan 2015	Water distribution systems	Flexibility
Jung et al. 2014	Water distribution systems	Robustness

Several frameworks contain universal principles for technical resilience assessment. The most frequently used principles are robustness and redundancy (Bruneau et al., 2003). Reliability, safe-to-fail, and flexibility are also crucial for assessing the infrastructure's physical components resilience. Reliability is practiced during the design or retrofit phase to ensure infrastructures are reliable under all conditions (Proag, 2016). Remain-functioning refers to designing systems such that the consequences of failure are manageable, also, known as fail-safe (de Bruijn et al., 2017). Fail-safe aligns with Hughes & Healy's (2014) safe-to-fail, as resilience approach involving adapting to changing conditions and potentially allowing controlled failure. Reliability, remain-functioning, and safe-to-fail encompass similar features. Safe designs of urban water supply systems principally focus on enhancing reliability—keeping the system remain in service—aiming to boost functionality in extreme events, admitting that failure cannot completely be eliminated in resilience thinking (de Bruijn et al., 2017). **Table 5.1** literature informed the researcher's conceptualization of potentially useful principles in evaluating how to operationalize resilience in the Tanzania water sector. Principles that they then decided with professionals through the Delphi method, a qualitative technical assessment tool for urban water supply systems.

5.3 METHODOLOGY

5.3.1 Tool development and evaluation examples

A literature review was initially conducted to identify principles and indicators that are relevant inform the urban water supply systems technical resilience. The review covered various frameworks, and other publications relating to water supply systems resilience. Indicators—the operational representations of the serviceability, quality, or characteristic of a system's resilience (Balaei et al., 2018) —had to meet the four principles of resilience (robustness, redundancy, safe-to-fail, and flexibility) in the search to develop a hypothesized tool to evaluate the water supply systems' technical resilience.

The hypothesized tool was prequalified through a pre-assessment using a questionnaire developed from the hypothesized tool. Ten experienced water supply experts from public institutions, private companies, and research institutions—the next paragraph provides more details—participated in the exercise. The pre-assessment generated four principles and 12 indicators (see **Table 5.2)**. The tool was also pretested through interviews with two water supply organizations using the findings to improve the tool further.

Table 5.2: Improved tool from the pre-assessment exercise

Principles	Indicators	Code	Descriptions	Reference
1. Robustness	1. System maintenance	TI1	Effectiveness of providing periodic maintenance and post floods rehabilitation of critical assets of the water supply system	Hughes & Healy 2014
	2. System renewal	TI2	Established assets renewal and upgrade plans to improve the resilience of the system against floods	Hughes & Healy 2014, Butler et al. 2017
	3. System design	TI3	Suitability of critical assets designs across the whole water supply system, their condition, and locations in areas known to be exposed to floods	Hughes & Healy 2014
	4. Standards/ codes	TI4	Design codes and other codes of practices, incorporating resilience principles for physical assets regarding the impacts of flooding.	Hughes & Healy 2014
	5. Upstream interdependencies	TI5	The impacts of robustness and redundancy issues in supplier utilities such as power, telecommunication, and roads to the water supply system	Hughes & Healy 2014
	6. Non-Revenue-Water (Water loss)	TI6	Quantity of water lost after production before reaching the consumers (unbilled water) due to some reasons such as leakages and vandalism	Researchers
2. Redundancy	7. System redundancy	TI7	Availability of alternate facilities and routes for critical assets such as intakes, treatment units, pumps, and transmission mains-that would probably not be affected during flooding.	Hughes & Healy 2014
	8. Back-up capacities	TI8	Availability of back-up facilities or equipment such as standby pumps, power generators and emergency supply to respond to flooding events	Hughes & Healy 2014
3. Safe-to-fail	9. Design approaches in existing assets	TI9	Consideration of safe-to-fail design approaches for critical assets in conjunction with robustness and redundancy design approaches (where considered relevant)	Hughes & Healy 2014
	10. Design approaches in guidelines	TI10	The stipulation of safe-to-fail design approaches into design guidelines	Hughes & Healy 2014
4. Flexibility	11. The connectedness of the system	TI11	The extent at which different water schemes are interconnected such that one can dampen failure in another, and the degree of connectedness of the service points in individual distribution schemes.	Proag 2016
	12. Buffering capacity/factor of safety	TI12	The Additional capacity of the system's critical components to cater for water supply in the events of partial failure or surge in demand	Mugume et al. 2015

The improved tool went through a three-round Delphi study. A list of 22 experts in the three-round Delphi exercise included the ten experts who were involved in the pre-assessment to enhance consistency. Experts selection relied on the relevance of their professionalism to the water sector, educational background (at least a bachelor's degree), experience and exposure to water supply systems disaster resilience, and willingness to proceed in the progressive rounds**.** Thus, the panel consisted of government officials—Ministry of water, academicians, and practitioners "WSSAs, Consultants, and contractors."

At the beginning of each round, the researcher approached all experts asking to develop consensus and prioritize the principles and indicators systematically. In the first round, responders were asked to comment on the principles and indicators and add more indicators, whereas, they ranked the principles and rated the importance of the indicators during the second and third rounds. Ranking of principles was in the order from 1 to 4 for the least important. Indicator rating used six key attributes—relevance, affordability, availability, reliability, simplicity, and transparency—as useful guide in indicators importance rating and their potential for inclusion in this study.

Each attribute was scored on a five-point Likert scale from strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4) strongly agree (5). Agreement was reached when, on average, at least 70% of experts scored 4 or 5 on the six attributes on the inclusion of the indicator (Wakai et al., 2013; Suwaratchai et al. 2011 and Zhong et al. 2015) and the standard deviation was between 0.3-0.988 (Zhong et al. 2015)

Thematic analysis was applied manually to the respondents' comments during the pre-assessment, pretesting, and the Delphi study-first round. Using Statistical Package for Social Sciences, IBM SPSS Statistics 25, standard descriptive statistical analysis for second and third-round Delphi data was performed. The mean ratings (MRs) and median ratings (MeR) were used in assessing the principles' ranking order. MRs and standard deviations (SDs) described the group opinion and the convergence of the range of indicators' importance ratings respectively. The t-test or non-parametric Mann-Whitney tests depending on whether the data were normally distributed, with $p < 0.05$ as the statistical significance level, determined whether there was a significant difference between the second and the third rounds. Kappa statistics applied in further comparison of the results, showing the percentage agreement between the two rounds.

Assessment tools for each indicator—consisting of measures and measurement scales were further derived through a literature review and used to demonstrate the tool's workability. Each measure contains scales showing five performance levels (Morley, 2012). The scales are qualitative statements representing the graduated performance levels based on a five-point Likert scale, from 1 for very poor performance to 5 for very high performance. Each indicator has at least one measure describing how it can be assessed. For instance, "system design" has three measures assessing the percentage of the assets that are at or below the current design code, the general condition of the water supply systems' critical assets, and the percentage of the critical assets in flood-hazard areas. Measures and their respective scales are align with the water supply systems' objectives of providing continuous and sustainable water service and agree with the principles to enhance water service availability during floods. For instance, measures for the "system design," "system maintenance," and "system renewal" indicators are designed to enhance the system's "robustness." Moreover, the evidence that critical spare parts are readily available and accessible during emergencies will enhance the system's flexibility by responding quickly to any flood damage lowering the water service disruption criticality. Examples for measures and measurement scales are presented in **Table 5.3**, whereas a complete list is attached in **Appendix 4**.

Table 5.3: Examples for measures and measurement scales

Indicator	Code	Measure	Measurement scale
The connectedness of the system	TI11	Percentage of the service area that is likely to receive service from more than one scheme.	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%
		The proportion of looped distribution network versus dead end distribution network in the service areas (LS/DeS)	1. No information 2. <40% large part of the service areas has a dead-end distribution network 3. 40 – 60% the two networks co-exist in nearly the same proportion 4. 60 -80% Improved efforts for implementing a looped system 5. 80 – 100% The looped distribution network is dominant
System decentralization	TI13	Evidence that the water supply system has more than one subsystem (schemes)	1. No information 2. Centralized system comprising of a single production system 3. Different production systems, with the centralized distribution scheme 4. Different production systems, with clear decentralized distribution schemes, and very few interconnections 5. Different production systems with clear decentralized distribution schemes, well-planned interconnections within the whole system
System renewal	TI2	Evidence for existing and implemented assets renewal and upgrade plans for improving resilience	1. No plan exists and no controlled renewal or upgrades of assets. 2. The plan is not linked to resilience, and an ad hoc approach is undertaken. 3. Renewal and upgrade plans exist for critical assets and are linked to resilience, however no evidence that they are followed. 4. Renewal and upgrade plans exist for critical assets, linked to resilience, and an ad hoc approach is undertaken 5. Renewal and upgrade plans exist for critical assets, are linked to resilience, and are reviewed, updated, and implemented.

The tool was evaluated in two WSSAs, which were physically approached to provide scores for each measure based on the respective scales. For the sake of the examples, each principle or indicator was assigned equal weightings.

5.3.2 Final technical resilience index (FTRI) calculations

The initial scores represented the indicator resilience R_I. The scores were aggregated to the principle resilience R_P and the final technical resilience index *FTRI*. The current resilience index equations are modified from Morley (2012), whose study assessed the operational and economic resilience of water supply systems. The final resilience index was described based on the five-point Likert scale from 1 for very low resilience to 5 for very high resilience.

The following equations were used in the evaluation.

$$X_{wj} = w_i X_i \tag{5.1}$$

$$R_{P(Agg)j} = \sum_{i=n}^{n} w_{Ii} R_{Ii} \tag{5.2}$$

$$FTRI = w_{ROB} R_{ROB} + w_{RED} R_{RED} + w_{FLEX} R_{FLEX} + w_{STF} R_{STF} \tag{5.3}$$

Where; X_w = weighted resilience for variable j (indicator or principle)

w_i = weighting of a variable i

$R_{P(Agg)i}$ = Aggregated principle resilience j

w_{Ii} = weighting of an indicator i

R_{Ii} = Indicator resilience for i^{th} indicator

$FTRI$ = final technical resilience index

w_{ROB} = weighting for robustness principle

R_{ROB} = resilience for the robustness principle

w_{RED} = weighting for redundancy principle

R_{RED} = resilience for the redundancy principle

w_{FLEX} = weighting for flexibility principle

R_{FLEX} = resilience for flexibility principle

w_{STF} = weighting for safe-to-fail principle

R_{STF} = resilience for safe-to-fail principle

5.4 RESULTS

The study began with a literature review, three thematic indicators; “structural indicator,” “procedural indicator,” and “interdependencies indicator” were initially hypothesized for the tool (see **Appendix 2**). The “structural indicator” refers to assets/network design, maintenance and renewal, alternate pipelines, back-up supplies, and the degree to which innovative design approaches are implemented to allow controlled failure during crises. The “procedural indicator” relates to non-physical measures relating to existence, stability and application of design codes, guidelines, and communication plans and the extent to which safe-to-fail designs are specified in design guidelines. The “interdependencies indicator” relates to upstream dependencies and their relative robustness and redundancy in both a structural and procedural sense.

5.4.1 Pre-assessment and pretesting

Of the ten experts involved in pre-assessment, 50% possessed PhD qualifications with over ten-year’s water-related experience and were ranked at their workplaces as senior professionals. The rest were senior associate professionals with experience from 5 to 10 years. 80% of all experts had disaster management experience with a high degree of research ability. Results show that 80% to 100% of experts accepted the hypothesized indicators for inclusion in the study. The decision was supported by the SDs ranging from 0.42 to 0.71 of the indicators’ importance ratings. The lowest rating was given to interdependencies indicator, which also earned comments such as "I think I did not understand interdependencies reflecting the water supply system we have." Expert 7 also suggested for a further breakdown of the indicators to improve clarity, which aligns with Expert 3 who recommended the addition of issues such as knowledge capacity and technology under the structural and procedural indicators.

Other additions were the consideration of the spatial aspect of the water supply services and location of the water supply infrastructure. “There are cases where people with inadequate expertise design and implement the water supply systems; refer to the community-managed water supply system, see if this indication takes on board such circumstances," Expert 1 said. Such comments prompted the need for revision and further indicators’ breakdown to better the comprehension. Subsequently, 12 indicators were proposed across four principles.

The pretesting of indicators involved the Dar es Salaam Water Supply and Sewerage Authority (DAWASA) and Dar es Salaam Water and Sewerage Corporation (DAWASCO) in

Dar es Salaam, currently merged into one institution "DAWASA." The Dar es Salaam water production system was upgraded in 2011-2015 to double the capacity compared to the distribution system. As in many occasions, there was a 48hrs interruption in January 2015, due to the installation of the interconnection of the Lower Ruvu Trunk Main Pipeline. The interruption affected part of Bagamoyo district, 31 wards in Dar es Salaam, and the Muhimbili National Hospital. Besides, it took over a week to fix a transmission main that had broken due to flooding across the Mbezi River in 2017. Moreover, the water demand in the city is approximately 545,000m^3/day, whereas production capacity is 488,000m^3/day. As such observations, four indicators emerged, as shown in **Table 5.4**.

Table 5.4: Additional indicators based on pretesting results

Issues raised during pretesting	Added indicator	Reference
The production system is heavily invested than the distribution system (production was doubled following the 2011-2015 production system upgrade)	Unbalanced system development	Researchers
The large area lacks service when the water mains are affected by floods; for instance, in January 2015, there was a 48hrs interruption due to the installation of interconnection for the Lower Ruvu TMP. Part of Bagamoyo district, 31 wards in Dar es Salaam, and the Muhimbili National Hospital were affected.	System decentralization	Mugume et al. 2015
No additional capacity in the system; Demand is approximately 545,000m^3/d while production capacity ins 488,000m^3/d.	System future expansion capability	Researchers
The longer time is taken to fix post-floods problems; it took more than a week to fix a transmission main that had broken due to flooding across the Mbezi River in 2017	Critical spare parts and equipment availability	Morley 2012

5.4.2 Three-round Delphi survey

Twenty-two experts participated in the study, including ten who participated in the pre-assessment. Sixteen completed the first round, and among those, 12 completed the second and the third rounds. The response rate was 72.7%, 75%, and 100% respectively, and no new expert joined after the first round commenced.

First-round Delphi survey

Experts commented on the significance of the principles and indicators and modified or added more indicators that seemed significant for the study. Ten experts had participated in the pre-assessment exercise. Of those, two experts did not complete the first-round assessment—new experts thus replaced them. The two replacements came from the same institutions ensuring there was no lack of the influence of such institutions. Therefore, the first round consisted of feedback from eight new experts, equivalent to 50% of the total respondents. Of all respondents in this round, 75% had comments relevant to the tool and strongly reflected in this study.

Meaningful comments were summarized for a later addition, revision, or integration. The technical resilience description improved to the “ability of the physical components of water supply systems to continuously deliver water at the acceptable standards in terms of quantity and quality when hit by floods." It involves all aspects of the functionality of physical components such as intakes, dams, pumps and pumping stations, treatment units, pipelines, and storage facilities during flood emergencies. The dimension comprises of four principles whose improved descriptions appear in **Table 5.5**. Experts raised issues such as spatial or physical planning of urban areas indicating that "the critical problem in Tanzania is the development of infrastructures without proper physical planning." Such comment applied in improving the description for “standards and codes” indicator which discusses the resilience-based design approaches. The indicator was improved further to accommodate construction practices. Other comments such as consideration of electric power interruption fell under the “interdependency” indicator. “System decentralization” moved from “flexibility” to “redundancy” principle, and “critical spare parts and equipment availability” indicator was revised to include preparedness aspects.

Table 5.5: Improved principles

Principle	Description
Robustness	Strength, or the ability of elements, systems and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function
Redundancy	The degree to which multiple elements or components provide similar functions, to minimize failure propagation through the system or to enable critical operations to be diverted to alternative parts of the system during disasters.
Safe-to-fail	An innovative design approach that acknowledges that failures are inevitable and seeks systems that can easily survive and afford (cost reduction) failures and provide room for learning rather than rely on preventing their occurrence ‘fail-safe.'
Flexibility	Inbuilt system capability to adjust or reconfigure to maintain acceptable levels when subject to the impacts of disasters. It can be increased through intentional one-off or phased interventions that enhance inbuilt system properties of resilience.

Second-round Delphi survey

Ranking of the principles

Importance ranking of the principles shows that “robustness” ranked five times as the most important principle than other principles, followed by “safe-to-fail” four times. “Robustness” was supported by lower MR=1.92 and MeR=2.00, closer to one than any other principle. Despite ranking “safe-to-fail” four times as most important principle, it was also ranked five times as the least important—many times than any other principle, with MR=2.75 and MeR=3.00 relatively higher than others. Group opinion thus suggested that safe-to-fail is least important than others. Consequently, the importance of ranking-order was 1-robustness, 2-flexibility, 3-redundancy, and 4-for safe-to-fail.

Rating of indicators

The six attributes presented in chapter three were applied as useful guidance in rating the importance of the indicators and their potential for inclusion in this study. The MRs show that all indicators were scored between 4 and 5 for *relevance*, suggesting experts agreed or strongly agreed that the indicators are appropriate to this study. 93.8% were rated between 4 and 5 for *reliability* and *transparency* except for "upstream interdependencies," and 93.8% had similar ratings for *simplicity* except for "system redundancy." Results revealed further that, 68.8% of the indicators were considered *affordable*, and their data are readily *available*. Although “upstream interdependencies” had better scores for *relevance* and *simplicity*, it had the least scores in terms of *affordability, availability, reliability*, and *transparency*, followed by “system redundancy” in terms of *affordability, availability*, and *simplicity*. For all indicators which rated below four at least once across all six attributes, each case, either *affordability* or *availability* attributes were involved.

Six indicators were excluded as less than 70% of the experts, on average, agreed or strongly agreed on their importance for the current study. Excluded indicators also consisted of relatively low MRs and higher SDs, suggesting that the group opinions for their inclusion was low, and the experts’ ratings had low convergence. On the other hand, ten indicators were important and were included in this study. The indicators also had MRs ranging from 3.67 to 4.17, and SDs between 0.39 and 0.97, suggesting that the group opinions were relatively high, and the overall convergence of importance ratings is acceptable.

Results show that “system future expansion capability” was the most important indicator according to 91.7% of the experts, the indicator also contained a high MR=4.00 and lower SD=0.43 than others. The ranking-order was followed by “system maintenance,” and “system renewal” with “connectedness of the system” in the third place. The least important indicator was “system decentralization” having higher SDs=0.90, suggesting that the level of convergence of the experts was lower than for other indicators.

Third-round Delphi survey

The improved tool includes four principles and ten indicators. Experts reconsidered their voting and re-ranked the principles and re-rated the indicators. 83.3% of the experts were satisfied with the tool from the second-round assessment and did not revise their voting. Some experts said that; "I’ve gone through the indicators and find the assessment is sufficient at the stage you have reached—thus, I don’t have any additional input to it", "yes please, kindly take further steps, I don’t have different opinions," "I think there are no changes, you can proceed." 16.7% of the experts reconsidered their voting the following paragraph describes the results.

Slight changes emerged in the principles’ ranking-order where “flexibility” and “redundancy” swapped their positions: “redundancy” rated lower MR=2.50 and MeR=2.00 than “flexibility” 2.7 and 2.50 for MR and MeR respectively suggesting that “redundancy” was slightly more important than “flexibility at this stage.” This refreshed the ranking-order to 1-robustness, 2-redundancy, 3-flexibility, and 4-safe-to-fail. 75% to 100% of the experts accepted the inclusion of all ten in this study. The MRs ranged from 3.75 to 4.17 and SDs from 0.45 to 0.90; thus, the overall convergence of the importance ratings can be considered acceptable. The first five top-rated indicators during the second round; TI1, TI2, TI15, TI16, and TI11 were also rated the same in this round. The only adjustment was that “system maintenance” became the first ranked indicator exchanging with "system future expansion capability."

Level of agreement between the second and third rounds

Statistical results show that the p-values ranged from 0.35 to 0.50, suggesting that there was no significant difference between the second and third rounds in principles’ ranking-order. Further statistical comparison for the indicators’ importance ratings revealed p-values ranging from 0.34 to 0.49, suggesting no significant difference between the second and third rounds. The Kappa values of the principles and indicators showing the extent of agreement between rounds two and three ranged from 0.74 to 1.0 (mean = 0.95, median = 1.00). These values suggest that there was a substantial agreement between the two rounds. The final tool, including four principles and ten indicators, is presented in **Table 5.6**.

Table 5.6: Final tool for measuring the resilience of water supply systems in Tanzania

Principles (MR, MeR) (P-value, Kappa)	**Indicators**			
	Indicator (MR, SD)	**Code**	**p-value, Kappa score**	**Rank**
1. Robustness (*2.00, 2.00*) (*0.432, 0.74*)	1. System maintenance (*4.17, 0.58*)	TI1	*(0.36, 0.82)*	**1**
	2. System renewal (*4.08, 0.67*)	TI2	*(0.49, 1.00)*	**3***
	3. System design (*3.92, 0.79*)	TI3	*(0.49, 1.00)*	**7**
	4. Standards/ codes (*3.91, 0.90*)	TI4	*(0.40, 0.87)*	**8**
2. Redundancy (*2.50, 2.00*) (*0.35, 0.78*)	5. System decentralization (*4.00, 0.85*)	TI13	*(0.41, 0.87)*	**6**
	6. System redundancy (*3.75, 0.45*)	TI7	*(0.39, 0.81)*	**9**
3. Flexibility (2.67, 2.50) (0.49, 1.00)	7. System future expansion capability (*4.08, 0.52*)	TI15	*(0.34, 0.77)*	**2**
	8. Critical spare parts and equipment availability (*4.08, 0.67*)	TI16	*(0.49, 1.00)*	**3***
	9. The connectedness of the system (*4.00, 0.60*)	TI11	*(0.38, 0.85)*	**5**
4. Safe-to-fail (*2.83, 3.00*) (*0.46, 0.77*)	10. Design approaches in guidelines (*3.75, 0.75*)	TI10	*(0.39, 0.85)*	**10**

5.4.5 Evaluation of the tool using examples

Tool evaluation in Dar es Salaam Urban water supply system

Dar es Salaam is Tanzania's major city with a total population of 4,364,541 (URT, 2012b) currently standing at around six million and total water demand of about 545,000m^3/day. DAWASA is the primary water service provider for Dar es Salaam and part of the coastal region. The public water supply system is composed of three main water sources—Ruvu River, Mtoni River, and Kimbiji well-fields. DAWASA controls all water supply system developments, water production, transmission, distributions, connections, and billing activities in the service area.

Evaluation results show that the final technical resilience index *FTRI* is 2.45 ≈ 3.00—meaning that the system has moderate resilience with less than desirable performance and specific improvements should be prioritized. Principles such as "flexibility" and "safe-to-fail" have low performance (2.00) such that the percentage of components with options for future expansion needs to be improved enhancing the utilization of locally available spare parts and equipment or using materials and equipment whose spare parts are readily available and accessible to avoid delays in flood responses. Moreover, there is a need to include safe-to-fail design approaches in the critical assets design codes and guidelines. In that regard, the existing design standards/codes *"The Tanzania design manual for water supply and wastewater disposal"* needs improvement to incorporate resilience approaches that would lead to flood-resilient water supply systems.

Tool evaluation in Morogoro Urban water supply system

Morogoro Municipal's population is 315,866 (URT, 2012b) which is currently around 400,000 and total water demand of about 40,755m^3/day. The main water service provider is the Morogoro Urban Water Supply and Sanitation Authority (MORUWASA). The water authority produces about 24,000m^3/day serving about 61% of the population and supplying about 85% of the Municipality's total water. Water production is from six sources; Mindu dam is the primary water source contributing up to 81% of the total production. Mindu is a pumped scheme, while 19% is from gravity sources such as Mambogo, Vituli, Mgolole, Kibwe, and Kigurunyembe.

MORUWASA evaluation results show that the final technical resilience index *FTRI* is 2.47 ≈ 3.00—meaning that the system has moderate resilience with less than desirable performance and specific improvements should be prioritized. “Safe-to-fail” principle was the least scored (1.0) indicating the need for substantial improvements such as including the safe-to-fail design approaches within the critical assets design codes and guidelines. Also, significant improvements are needed in developing and implementing assets renewal and upgrade plans and improving the percentage of the critical assets which are at or above the current design codes to enhance the system’s “robustness.” Moreover, enhancement is needed for “flexibility” by increasing the percentage of the service areas that are likely to receive water from more than one scheme.

The implication of the tool evaluation results

The examples indicate that the Tanzania urban WSSAs can utilize the tool using their existing data. A data inventory is required should the authority decide to assess its technical resilience ensuring easier and quicker application of the tool. Both examples portrayed similar final resilience indices and the areas of improvements such as safe-to-fail and robustness. It shows that both officials were able to understand the tool indicating certain confidence that most of the country’s water supply systems are facing similar problems based on the current tool. For instance, both authorities have not adequately integrated safe-to-fail design approaches into their design codes and guidelines, probably due to using the same design codes and guidelines. Other indicators showing similar results are “connectedness of the systems,” “system redundancy,” and “system decentralization.” On the contrary, DAWASA has a very low percentage of components with future expansion options, whereas MORUWASA has a very high percentage of components with future expansion options. This is consistent with the influence of rapid population growth (5.29%)[15] of Dar es Salaam city to the water demand than Morogoro (3.67%)[16] as most facilities are demand-based designed. The examples confirm that the variables of the current tool are crucial in determining the systems’ weaknesses and their areas of improvements. Most Tanzania urban-WSSAs may not show significant discrepancies when using the tool due to using the same design guidelines “demand-based,” and having a similar water supply management culture with low attitude on resilience issues.

[15] https://www.macrotrends.net/cities/22894/dar-es-salaam/population
[16] https://www.macrotrends.net/cities/22898/morogoro/population

5.5 DISCUSSION

The study applies a five-stage process; literature review, pre-assessment, pretesting, and a three-round Delphi study to develop a technical resilience measurement tool for Tanzania urban water supply systems, and later evaluated using two examples. The three hypothesized thematic indicators diffused further to 12 more specific indicators during the pre-assessment. The indicators lie into four important factors; robustness, redundancy, flexibility, and safe-to-fail that had been used in various frameworks for measuring physical infrastructures resilience.

Four major issues emerged during pretesting; firstly, there is massive investment more in the production systems than the distribution system, so while more water can be produced, distribution systems are unable to supply adequate water to the residents. Secondly, many service areas suffer water-shortage as flood destroys the water-mains. Thirdly, the systems do not have additional capacities to serve when there is a surge in demand. Fourthly, too much time is taken for services restoration post-flood events. The issues resulted in four additional indicators; unbalanced systems development, systems decentralization, systems future expansion capability, and critical spare parts and equipment availability.

The response rates increased from 72.7% in the first round to 100% in the final round aligning with Gargon et al. (2019) who suggest that small size panels "such as those used by Ward et al. (2019)" are likely to have significantly better response rates. The rates were enhanced by the recruitment method, and participants contact where panels were contacted personally at the beginning of each round and regularly reminded to provide feedback. Most experts (83.3%) were satisfied with the tool encompassing four principles and ten indicators after the second round such that they did not revise their opinions in the subsequent round. It is normal to achieve consensus in two rounds since, principally, Delphi techniques require at least two rounds and studies such as Suwaratchai et al. (2011) reached consensus in two rounds.

The importance ratings revealed that the attribute that mostly influence the indicators is data availability, affecting Tanzania and most developing countries. The finding aligns with Balaei et al. (2018) indicating that the most significant difficulties are due to data deficiency, data collection difficulty, and lack of unity on country-to-country definitions, data holders' reluctance to share, and deliberate misrepresentation to progress the country's benefits. Some indicators were also influenced by *affordability* and *reliability* attributes. The indicators underrated for such attributes, their importance and potential for inclusion in the study are also affected; thus, the majority face exclusion, suggesting that the three attributes are critical guidelines to be used as guidelines for selecting indicators in Tanzania.

Ranking of the principles showed no significant difference between the second and third rounds, with a reasonable consensus between the rounds; thus, the ranking results from either round could be useful. Similarly, indicators' importance rating results had no significant difference between the two rounds; the MRs and SDs suggest better group opinions with acceptable overall convergence of the importance ratings. The ranking values seem very close due to the decision rule where the indicators' acceptance relied on at least 70% of the experts agreeing (4) or strongly agreeing (5). With such a margin, such results are apparent when using the current methodology. Kappa statistic values for the principles and indicators suggest a substantial agreement between the two rounds and attainment of the consensus.

Tanzania's water supply physical infrastructure is influenced by four factors: “robustness,” “redundancy,” “flexibility,” and “safe-to-fail.” “Robustness” is the most influential factor indicating the ability of the physical elements of the infrastructure to withstand flood emergencies without enduring degradation or loss of function. The principle is measured using indicators such as “system maintenance,” “system renewal,” “system design,” and “standards or codes.” The second influential principle is “redundancy;” portraying the degree to which multiple elements of the physical infrastructure provide similar functions to dampen failure propagation in the system. Indicators such as “system decentralization” and “system redundancy” apply in this principle. The third influential factor is “flexibility;” entailing the inbuilt system capability to adjust or reconfigure to maintain acceptable levels of performance when hit by floods. Three indicators can assess flexibility; “system future expansion capability,” “critical spare parts and equipment availability,” and “connectedness of the system.” The “safe-to-fail” factor is concerned with the innovative designs that acknowledge that failures are inevitable and seeks systems that can easily survive and afford failures and provide room for learning rather than relying on preventing their occurrences (see **Figure 5.1**).

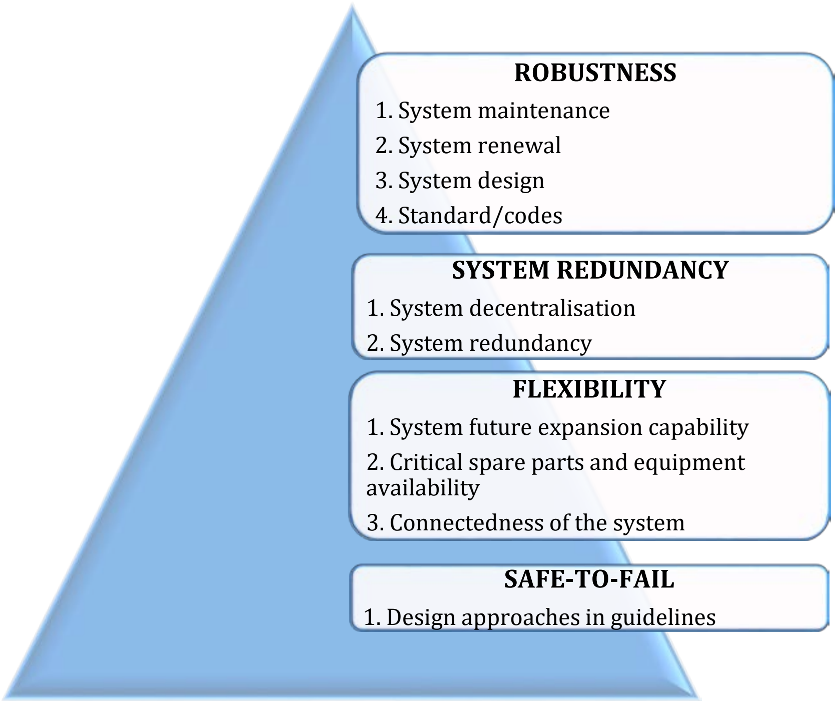


Figure 5.1: Significant variables of the tool for assessing technical resilience of water supply systems in Tanzania

In all cases, the most significant indicators for measuring the resilience of water supply physical infrastructures in Tanzania are "system maintenance," "system future expansion capability," "system renewal," "critical spare parts and equipment availability," and "system connectedness." Well maintained infrastructures having future expansion options integrated with renewal plans and implementation are resilient. Furthermore, water schemes which are linked together and have well-interconnected service points provide system failure dampening options during flooding while the availability of critical spare parts and equipment serves time in flood impacts response.

Evaluation examples suggest that the tool is applicable in assessing the technical resilience of the urban water supply systems using existing internal data. Most of the information required during the assessment is not new and is readily available at the urban WSSAs. The tool generates results in terms of graduated scales that describe the resilience status of a variable such as an indicator, principle, or the final index. The conclusion can be drawn from each scale of each principle or indicator, showing the need for interventions, and setting priorities to enhance the technical resilience. The urban water supply system authorities would need to create an inventory of the information and conduct a regular update so that current data are available at any time the assessment is required.

The study makes several contributions. Firstly, it entails an essential starting point for broad agreement about the important principles of the technical dimension of resilience of urban water supply systems against floods in Tanzania achieved through integrating a wider range of global infrastructures including water supply resilience physical characteristics from various frameworks into a comprehensive tool with four principles and ten indicators. To date, studies on Tanzania water supply systems have discussed a limited range of elements focusing on "water management" (Kjellén, 2008; Smiley, 2016; Garcia-Valinas & Miquel Florensa, 2013), "climate change" (Casmir, 2009; Jones et al. 2007; Kebede & Nicholls, 2011), and "floods risks analysis" (Sakijege et al. 2012; Kijazi & Reason 2009), with little emphasis on the resilience of water supply systems to floods. Thus, the current tool, covering a suitable range of indicators, focusses, applies in evaluating the resilience of Tanzania urban water supply systems. The tool aligns with a management approach with an achievable goal of enabling the WSSAs to make decisions, prioritize and budget for the appropriate interventions to enhance resilience and provide sustainable water services during flood hazards.

Secondly, water supply practitioners and managers (e.g., WSSAs for Tanzania) can apply the tool to assess the technical resilience of the urban water supply systems using their own internal data. Also, the tool applies as a checklist to identify priority practices assisting in planning to address future floods. Thirdly, the methodology used in developing the current tool is a significant contribution encompassing simple processes and analyses that other researchers can easily replicate in developing resilience tools. Finally, since the tool originates from a broad consultation of general concepts presented in the literature, it informs assessment variables that could be applied in other developing and developed countries, also applying as the foundation and being customized by other researchers to suit applications in other countries or water supply systems.

Despite the potentiality of the tool, some limitations can be drawn. The application of the tool may face data availability and data affordability issues in the country and in other developing countries with ineffective data management systems. A feasible and inexpensive way of addressing this limitation would be implementing databases to coordinate the discrete-data, bringing them together into an effective management system. Also, the data acquisition and tool implementation will rely on public institutions leading to susceptible prejudices and subjectivity when assigning weightings and scores. There is a need for involving a group of experienced and qualified experts to assign the weights and develop the scores to address the limitation.

5.6 CONCLUSION

This study developed a comprehensive qualitative technical resilience assessment tool with four principles and ten key indicators of the technical resilience of the urban-WSSs in Tanzania. It provided a starting point for broad agreement regarding the key principles and indicators of the resilience of the physical infrastructures for urban-WSSs in Tanzania. Although the initial focus of the paper was on flood impacts, that scope was expanded during expert elicitation to address general urban water supply resilience. The methodology employed in the current study for urban water supply indicator development and ranking with local experts in Tanzania could be applied anywhere in the world. Moreover, the tool is useful for evaluation and informing the priority practices that can assist Tanzania urban-WSSAs, and other developing and developed countries to address future emergencies on urban-WSSs. The next chapter evaluates the essentiality of the organizations that operate the water infrastructure and develops variables that can be used to measure the organization resilience for water supply systems.

Chapter 6

Development of Organizational Variables for Measuring the Resilience

The current chapter is based on the following article:

Sweya, L. N., Wilkinson, S., Kassenga, G., & Mayunga, J. (2020). Developing a tool to measure the organizational resilience of Tanzania's water supply systems. *Global Business and Organizational Excellence*, 39(2), 6-9

6.1 INTRODUCTION

Understanding how organizations that operate the water infrastructure is important to ensure that service is always uninterrupted. The current chapter examines the variables that influence water organizations in their quest to delivering continuous water services and suggest the most significant variables that can be used to enhance the resilience of the country's water supply systems. The impact of extreme weather, such as flooding, threatens water supply systems, roads, and other fundamental facilities and forms of infrastructure that provide essential services to communities around the globe. Such events are expected to occur more frequently with changes in the earth's climate (IPCC, 2014), putting people, their homes, and their businesses at high risk unless corrective measures are taken.

A variety of technical, social, economic, and environmental problems affecting water supply organizations can also have an impact on the resilience of their systems and make them more vulnerable to the effects of flooding (Sweya et al., 2018). Those issues also come into play when evaluating the resilience of water supply in case of an earthquake (Balaei et al., 2018). In any instance of disaster, it is vital for organizations that are responsible for operating water supply infrastructure to ensure that services are uninterrupted. Such resiliency would help guarantee that the surrounding community would be able to plan for, respond to, and quickly recover from the disaster, regardless of its cause (Lee, Vargo, & Seville, 2013).

Of particular concern in Tanzania, these issues prompted a study of the elements of resilience and led to the development of a tool to assess the ability of the nation's water supply organizations to ensure uninterrupted service to their local communities in any type of weather.

6.2 TANZANIA’S WATER SUPPLY CHALLENGES

A tropical East African nation, Tanzania experiences a rainy season from March to May that is characterized by heavy downpours and unpredictable short rainy periods from November to December. The heavy rains lead to flash floods and riverine floods in various parts of the country, which frequently disrupt the local water supply. The coastal areas—which include Tanzania’s most populous city, Dar es Salaam, and the major centers of Tanga, Mtwara, and Lindi—are highly vulnerable, as they are also prone to coastal cyclones originating in the Indian Ocean that have resulted in catastrophic damage.

Tanzania’s Water Supply and Sanitation Authorities (WSSA) are the principal water supply organizations in the country, covering about 79 percent of the population (URT, 2017a). Their functions are described in section 20(a-1) of the Water and Sanitation Act 2009. Hundreds of community-based water supply organizations (COWSOs), which were established under section 31(1) of the same act, and various private vendors also supply local residents and businesses with water (Kjellén, 2000). Section 20(b) of the act requires the WSSAs to provide a continual supply of water for all lawful purposes. During floods, however, the authorities’ lack of sufficient disaster risk management has led to an inadequate response, prolonging recovery.

A focus on service coverage rather than resilience against extreme weather events has left water suppliers ill-prepared during floods. To date, organizations charged with ensuring a supply of water in Tanzania lack the resources to assess their level of resilience and take any corrective action to improve it. To address this gap, water experts collaborated with selected WSSAs and Tanzania’s Ministry of Water to develop and demonstrate the use of a tool for measuring organizational resilience. The study identified various measures of resilience that can contribute to policy changes and intervention, and the tool is expected to be used in the water authorities’ planning processes and budgeting for improving the resilience of the nation’s water supply systems.

6.3 MEASURES OF ORGANIZATIONAL RESILIENCE

Resilience was first described in the field of ecology as a measure of the persistence of systems and of their ability to absorb change and disturbance while maintaining the same relationship between populations or state variables (Holling, 1973). Since then, the concept has been applied in different areas—including how organizations help a community prepare for, respond to, and recover from disasters—without a universal definition or set of measures.

A resilient organization directly contributes to the speedy and successful recovery of its community following a disaster (McManus, 2008). Organizational resilience has been considered a critical dimension for assessing the resilience of various systems, such as a community (Bruneau et al., 2003), multiple infrastructures (Vugrin et al., 2010), transportation infrastructure (Hughes & Healy, 2014), and water supply (Balaei et al., 2018). The critical elements of organizational resilience are the ability to adapt, the need to detect the drift toward failure or weak signals, the organization's preoccupation with failure, and the level of organizational reliability (Lee et al., 2013). These elements contribute to an organization's capacity to make decisions and to take actions to build resilience (Bruneau et al., 2003).

By measuring an organization's resilience, its leaders can demonstrate progress toward being more resilient, determine leading indicators as opposed to lagging indicators of resilience, link improvement in organizational resilience with competencies, and make a business case for the need to improve resilience (Lee et al., 2013). They face several challenges in doing so, however, such as the prioritization and allocation of resources to build resilience. These difficulties are compounded when leaders fail to get a grasp of the organization's level of resilience before it is tested by a natural disaster or other crisis, as well as by any barriers to understanding the link between resilience and the organization's profitability and competitiveness.

In one previously conceived model, relative overall resilience (ROR) comprised three factors: situation awareness, managing key vulnerabilities, and adaptive capacity (McManus, 2008). This model was subsequently used to develop tools to measure and compare organizational resilience, and researchers eventually determined that resilience is a function of two factors: adaptive capacity and planning (Lee et al., 2013). A research and consulting group in Christchurch, New Zealand that specializes in risk and recovery analyzed a range of studies and concluded that there are three core principles that help define a resilient organization: leadership and culture, networks and relationships, and being ready for change (Resilient Organizations, 2012). These principles were later applied to measure the organizational resilience of transportation systems in New Zealand (Hughes & Healy, 2014). These studies were used to inform the process of developing a tool to measure the organizational dimension of resilience for water supply systems in Tanzania.

6.4 SOLICITING EXPERT INPUT

Following an extensive review of previous research on various aspects of resilience, researchers used the Delphi technique—a method of group decision-making and forecasting that involves successively collating the judgments of experts—to identify potential elements of a tool that can be applied to measure the organizational resilience for water supply systems against floods in Tanzania. Ten experts from public, private, and research institutions with at least five years' experience relevant to the water sector voluntarily took part in the pre-assessment phase of the study; 22 experts voluntarily participated in the three-round Delphi process. Data from the Morogoro Water Supply and Sanitation Authority (MORUWASA) of Tanzania subsequently was used to demonstrate how the tool could work in practice.

The processes used in conducting the study include literature review, pre-assessment, a three-round Delphi survey, and tool evaluation. The literature review covered water-related publications on Tanzania and international water supply systems, particularly those in developing countries that share Tanzania's economic features. It identified 22 indicators from various resilience frameworks that could help inform water supply resilience measurement. The ROR model developed by McManus (2008) and improved by Resilient Organizations, a research and consulting group based in Christchurch, New Zealand, served as a starting point for developing the tool. Other frameworks (for example, Hughes & Healy, 2014, and Balaei et al., 2018) were also used during the process.

The hypothesized tool was pre-qualified through a pre-assessment exercise between September and October 2017 in Dar es Salaam, Tanzania. A semi-structured questionnaire was administered to 10 water industry experts in the pre-assessment phase. They were asked to comment on, modify, and add to 22 organizational indicators (OI) concerning water supply resilience and rate their importance. The results were used to improve the indicators derived from previous research. The improved tool comprised 3 organizational principles (OP)—change readiness, networks and relationships, and leadership and culture— and 15 organizational indicators.

This tool was then subjected to three-rounds of Delphi inquiry. To maintain consistency, the 10 ten experts who had participated in the pre-assessment phase were included among the 22 experts in the Delphi stage. The researchers contacted all 22 experts at the beginning of each round and asked them to develop consensus and prioritize the principles and indicators systematically.

In the first round, respondents were asked to comment on the organizational principles and indicators and to add more indicators. During the second and third rounds, they were instructed to rank the principles and rate the importance of the indicators from 1 (highly important) to 4 (least important). Six key attributes—relevance, affordability, availability, reliability, simplicity, and transparency—were to be considered when rating the importance of the indicators and their potential for inclusion in this study. Each attribute was scored on a five-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, and 5 = strongly agree). Consensus on a particular indicator was considered to have been reached when at least 70% of the experts, on average, had agreed or strongly agreed to its inclusion, and the standard deviation was less than 0.998 (Zhong, Clark, Hou, Zang, & FitzGerald, 2014)

Researchers began analyzing the data by manually noting common themes among respondents' comments during the pre-assessment and the first-round of the Delphi study. Next, they conducted a standard descriptive statistical analysis for second- and third-round data of the Delphi study. The mean ratings and medians were used to rank the order of the elements in the tool. In addition, mean ratings and standard deviations were used to describe group opinions and the convergence of the range of the experts' importance ratings of the indicators. To compare whether there was a significant difference between the second and the third round, a t-test or non-parametric Mann-Whitney U test was used, depending on whether the data were normally distributed, with $p < 0.05$ as the level of statistical significance. To further compare the results from the second round and third rounds, Kappa statistics were calculated to show the percentage agreement between them.

Assessment tools were developed and further tested using a hypothetical example to show how the tool works. The assessment tools comprise the measures and measurement scales for each indicator. Developed from those used in previous studies, the measures and their scales were modified to suit the current study. Initial scores corresponded to the measure and the respective indicator for resilience. Some indicators had more than one measure; thus, an average score was calculated. All variables were considered equally important, and equal weights were assigned in each category. Moreover, the weighted scores were aggregated to the final organizational resilience index. Aggregation relied on the utility index used by Morley (2012) in a study that assessed the operational and financial dimensions of resilience in the water sector. The variables of the equations were changed to suit the current study.

6.4.1 Pre-assessment results

Of the ten water experts who took part in the pre-assessment, half had doctoral degrees and more than ten years' experience in water-related fields and were ranked as senior professionals in their workplaces. The other 50% were senior associate professionals with 5 to 10 years' experience. Eighty percent of the experts had disaster management experience and a high level of research capability.

The results of this stage show that out of 22 hypothesized organizational indicators (see **Appendix 2**), 10 were acceptable, as at least 70% of the experts agreed or strongly agreed on their inclusion, and the standard deviation of each importance rating was between 0.3 and 0.998. The rest of the indicators (54.5%) were excluded because less than 70% of the experts agreed or strongly agreed on their inclusion (3 indicators), the standard deviation was above 0.998 (6 indicators), or less than 70% of the experts agreed or strongly agreed on their inclusion, and the standard deviation of the rating was above 0.998 (3 indicators).

The omission of some indicators was in line with the comments from experts. For instance, one expert said, "The stress testing/drills and response exercises indicator is applicable, but it is not practical, especially in countries like Tanzania." He also questioned, "at which level simulations would be exercised (organizational level or beyond?)," and so the indicator was revised accordingly.

Some experts felt that the list of indicators was too long and needed to be reduced. Considering this suggestion, the researchers merged indicators that were closely related. For example, the *meaningful lessons learned, and procedures changed* indicator was merged with one that addressed learning. A *leadership* indicator was initially excluded because of a high standard deviation, which resulted from one expert assigning a score of 5 to all indicators except leadership. Researchers subsequently included *leadership* and *resources* as indicators, for they considered them important to the study. The resources indicator was further revised to *internal resources* to reflect an organization's level of preparedness in an emergency.

Four more indicators were added to the list. *Political will* was added because one expert noted that "it affects the decision-making and implementation process." *Restructuring* was added because of frequent changes in the Ministry of Water and the water authorities. An *awareness* indicator was also added to respond to comments from two other experts. Also, *emergency response plan* (ERP) was added as an indicator to assess whether the organization has put forth plans for a response during flood emergencies. The refined list of 15 organizational indicators is presented in **Table 6.1**.

Table 6.1: Improved tool from the pre-assessment exercise

Principles	Indicators	Code	Reference
1. Change readiness	1. Emergency Response Plan (ERP)	OI1	Morley, 2012 and Balaei et al., 2018
	2.Communication and warning	OI2	Hughes & Healy, 2014
	3. Proactive posture	OI3	Resilient Organizations, 2012.
	4. Planning strategies	OI4	Resilient Organizations, 2012.
	5. Awareness	OI5	******
2. Networks and relationships	6. Effective partnership	OI6	Resilient Organizations, 2012.
	7. Leveraging knowledge	OI7	Resilient Organizations, 2012.
	8. Learning	OI8	Hughes & Healy 2014
	9. Internal resources	OI9	Resilient Organizations, 2012.
3. Leadership and culture	10. Leadership	OI10	Resilient Organizations, 2012.
	11. Engagement and involvement	OI11	Resilient Organizations, 2012.
	12. Decision making	OI12	Resilient Organizations, 2012.
	13. Innovation and creativity	OI13	Resilient Organizations, 2012.
	14. Political will	OI14	******
	15. Restructuring	OI15	******

Notes: OI = Organizational Indicator
****** Indicators added by researchers based on experts' opinions

6.4.2 The three-round Delphi survey

With the organizational resilience tool improved after the pre-assessment, the researchers moved on to conduct a three-round Delphi survey of its potential effectiveness. Twenty-two experts, including ten who took part in the pre-assessment stage, were contacted to participate in the study. Of the 22 experts, 16 completed the first round, and 12 completed the second and third rounds. No experts were added during the process: The same experts who were contacted during the first round were involved throughout the study.

First round

In the first round, 16 experts were asked to comment on the significance of the potential organizational principles and indicators and to modify or add more indicators that seemed significant for the study. Experts 1 to 10 had participated in the pre-assessment of the tool. Of those, two (5 and 6) did not participate in the Delphi study; thus, they were replaced by new experts from the same institution who participated in the study for the first time. Therefore, half the experts in this round were new to the study. Of the 16 experts, 13 of them commented on the tool.

Among the significant comments that emerged during this round were suggestions to include policies, legal frameworks, and institutional guidelines that influence water supply decisions in the description of the organizational dimension of resilience for water provision during flood emergencies. The description was improved further to include other institutions, such as non-government organizations (NGOs) and community-based water supply organizations that are involved in water supply activities. Thus, organizational resilience was re-described as the supply service capacity of the urban water supply authorities and other public and private institutions whose performance affects the water supply systems.

In line with those changes, a fourth organizational principle, *legal framework and institutional set-up*, was introduced (**Table 6.2**) that included such organizational indicators as *laws and policies* and *organizational structure,* as well as *restructuring*, which previously had been an indicator of the *leadership and culture* principle. Furthermore, the *communication and warning* indicator of the *change readiness* principle was improved to better focus on threats that affect water supply systems, and the description of *political will* for the *leadership and culture* principle was changed from *political influence* to *political support*.

Table 6.2: Improved principles of organizational resilience

Principle	Code	Description
Change readiness	OP1	Planning is undertaken, and direction established to enable the organization to continuously initiate and respond to changes in ways that create advantage, minimize risks, and sustain performances. This principle includes such attributes as the ability to sense and anticipate hazards, identify problems and failures, develop a forewarning of disruption threats, understand social vulnerability, adapt and learn from the success or failure of the past adaptive measure, and mobilize resources.
Networks and relationships	OP2	The ability to establish relationships, mutual aid arrangements, and regulatory partnerships; understand connectedness and vulnerability across all aspects of supply chains and distribution networks; and promote open communication and mitigation of internal/external silos (isolation from others). This principle also emphasizes the need for broad consultation and many views to create a sense of shared ownership or a joint vision to build system resilience.
Leadership and culture	OP3	The ability to develop an organizational mindset/culture of enthusiasm for meeting challenges, agility (the ability to think, understand, and act quickly and easily), flexibility, adaptive capacity, innovation, and seizing opportunities.
Legal framework and institution set-up	OP4	Broad set of rules that govern and regulate decision-making regarding building resilience for water service provision during flooding. Also involves the formal organizational structure, rules, and informal norms that strengthen resilience in the water supply systems.

Note: OP = organizational principle

Second round

During the first-round of the Delphi study, two indicators were added to improve the initial list to 17. During the second round, one indicator was omitted; thus, the final list was composed of 16 indicators. In the second round, experts were asked to rank the organizational principles and rate the organizational indicators according to their importance. The results showed that *change readiness* ranked first, *leadership and culture* ranked second, *legal framework and institutional set-up* ranked third, and *networks and relationships* ranked fourth.

The six attributes listed in in chapter three—**Table 3.3**—were used to guide participants in rating the importance of the indicators and their potential for inclusion in this study. Results revealed that 70.6% of the indicators passed all attributes. Although all indicators were considered relevant to this study, 11.8% of them underscored in terms of one of the attributes, and 17.6% underscored in terms of half of them. For instance, *planning strategies* (OI4) was underscored on availability, *laws and policies* (OI17) was underscored on reliability, *proactive posture* (OI3) was underrated on affordability and availability, and *internal resources* (OI9) was underrated on availability and reliability attributes. The attribute of availability was found lacking in 29.4% of the indicators.

Of the original 17 indicators, 94.12% were considered important, as at least 70% of the experts agreed or strongly agreed on their inclusion in the study during this round. Only one indicator, restructuring, was excluded during this round, as less than 70% of the experts agreed or strongly agreed on its inclusion.

The overall ranking of the 16 indicators showed that *awareness* (OI5) was the most important indicator; followed by *learning* (OI8) and *emergency response plan* (OI1), which shared second place; and *communication and warning* (OI2) in fourth place. The least important indicator was *innovation and creativity* (OI13).

Third round

The tool that emerged from the second round included 4 organizational principles and 16 organizational indicators. In the third round of the study, the experts were invited to re-rank the principles and re-rate the indicators. Most of the experts (83.3%) were satisfied with the principles and indicators that had emerged from the second-round assessment and did not revise their voting. The remaining experts (16.7%) revised their earlier assessments. Statistical analysis, however, found no significant difference between the second- and third-round results ($\alpha>0.05$). The ranking order of the principles also remained the same for both rounds. Further statistical analysis to compare the importance rating of the indicators revealed p-values ranging from 0.3819 to 0.4876, suggesting that there was no significant difference between the second round and the third round.

Between 75% and 100% of the experts in the third round agreed or strongly agreed on the inclusion of the 16 indicators, suggesting that consensus had been reached. The mean rating values ranged from 3.7500 to 4.3333 and standard deviations from 0.57735 to 0.96546; thus, the overall convergence of the importance ratings can be considered to be acceptable. The position of the top 8 indicators in the second round—awareness (OI5), emergency response plan (OI1), learning (OI8), communication and warning (OI2), leadership (OI10), planning strategies (OI4), political will (OI14), and engagement and involvement (OI11)—did not change in this round, while innovation and creativity (OI13) remained the lowest-rated indicator. The Kappa values for the principles and indicators, which ranged from 0.85 to 1 (mean = 0.9648, median = 1), suggest that there was substantial agreement between the two rounds. The final tool, which includes four principles and 16 indicators, is presented in **Table 6.3**.

Table 6.3: A tool for measuring the resilience of water supply systems in Tanzania

Principles (MR, MeR) (P-value, Kappa)	Indicators				
	Indicator (MR, SD)	**Code**	**Description**	**p-value, Kappa**	**Rank**
1. Change readiness (2.00, 2.00) (0.4878, 1.000)	2.1.1 Awareness (4.333, 0.651)	OI5	Staff and public awareness of flood disasters and their impact on the water supply system	(0.4872, 1.000)	**1**
	2.1.2 Emergency Response Plan (ERP) (4.167, 0.577)	OI1	Set of intended actions developed to mitigate the impact of flooding events that could affect the water supply infrastructure and the ability of the water authority to deliver the service to the community	(0.4861, 1.000)	**2***
	2.1.3 Communication and warning (4.083, 0.793)	OI2	Means of warning the staff and community regarding water issues, inform about water service options and devise communication options ahead of time to enhance information flow.	(0.4861, 1.000)	**4**
	2.1.4 Planning strategies (4.167, 0.718)	OI4	Development and evaluation of plans to manage water supply system exposure to flood hazard in relation to the system environment and stakeholders	(0.4874, 1.000)	**6**
	2.1.5 Proactive posture (3.917, 0.793)	OI3	A strategic and behavioral readiness to respond to early warning signs of change in the water authority's internal and external environment before they become a crisis	(0.3949, 0.852)	**8***
2. Leadership and culture (2.25, 2.00) (0.3562, 0.879)	2.2.1 Leadership (4.000, 0.739)	OI10	Strong leadership to provide good management and decision-making during flooding, as well as continuous evaluation of strategies and work programs against the goals of the water authority	(0.4848, 1.000)	**5**
	2.2.2 Political will (4.000, 0.853)	OI14	The political support and commitment in decision-making regarding water supply resilience to flooding issues	(0.3819, 0.850)	**7**
	2.2.3 Engagement and involvement (3.917, 0.793)	OI11	Staff awareness and involvement in regular resilience discussions. Also, full consultation of stakeholders/public during water project development to create a sense of ownership	(0.4862, 1.000)	**8***
	2.2.4 Decision-making (3.917, 0.669)	OI12	The clear delegation that enables highly skilled staff to make an appropriate decision in response to flooding	(0.4870, 1.000)	**11***

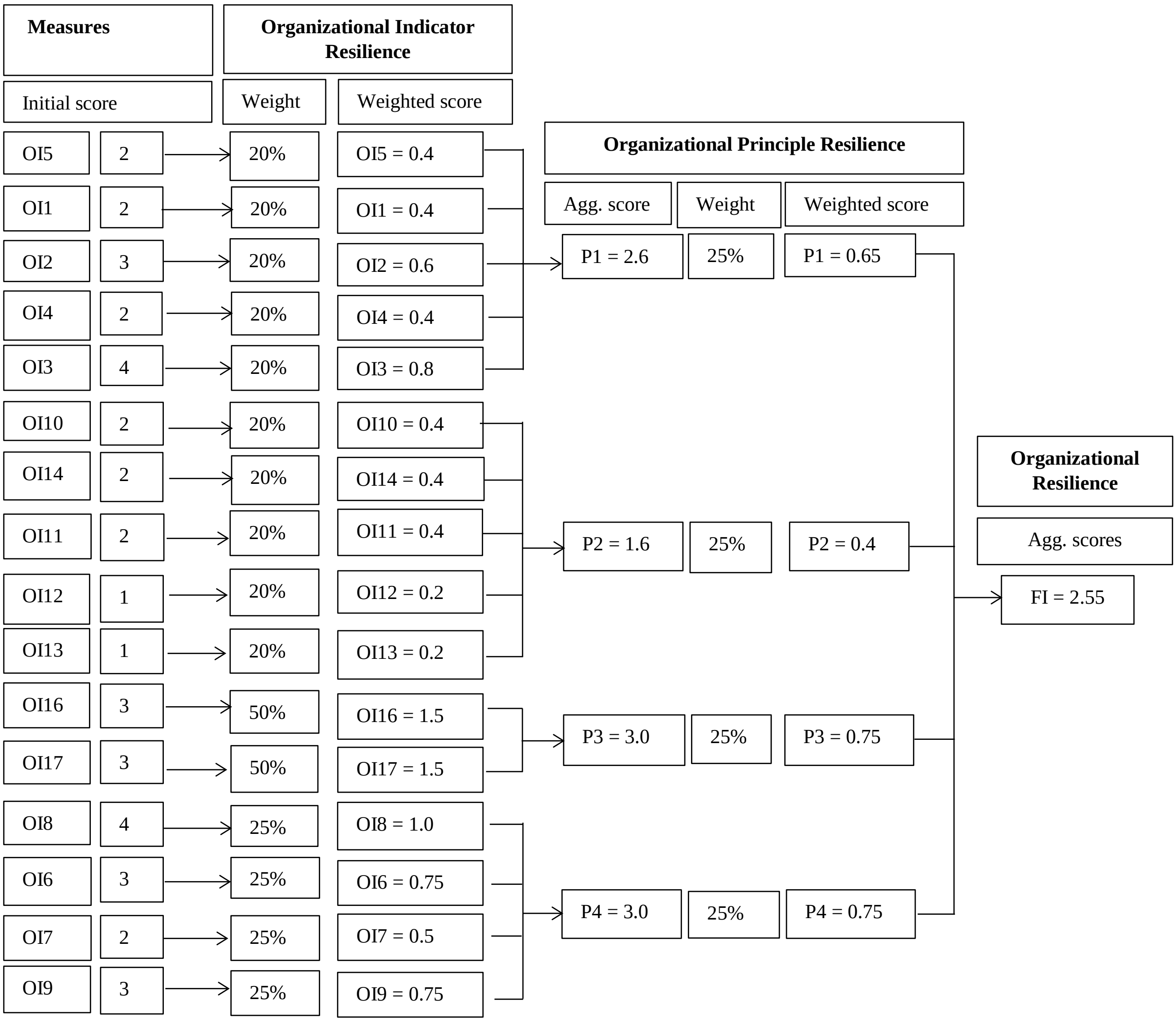
	2.2.5 Innovation and creativity (3.750, 0.754)	OI13	Staff are encouraged and rewarded for using their knowledge and innovative and creative approaches to address flooding challenges	(0.4862, 1.000)	**16**
3. Legal framework and institutional set-up (2.42, 3.00) (0.4878, 1.000)	2.3.1 Organizational structure (3.917, 0.669)	OI16	The way roles, power, and responsibility are assigned, controlled, and coordinated, and how the information flows between the different levels of management to achieve the goals of building resilience against floods.	(0.4870, 1.000)	**11***
	2.3.2 Laws and policies (3.917, 0.900)	OI17	Content of laws and policies related to water supply systems, their description of roles of institutions and other groups, and implementation effectiveness in building resilience to floods	(0.4876, 1.000)	**13**
4. Networks and relationships (3.083, 3.5) (0.3556, 0.876)	2.4.1 Learning (4.167, 0.577)	OI8	Exposure of staff and the public to education and awareness material/messaging	(0.4861, 1.000)	**2***
	2.4.2 Effective partnership (4.000, 0.953)	OI6	An understanding of the relationships and resources the water authority might need to access from other organizations during flooding, and planning to ensure this access	(0.4025, 0.876)	**10**
	2.4.3 Leveraging knowledge (3.833, 0.835)	OI7	Critical information is stored in several formats and locations, and the staff has access to expert opinions when needed. Roles are shared, and staff is trained so that someone will always be able to fill key roles	(0.4871, 1.000)	**14***
	2.4.4 Internal resources (3.833, 0.835)	OI9	The management and mobilization of the water authority's resources to ensure its ability to operate over usual circumstances, as well as being able to provide the exact capacity required during flooding events	(0.4741, 0.859)	**14***

Notes: OI = organizational indicator, MR = mean rating, MeR = median rating, SD = standard deviation. One indicator, OI15, was omitted during the second round of the Delphi survey, for a remaining total of 16 indicators

6.4.3 Putting the tool into operation

Similarities in the way different organizations engage in managing infrastructure, especially in building resilience, was a major driver for the creation of a tool to assess the organizational resilience for water supply. The researchers tested the tool they devised (**Figure 6.1**) with a hypothetical example using data from the Morogoro Water Supply and Sanitation Authority (MORUWASA), which is responsible for operating and managing water supply and sanitation services in a municipality of Tanzania that often experiences water shortages. The tool uses a 5-point Likert scale to denote the performance of each measure (1 = poor performance to 5 =highest performance). The scores were then weighted and aggregated to obtain a final value or index that portrays the level of resilience of the organization from 1 (very poor resilience) to 5 (very high resilience).

Further live testing could give an alternative view or confirm the accuracy of those demonstration scores. In the hypothetical example, the indicators for *decision-making* (OI12) and *innovation and creativity* (OI13) were the least scored, and *proactive posture* (OI3) and *learning* (OI8) were the highest scored. The weightings for the indicators range from 20% to 25%, depending on their number in the respective principle. Similarly, the weightings of the four principles are 25% each. Weightings also influenced the scores. For instance, even though *organizational structure* (OI16) scored less than *proactive posture* (OI3), its weighted score was higher (1.5) because of its weighting (50%). The principle resilience also seems to be affected by the initial score, as is the weighted principle resilience score. The aggregated principle performance is equal to the sum of weighted indicator scores and ranges from 1.6 to 3. Similarly, the final organizational resilience index is the sum of the weighted principle performances and is equal to 2.55 ≈ 3.



Notes: OI = organizational indicator, P = principle, P1 = change readiness, P2 = leadership and culture, P3 = legal framework and institutional set-up, P4 = network and relationships, Agg. = aggregated

Figure 6.1: Hypothetical test of a Tanzanian water supplier's resilience

6.5 RESILIENCE TO SECURE A KEY RESOUCE

This study applied a literature review, pre-assessment, three-round Delphi study, and hypothetical testing to develop and demonstrate the application of a tool for measuring organizational resilience for water supply systems in Tanzania. Twenty-two indicators were extracted from various organizational resilience frameworks, including 13 indicators from the ResOrg relative overall resilience model, which accounted for 59% of all indicators. During the pre-assessment stage, water experts recommended 15 indicators, 68.2% of the total, for inclusion in the study. Those indicators included nine from the ResOrg framework. Indicators that were considered irrelevant to the environment of a country like Tanzania were omitted. To facilitate understanding of the most salient issues, the 15 indicators that passed the pre-assessment stage were clustered into three categories of principles that were based on the ResOrg framework (Resilient Organizations, 2012).

The tool was further subjected to a three-round Delphi survey. The rate of responses in the study increased from 72.7% in the first round to 100% in the final round. The number of experts involved in the Delphi study is considered a small size panel, which has been found to have significantly better response rates (Gargon, Crew, Burnside, & Williamson, 2019). The rates were enhanced by the method of recruitment and participant contact: Panelists were contacted directly at the beginning of each round and regularly reminded through phone calls, text messages, or emails to provide feedback.

During the first-round of the survey, *legal framework and institutional set-up* was added as an important principle encompassing indicators regarding organizational structure and laws and policies. This addition resulted from the need to assess:

- ❖ the way roles, power, and responsibility are assigned, controlled, and coordinated;
- ❖ how information flows between different levels of management to build resilience;
- ❖ the contents of laws and policies related to water supply systems, and their description of the roles of institutions and other groups; and
- ❖ the effectiveness of implementing laws and policies in building resilience to floods.

Most of the experts (83.3%) reached consensus on a tool that involved 4 organizational principles and 16 organizational indicators during the second round of assessment (see **Figure 6.1**) and did not revise their voting when given the opportunity to do so in the subsequent round. That number of iterations aligns with another study in which consensus was reached during a two-round Delphi survey (Suwaratchai et al., 2011). In this study, only 16.7% of the participants revised their opinions in round 3.

The importance ratings in the second round revealed that the attribute that most affects the indicators is data availability. The affordability and reliability of the data also would affect the resilience assessment process. Water supply organizations and their partners need useful data that are accurate, timely, and widely available for the organizational resilience metrics and assist in making data-driven decisions. The lack of a rooted culture of data use in Tanzania, and other developing countries hampers this aspect of organizational resilience. Without good data that meet the six attributes of relevance, affordability, availability, reliability, simplicity, and transparency, it would be difficult to generate evidence regarding existing situations and policies. The findings, therefore, suggest that the accepted indicators presented in **Table 6.3** would be able to offer a good platform for effectively measuring, monitoring, and evaluating a water supply system's resilience.

There was no significant difference in the ranking of organizational principles between the second and third-round of the survey, which suggested that there was a good consensus between the two rounds and, therefore, the rankings from either round could be used. Similarly, the importance rating results for the organizational indicators showed no significant difference between the two rounds. The MRs ranged between 3.75 and 4.33, and standard deviation values were from 0.57735 to 0.96546, suggesting adequate group agreement and that the overall convergence of the importance ratings were acceptable.

The results of this study suggest that resiliency in Tanzania's water supply organizations depends on four factors (**Figure 6.2**). The factor that merits top priority is change readiness. The level of an organization's readiness for change, however, depends on two factors: leadership and culture, and legal framework and institutional set-up. Moreover, even though networks and relationships ranked low in study participants' ratings, they equip an organization with public, private, and international encounters that provide opportunities for consultation on water projects that can create a joint vision of resilience.

In all cases, the principal indicators for resilient water supply organizations include organizations whose staff are well informed regarding the impact of floods on organizational systems, have the ability to learn from past events, and have an effective emergency response plan, as well as communication and warning systems, in place. Strong leadership will help ensure proper management and decision-making during flooding, as well as continuous evaluation of planning strategies and work programs.

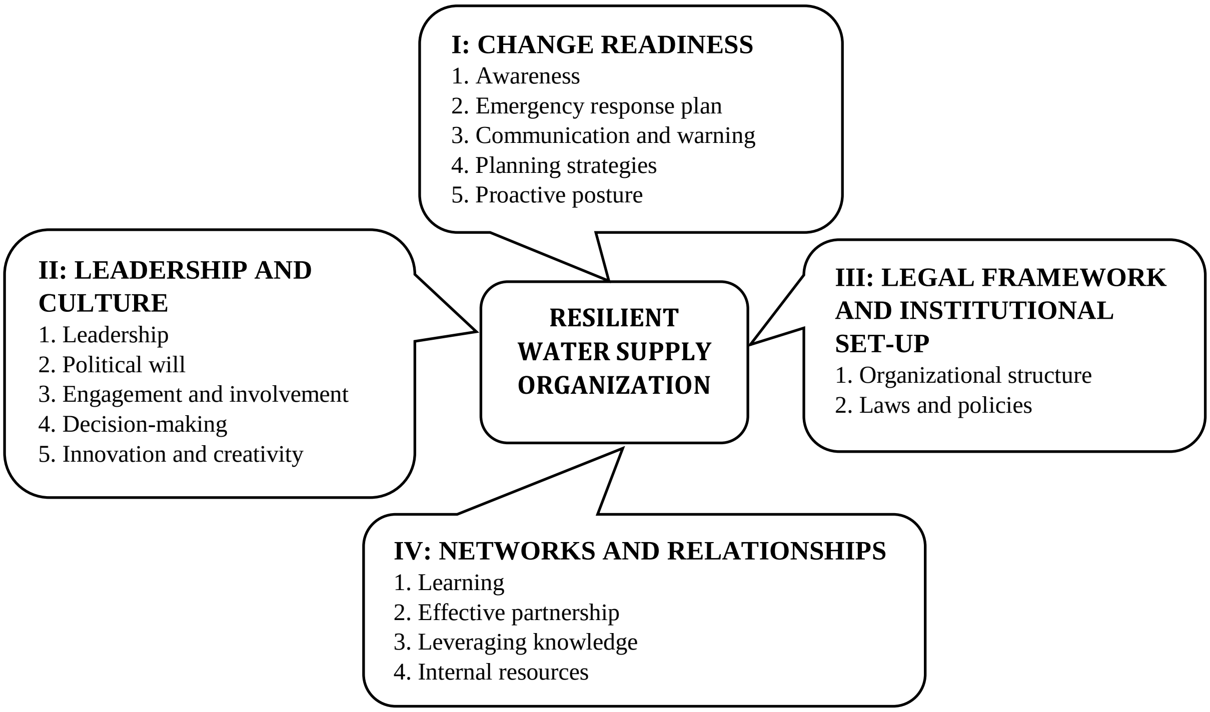


Figure 6.2: New model of organizational resilience for water supply systems in Tanzania

Conducting an assessment of organizational resilience can lead to policy changes and effective interventions. The hypothetical case indicates that the MORUWASA's organizational resilience score was 2.55 ≈ 3. This suggests that the organization has a medium resilience when faced with flood hazards and, therefore, improvement measures are needed. Since the organization received its lowest score (1.6 ≈ 2.0) on the *leadership and culture* principal, immediate interventions in this area are required to improve resilience. Specifically, the organization could seek to improve its level of innovation and creativity. For instance, it could try to establish strategies to encourage and reward staff for using their creativity and innovative ability in addressing water issues during flooding. To improve decision making, it could try to put procedures in place to assign authority to make timely decisions and reduce excessive bureaucracy in relation to the deployment of staff and resources during flooding.

Although international agencies have recognized the need to develop resilient infrastructures (United Nations, n.d.), Tanzania's Water Policy (URT, 2002) does not address resilience. This relatively new concept for Tanzania needs to be incorporated into its official policies and practices.

In analyzing the principles and indicators that can be used to measure the organizational resilience of water supply systems in Tanzania, this study created a new model of the essential components of resilience and a comprehensive assessment tool to help guide water suppliers in providing uninterrupted service, regardless of environmental conditions. It also can be used to evaluate and inform practices to help water supply authorities not only in Tanzania but also in other developing countries, to address future flooding hazards and ensure access to a precious and life-giving resource. The next chapter evaluates the influence of environmental variables on the resilience of water supply systems, leading to significant variables that can be used to systematically assess the environmental resilience for the systems.

6.6 CONCLUSION

The study developed and demonstrated a comprehensive tool comprising of principles and key indicators that can be used to measure the organizational resilience for the water supply systems in Tanzania. The new model of organizational resilience developed through this research regarded resilience as a function of four factors: change readiness, leadership and culture, legal frameworks and institutional set-up, and network and relationship. It provides a starting point for broad agreement regarding the key components of the organizational resilience for water supply systems in the country. It also can be used for evaluation and to inform the priority practices that should assist water supply authorities in Tanzania and other developing countries to address future impacts of flood hazards.

Chapter 7
Development of Environmental Variables for Measuring Resilience

The current chapter is based on the following article:

Sweya, L. N., & Wilkinson, S. (2020). A tool for measuring environmental resilience to floods in Tanzania water supply systems. *Ecological Indicators*, *112*, 106165.

7.1 INTRODUCTION

Water sources, catchments and recharge areas are important components forming the water supply systems. Their influence on the resilience of water supply systems cannot be overlooked as they exist in sensitive environments needing protection against natural and manmade pollutions and degradation actions. The current chapter identifies environmental variables related to water supply systems and ones that are useful in measuring the resilience of the systems against the impacts of floods. The world is facing a rise in both magnitude and frequency of risks that have aggravated life and property losses. Environmental risks such as extreme weather events and failure of climate change mitigation and adaptation have persisted in the top ten list for the past decade. WEF (2019) indicates that the environmental risks continued to dominate in 2018, accounting for three of the top five in terms of likelihood and impacts from which extreme weather was a major concern. The number two risk of concern "failure of climate change mitigation and adaptation" indicates that environmental policies have failed after an immediate success following the Paris Agreement (UN, 2015). There is a worry that if the trend continues, implementation of the Paris Agreement will be impossible. Consequently, GHGs will increase, the temperature will rise and surpass the 1.5^{o}C limit proposed by the Paris Agreement resulting in more severe climate change-related risks, including floods. Communities will be at risk of lacking sustainable water resources. Thus, more effort is needed to increase the countries' ability to deal with climate change impacts through enhancing water supply systems resilience.

As floods are expected to be more intense and frequent due to climate change (IPCC, 2014), they have already demonstrated grave consequences to peoples' lives, infrastructure, and the environment (EM-DAT; NBS, 2017). There is a strong interplay between the society, the environment, the water supply systems, and flooding impacts (Sweya et al., 2019). In most cases, interaction can best be understood by introducing the climate change concept. For instance, human activities such as the use of fossil fuels and onsite sanitation systems contribute to the GHGs emissions. The gases are known for their ability to trap heat energy.

In 2013, the emission of carbon dioxide (CO_2) from fossil fuels and cement production was 36.1 gigatons (Tkemaladze & Makhashvili, 2016). IPCC (2018) shows that the global total net CO_2 emission is more than 40 billion tons of CO_2/year. That alone is equivalent to 109.6 million tons per day. Methane, black carbon, and nitrous oxide emissions contribute to more than 3 billion tons per year. That means more than 110 million tons of (GHGs) are emitted to the atmosphere every day. The extra heat exerted by GHGs accumulated in the atmosphere has been visualized in the scale of atomic bombs. Hansen (2012), Braasch (2013), and Lakoff (2012) indicate that the extra energy accumulated due to the heating of the earth is equivalent to exploding 400,000 Hiroshima atomic bombs per day 365 days. A recent statement by Albert Gore, the former U.S. Vice President and Environmental activist, when addressing the 2019 World Economic Forum annual meeting reveals that the current energy equivalent is 500,000 Hiroshima atomic bombs per day 365 days[17]. Most of that heat energy goes into the water bodies disrupting the water cycle, causing much more evaporation and resulting into among others, tropical cyclones, severe rains and flooding.

As discussed earlier, human activities are polluting and degrading the environment, affecting the water cycle and causing a high magnitude of flooding, which disrupts the water infrastructures. These emergent climate-related risks will negatively alter most of the current risk metrics. Growth in death loss and damage is expected to surpass already inadequate risk mitigation, response, and transfer mechanism (UNDRR, 2019). For this reason, the UN (2015); IPCC (2018); WEF (2019) and UNCC (2019) call for immediate intervention to limit the increase of the temperature and increase the ability of the countries to deal with climate change impacts. The Sustainable Development Goal 9 calls for resilient infrastructures to be able to better cope with the impacts of disasters[18]. Such resilient infrastructure as water supply systems should be able to survive those impacts. However, the concept of resilience only becomes operational when there is the ability to measure (Prior, 2015).

[17] https://www.weforum.org/events/world-economic-forum-annual-meeting-2019
[18] https://www.undp.org/content/dam/undp/library/corporate/brochure/SDGs_Booklet_Web_En.pd

Several studies such as Balaei et al. (2018); Vugrin et al. (2010); Perry (2013) and Morley (2012) have developed tools for measuring the resilience of water supply systems that are not universally accepted for application across systems, hazards, and locations. Besides, a specific tool to measure water supply systems environmental resilience is lacking. Most studies involving environmental aspects assessed community resilience (Sharif, 2016). However, the environmental aspect has not been adequately incorporated into the assessment frameworks despite its significance in building resilience (Sharif, 2016). Inclusion of the environmental aspects in assessing water supply systems resilience is a recent idea, although, studies that attempted could not go further to measures and assessment tools. For instance, while Vugrin et al. (2010) included the environmental dimension in assessing the resilience of 18 different critical infrastructures and economic systems, there are no details about the indicators, measures and assessment tools pertinent to environmental aspects. Similarly, Balaei et al. (2018) included environment in their five dimensions framework for assessing water supply systems resilience against earthquake, yet, there's no further details of indicators, measures and measurement tools for the environmental aspect. Thus, there's a need for a tool that is rendered appropriate to measure the environmental resilience in Tanzania's water supply systems.

The objective of the study for which the current paper was prepared is to develop an environmental tool that is made more appropriate through Delphi technique to measure Tanzania's water supply systems resilience. The study uses qualitative assessment tools to further evaluate the tool using a realistic scenario to demonstrate its applicability. The tool embraces a management approach that accounts for various national and international recommendations for reducing environmental consequences to water supply systems "catchments, recharge areas, and water sources." Furthermore, the study integrates the environmental variables and suggests that water supply resilience assessors "water managers and other practitioners," should apply the environmental tool as part of the overall water supply systems resilience assessment.

7.2 ENVIRONMENTAL RESILIENCE

Resilience is multi-disciplinary (Perry 2013; Manyena 2006); it is open to multiple interpretations presenting challenges on understanding and operationalizing the concept (Johannessen & Wamsler, 2017). The vast number of resilience definitions in the literature indicates that no definition is universally accepted. However, the variables used in most definitions have commonality. In many cases, resilience is referred to as the system ability to survive after disruptions. The important distinction in resilience is engineering resilience and ecological resilience. Engineering resilience refers to the efficiency to return to the equilibrium or steady-state after a disruption. It is characterized by the return time to the equilibrium, and only one equilibrium exists (Amarasinghe, 2014).

Water supply systems are more than the sum of their engineering parts. They can be described as socio-technical or socio-ecological systems as they involve complex interactions between human, technology, and environmental components (Smith, 2014). In the water sector, those ideas imply moving from engineering resilience, traditional predictions, and withstand approaches for extreme conditions towards more dynamic and flexible systems (Smith, 2014). The complex interaction in water supply systems means that the systems cannot return to only one equilibrium after disruption; thus, they should not be defined based on engineering resilience. In particular, the environmental aspect comprises of components that adapt to different stabilities after disasters. This shows the current study is best suited to the concept of ecological resilience, which focuses on different aspects of stability "the persistence of the system close or near to the equilibrium state."

In ecological resilience, it is assumed that there are multiple stability domains and tolerance of the system to disruptions that facilitate transformation between different states (Amarasinghe, 2014 from Holling 1973). To that understanding, Walker et al. (2004) defined resilience as the ability to absorb disturbances and reorganize itself into a better configuration while still retaining its fundamental characteristics. The definition is in line with the idea of adaptation and aligns with the ecological resilience showing that the system can adjust in order to suit the changing environment. This definition is adopted for the current study. Moreover, there are two questions that need to be answered to make the resilience definition more compelling: "resilience of what?" and "resilience to what?" the former term represents the water supply system whereas the latter depicts the type of pressure exerted to the system "floods" in the current study.

Resilience remains a theoretical concept unless there is the ability to measure (Prior, 2015). Ability to measure turns the concept operational. However, measuring resilience is as complicated as understanding the concept. Likewise, the fact that resilience is a multi-disciplinary concept drawing attention to diverse researchers who have not reached consensus on a single accepted measure that can be applied across systems. The concept is also multi-dimensional, having seen various measurement tools applying different dimensions during the assessments. Studies such as Vugrin et al. (2010); Balaei et al. (2018), and others built on TOSE framework (Bruneau et al., 2003) and integrated the environmental dimension towards measuring the resilience of water supply systems. However, there are not enough details on how the environmental variables are used to assess the resilience of the water supply systems. Morley (2012) focused on the operational and economic indicators for measuring the resilience of water supply systems, while Perry (2013) was interested in the service provision. None of the studies provided enough details on integrating environmental aspects.

Inclusion of the environmental dimension in resilience assessment is important (Sharifi, 2016). That way, it will be possible to situate challenges facing the urban water supply systems within broader responses to climate change and improve the governance of ecosystems services. Through enhancing the conservation and health of freshwater ecosystems, the urban areas can help sustain their new supply line. Sharifi (2016) identified a sub-dimension "natural assets" with some criteria such as erosion protection, availability, and accessibility of water resources, and reduction of environmental impacts to assess the environmental dimension for community resilience. Brenkert and Malone (2005) indicated that “environmental capacity,” “ecosystem sensitivity,” and “water resources sensitivity” are the aspects that can inform the resilience in the environmental dimension. Moreover, Cutter et al. (2014) suggested that "natural flood buffers" could assist in determining environmental resilience. These studies were used as essential constructs to inform the variables for developing the tool to measure the environmental resilience in Tanzania’s water supply systems.

The variables obtained from those studies are in line with Tanzania’s water supply systems environmental resilience improvement needs. For instance, the growing exploitation of resources such as mining activities and irrigation activities have been imposing environmental impacts such as pollution, soil erosion, water quality issues, and water use conflicts (NBS, 2017; 2015). The widespread use of firewood and charcoal has also been linked to soil erosion in the country (World Bank, 2019). NBS (2017) and URT (2006b) indicate that water resources accessibility and availability are decreasing as the annual renewable water resource is declining due to climate change effects, population increase, catchments degradation etc. The population increase is causing excessive resources exploitation resulting in rapid deterioration of the environment (NBS, 2017, 2015; URT, 2014). In totality, human beings have been identified as major agents of the resource depletion and resultant of environmental degradation (NBS, 2015; URT, 2006). Wetlands encroachment is also evident (URT, 2006) such that their ability to intercept runoff have been reduced. The current trend in the use of the natural resources is therefore unsustainable, degradation and loss of ecosystems are expected to continue (World Bank, 2019).

7.3 METHODOLOGY

The study applied a four-stage process to develop and demonstrate an environmental tool to measure the resilience of water supply systems against flood in Tanzania. Firstly, a literature review was conducted to hypothesize the variables of the tool. The variables were proposed based on their ability to inform the first two processes of disaster risk management: mitigation, and preparedness. The selection of the variables also assisted with the need to achieve water authority, national, and international development goals pertinent to the water supply. Secondly, the variables were subjected to pre-assessment and pretesting processes. The pre-assessment was used as a preliminary content validation where experts assessed the various components proposed to be utilized to measure the resilience and determine if indeed, they capture the aspects associated with the theoretical concept. Content validation through experts' judgement elicitation is not uncommon; Oktari et al. (2020) used 14 experts to conduct a content validation in their study. Yang et al. (2019) employed 12 experts to test the validity of their framework. Mayunga (2009) indicates further that, in resource-scarce conditions, two experts working within formalized operationalization procedure itself should provide a degree of content validity. Therefore, the current study involved ten water and environmental field experts from government and non-government organizations and academic institutions during the pre-assessment process as a too large number of experts would affect the response rate and time (Hsu & Sandford, 2007).

A semi-structured questionnaire was developed based on the hypothesized variables and distributed to the experts. Respondents were asked to comment on the variables, add more variables that seemed appropriate and rate their potential for inclusion in the study. The indicators were considered for inclusion in the study if at least 70% of the experts agreed or strongly agreed and the standard deviations (SDs) were between 0.3 and 0.998 (Zhong et al., 2015). The variables were further pretested in a selected WSSA in the country to obtain insights into the validity of the variables. The results were used to improve the variables.

Thirdly, the improved variables of the tool were subjected to a three-round Delphi survey to make them further relevant (Meijering et al., 2018) to Tanzania water supply systems. A Delphi study was applied in this study since it is a widely accepted method of developing consensus on real-world knowledge solicited from experts (Hsu & Sandford, 2007). A typical

Delphi panel size ranges from 15 to 35, with the expectation that 35% to 75% invitee will participate (Steele et al. 2008). Hsu & Sandford (2007) suggest that most Delphi studies have used between 15 and 20 experts. They indicate further that; too small panel size affects the representation regarding the target issue whereas too large panel size affects the response rate and time (Hsu & Sandford, 2007). In the current study, twenty-two experts were initially invited to participate in the Delphi process. In the first round, experts were asked to comment and add more variables. In the second and third rounds, they were asked to rate and rank the variables. Six criteria: relevance, availability, affordability, reliability, simplicity, and transparency were applied as useful guidelines for rating the variables. Each variable was scored based on a five-point Likert scale from 1 for strongly disagree to 5 for strongly agree. The variable was considered for inclusion when the average score for the six criteria is four to five representing "agree" and "strongly agree" respectively for at least 70% of the experts, and the SD is between 0.3 and 0.998.

A manual-based thematic analysis was used to analyze the pre-assessment, pretesting, and first-round Delphi survey information. The analysis was also assisted with a descriptive analysis using Statistical Package for Social Sciences, IBM SPSS Statistics 25. Median ratings (MeRs) and mean ratings (MRs) were used to rank the variables. MRs and SDs assisted in the process of rating the importance of the variables. To evaluate whether there were significant differences between the second round and third-round rating process, t-test or non-parametric Mann-Whitney was conducted "depending on whether the ratings were normally distributed," with a confidence level of 95%. Furthermore, kappa statistic values were calculated to evaluate the level of agreement between the second and third rounds.

Fourthly, assessment tools were developed from literature and used to demonstrate how the tool works-the assessment tools comprised of measures and measurement scales. The measurement scales in the current study are the qualitative statements that portray the level of performance of a certain measure using a five-point Likert scale from 1 for the lowest performance to 5 for highest performance. A realistic scenario was used as an example, and weightings were assigned using an arbitrary approach where all variables in the same category were assigned equal weights. The arbitrary approach was limited to assigning weights for demonstration of the tool applicability. Assigning equal weights may compromise the importance of one variable over another. Therefore, for a live application, it is important for the WSSAs to derive weightings based on their needs. The scores were weighted at each level then aggregated to a final water supply system environmental resilience index (see equations 1 and 2 below). Equation 2 indicates a positive linear relationship between the final environmental resilience score (FERS) and the weighted dimensions. That means, the weighted dimensions positively affect the FERS, the increase of the values of the variables increases the FERS and vice versa.

$$WV_i = w_i S_i \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (7.1)$$

$$FERS = w_{ERS}R_{ERS} + w_{NFA}R_{NFA} + w_{NA}R_{NA} + w_{EC}R_{EC} \dots \dots \dots \dots \dots \dots \dots \dots \dots (7.2)$$

Where; WV = weighted score for variable i (indicator or principle)

w = weighting of a variable i

S = Score of a variable i

w_{ERS} = weighting of the environmental sensitivity principle

R_{ERS} = aggregated resilience of the environmental resources sensitivity principle

w_{NFA} = weighting of the natural flood attenuation principle

R_{NFA} = aggregated resilience of the natural floods attenuation principle

w_{NA} = weighting of the natural assets principle

R_{NA} = aggregated resilience of the natural assets principle

w_{EC} = weighting of the environmental capacity principle

R_{EC} = aggregated resilience of the environmental capacity principle

$FERS$ = final environmental resilience score (aggregated score)

7.4 RESULTS

The study initially selected eight indicators from literature to propose a tool for assessing environmental resilience for water supply systems. Selected indicators are; "natural assets," "environmental capacity," "ecosystem sensitivity," "natural flood buffers," "efficient energy use," "pervious surface," "efficient water use," and "water resources sensitivity." During pre-assessment, experts provided useful opinions to improve the tool's variables. Experts screened-out indicators that were not significant to the current study. Most of the indicators (87.5%) were accepted for inclusion in the study at this stage. Too general indicators were further synthesized to better the understanding. For instance, "natural assets" was changed to a principle within which five indicators were proposed. Similar indicators such as “ecosystem sensitivity” and “water resources sensitivity" were merged to form a principle "environmental resources sensitivity" in which three indicators were proposed. In totality, eleven indicators emerged from the pre-assessment exercise. The indicators were further pretested in a WSSA in collaboration with a Basin water office in Tanzania, and the results used to improve the variables further, as shown in **Table 7.1**.

Table 7.1: Improved variables from the pre-assessment and pretesting exercises

Principles	Indicators	Code	Reference
1 Natural assets	1. Using local knowledge and native species	ENI1	Sharifi, 2016; Shemsanga et al. 2018
	2. Soil erosion protection	ENI2	Sharifi, 2016
	3. Accessibility of freshwater resource	ENI3	Sharifi, 2016
	4. Quality of water sources	ENI4	******
	5. Reduction of environmental impacts	ENI5	Sharifi, 2016
2 Environmental capacity	6. Population density	ENI6	Zhang & Hao 2016; Brenkert & Malone, 2005
3 Environmental resources sensitivity	7. Human encroachment	ENI7	Brenkert & Malone, 2005
	8. Renewable water supply and inflow	ENI8	Brenkert & Malone, 2005
	9. Water use/water security	ENI9	Brenkert & Malone, 2005; Maurya et al. 2019
4 Natural floods attenuation	10. Protection of wetlands	ENI10	Sharifi, 2016 & Cutter et al. 2014; Brody et al. 2012
	11. Control of urbanization	ENI11	******

****** Indicators added by researchers based on water and environmental fields experts’ opinions

A three-round Delphi survey was conducted on the improved variables, including four principles and 11 indicators. The survey involved a number of water and environmental experts from WSSAs, Ministry of Water (MoW), National Environmental Management Council (NEMC), Prime Minister Office (PMO), Energy and Water Utilities Regulatory Authority (EWURA), water and environmental consultancy and construction companies, and academic institutions., The majority (81.25%) were holders of at least a master’s degree. The experts had at least five years’ experience in the water industry, of which about 68.75% had engaged in disaster management projects at various levels, and 50% were senior professionals at their workplaces whereas the rest held senior associate positions.

As the Delphi survey progressed into the next rounds, the number of experts decreased. For instance, 22 experts were initially invited to take part in the first round, of those, 72.7% responded. Similarly, out of the experts invited to participate in the second round, 75% responded. This is not uncommon result in Delphi processes, as most studies (e.g. Wakai et al., 2013; Zhong et al. 2015) that used the technique had similar results. The response rates for the current study can be considered significant, suggesting that experts understood the subject matter as they moved on to the next rounds. This is evident since the response rate was 100% in the third round.

Results show that no major changes were made to the variables and their descriptions during the first-round of the Delphi survey. Experts focused on the description that environmental dimension is related to the ability of the water sources, catchments, and recharge areas and any surrounding environment to withstand environmental changes and maintain standards in terms of quantity and quality to meet the water users' demands during floods. The four principles and 11 indicators were considered adequate at the first-round stage. Descriptions of the principles are presented in **Table 7.2**.

Table 7.2: Improved principles for environmental resilience assessment

Principle	Description
Natural assets (environmental and resources)	Assets of the natural environment consisting of biological, land and water areas with their ecosystems, subsoil assets, and air
Environmental capacity	The ability of environmental properties to accommodate particular activities or rate of activities without unacceptable impacts.
Environmental resources sensitivity (ecosystem and water)	The degree at which the environment (i.e., ecosystem and water resources) can be upset due to exposure to low-level disruptions. It includes the extent of human intrusion into natural landscapes, land fragmentation, and pollution loading on the ecosystems. It is also related to the extent of the supply of water from internal renewable resources, and withdrawals to meet current or projected needs.
Natural flood attenuation	Floods control through natural processes where flood buffers such as wetlands naturally reduce the impacts of floods on water supply systems.

Experts ranked the principles and rated the indicators in the second and third rounds. Importance ranking results for the principles in the second round indicate that "environmental capacity" and "environmental resources sensitivity" are the most important, four times each, than others. Results show further that, "environmental resources sensitivity" scored the first and second place more times "eight" with the lowest MR and MeR than environmental capacity. "Natural assets" was considered the least important principle with a MR (3.33) and MeR (4.00) greater than other principles. At this stage, the ranking order was 1 for "environmental resources sensitivity," 2 for "environmental capacity," 3 for "natural flood attenuation," and 4 for "natural assets."

All indicators met the six criteria used in the rating process as guidelines except "using local knowledge and native species" and "soil erosion protection." The former was influenced by the simplicity—ease of understanding by decision makers—criterion, whereas the latter was affected by transparency—data reproducibility and verification—criterion. In all cases, nine indicators equivalent to 81.8% were accepted for inclusion in the study. Rating results show that "accessibility of freshwater resource" was the most important indicator supported by 100% of the experts and MR = 4.16667 and lowest SD = 0.38925. The second important indicator was "protection of wetlands" supported by 91.7% of the experts, MR = 4.1667 and SD = 0.57735. Others were "human encroachment" (MR = 4.167, SD= 0.577) and "quality of water sources" (MR = 4.083, SD= 0.515). Moreover, the least important indicator was "reduction of environmental impacts," supported by 75% of the experts the lowest percentage than for any other indicator.

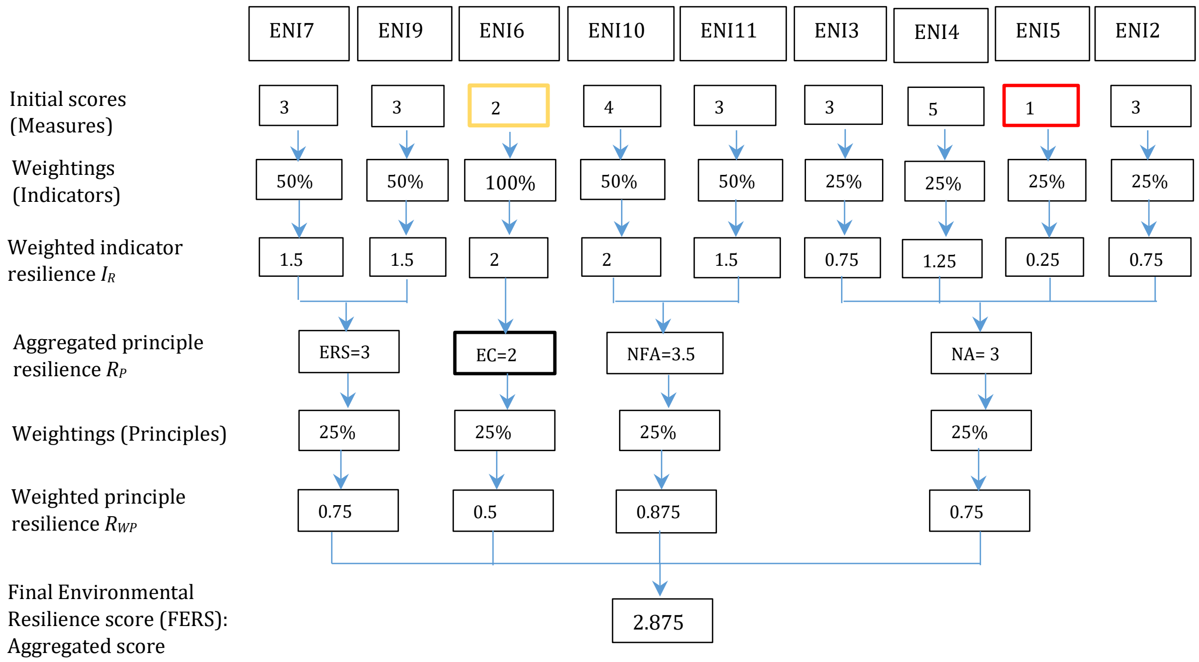
Only 16.7% of the invited experts in the third round reconsidered their vote on the ranking of the principles and rating of the indicators. The rest were satisfied with the tool's variables and their description; thus, they had no different opinions. The experts did not make any significant changes in the variables in the third round. The p-values for comparison of the ranking results ranged from 0.4862 to 0.5000 between the second and third rounds, whereas the ranking order remained the same as in the second round. Also, the p-values for the indicators ranged from 0.3587 to 0.4862 for importance rating results. The only improvement emerged when "ENI5" climbed from ninth to fifth place. The kappa values of the tool's variables ranged between 0.755 and 1.00 (Mean = 0.9391 median = 1.000). The values suggest that there was a significant level of agreement between the two rounds and that consensus had been achieved. The final tool's variables are presented in **Table 7.3**.

Table 7.3: Final variables for measuring environmental resilience for water supply systems

Principles (MR, MeR) (P-value, Kappa)	Indicators			
	Indicator (MR, SD)	Code	Description	p-value, Kappa score
3.1 Environmental resources sensitivity *(2.00, 2.00)* *(0.4878, 1.000)*	3.1.1 Human encroachment *(4.167, 0.577)*	ENI7	Degree of human intrusion into the natural landscape/catchment and recharge areas	(0.3587, 0.815)
	3.1.2 Water use *(4.000, 0.603)*	ENI9	Withdraw to meet current and projected needs	(0.4862, 1.000)
3.2 Environmental capacity *(2.17, 2.5)* *(0.4877, 0.755)*	3.2.1 Population density *(4.000, 0.603)*	ENI6	Population pressure and stresses on the environment/water resource	(0.4862, 1.000)
3.3 Natural floods attenuation *(2.58, 2.50)* *(0.5000, 0.776)*	3.3.1 Protection of wetlands *(4.167, 0.577)*	ENI10	Identification and protection of various wetlands, and riparian areas in the basin to enhance natural floods attenuation during flooding	(0.4861, 1.000)
	3.3.2 Control of urbanization *(4.000, 0.603)*	ENI11	Control of human development towards the protected zones such as catchment areas, recharge areas, wetlands, and water sources according to the WRMA 2009 Part VI section 34 &37, etc.	(0.4862, 1.000)
3.4 Natural assets *(3.33, 4.00)* *(0.4862, 1.000)*	3.4.1 Accessibility of freshwater resource *(4.167, 0.389)*	ENI3	The convenience of accessing water from various sources such as surface water, groundwater, and rainwater during flooding	(0.4822, 1.000)
	3.4.2 Quality of water sources *(4.083, 0.515)*	ENI4	Information about the suitability of water from the main source and alternative sources during flooding, and the possible regular monitoring during flooding	(0.4849, 1.000)
	3.4.3 Reduction of environmental impacts *(4.083, 0.669)*	ENI5	Efforts for addressing sources of pollution that have an impact on the water systems during flooding	(0.3992, 0.862)
	3.4.4 Soil erosion protection *(3.917, 0.515)*	ENI2	Protection of river banks to avoid soil erosion during flooding, which results in the change of river morphology, affect the depth at intakes, and increase turbidity in the water	(0.4848, 1.000)

KEY: MR = Mean Rating, MeR = Median Rating, SD = Standard Deviation

Assessment tools involving measures and measurement scales were developed and used to operationalize the tool. Measures originated from literature and other government and international documents such as policies, strategies, and targets for environmental management (the complete list is presented in **appendix 4**). For instance, annual per capita internal renewable water resources measure was extracted to gauge the “population density” indicator, whereas enforcement of the Tanzania Water Resources Management Act 2009 was used to measure the “control of urbanization” indicator. The example in **Figure 7.1** demonstrates how the tool works.



KEY: FERS = Environmental resources sensitivity, EC = Environmental capacity, NFA = Natural flood attenuation, NA =Natural assets

Figure 7.1: An example of operationalization of the environmental resilience measurement tool

Contacts were made with a WSSA and a Basin water office in Tanzania to obtain indicative scores that could assist in the example. The initial scores corresponded to each measure and each indicator. Equal weights were assigned to the variables depending on their number in each category. For example, there are four indicators in “natural assets” principle; thus, a weight of 25% was assigned to each indicator. Similarly, there are four principles of environmental resilience; therefore, each principle was allocated a weighting of 25%. Scores were then aggregated to the FERS, which is equal to 2.875 ≈ 3.0. The “environmental capacity” principle resilience was the lowest (2.0). The principle includes only one indicator “population density” that obtained the second-lowest indicator resilience score. Other principles had somewhat the same performance, from 3.0 to 3.5. High variations of the indicator resilience emerged in the "natural assets" principle. The scores ranged from 1 for the "reduction of the environmental impacts" indicator to 5 for the "quality of water sources" indicator. In all cases assigning weights to the variables did not have a significant effect on the final resilience score when compared to unweighted variables.

The results from the example show that the water supply system has moderate environmental resilience, with less than desirable performance. The system requires specific improvements in most aspects (77.8%). Of those, two aspects that received the lowest scores, such as shown in the example in red and orange colors, need immediate interventions. Improvements of those aspects will automatically adjust the resilience of the system to a higher level.

7.5 DISCUSSION

Selected variables for the current tool are in line with the disaster risk management processes and are intended to enhance resilience at various stages, including mitigation and preparedness for flood hazards. Also, they align with achieving water sector development goals at both national (URT, 2006a) and international[19] levels. For instance, "accessibility of freshwater resource" is consistent with the Sustainable Development Goal 6.1; to assess the percentage of people with access to safely managed water sources. And "control of urbanization" which is pertinent to the implementation of the Tanzania Water Resources Management Act 2009 to prevent human development within 60m from the water sources.

Three processes; pre-assessment pretesting and Delphi survey tailored the variables initially derived from literature to more appropriate to Tanzania water supply systems. There is confidence in the pre-assessment, and Delphi survey results since most of the experts involved have at least a master’s degree and are registered with various regulatory bodies such as the Engineers Registration Board, and the Environmental Management Council, Tanzania. Experts are "for at least five years” experienced in the water, environment and disaster management, and most are senior professionals at their workplaces. Majority of the experts reached a consensus regarding the tool’s variables during the second round. Reaching consensus in two rounds is a familiar result firstly because Delphi methods consist of at least two rounds (Meijering et al. 2018) and secondly, some studies such as Fernández-Llamazares et al. (2013) established consensus using two-round processes.

Two indicators; “using local knowledge and native species” and “renewable water supply and inflow” were excluded during the second round. The omission of the indicators was

[19] https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf

consistent with the fact that less than 70% of the experts agreed or strongly agreed on their inclusion. Most experts did not revise their voting in the third round, as indicated earlier; they were satisfied with the second-round results. The MSs of the importance of ranking and rating in the second and third rounds suggest that there were better group opinions regarding the inclusion of the variables. The p-values suggest that there was no significant difference in the importance ranking and rating results between the second and third rounds. Moreover, kappa values suggest that there was a significant level of agreement between the two rounds and that consensus had been established. The findings suggest that the water supply systems environmental resilience can be influenced by four main factors/principles.

7.5.1 Environmental resources sensitivity

This factor refers to the degree to which, due to exposure to low-level perturbations such as floods, the environment (i.e., water catchments and recharge areas, and water sources together with their ecosystems) can be disrupted. It includes the extent of human intrusion in the catchments and water recharge natural landscapes, fragmentation, and pollution loading in the water sources and their surrounding environments. Clearing catchment forests lowers the catchments ability to control runoff, prevent soil erosion, and ensure a good water supply downstream the catchment. Sensitivity also includes the extent of utilization of the water from internal renewable sources and how withdrawal is monitored to enhance sustainable use of the water resources. This factor is in line with the current Tanzania Water Policy of 2002[20] whose emphasis is on water resource and supply sustainability.

The study suggests further that "environmental resources sensitivity" can be assessed by using two indicators; "human encroachment" and "water use." As indicated earlier, human encroachment is assessed by the degree of catchments/recharge areas forest cover losses due to human activities. As such, it entails the loss of forest cover per year and the existing forest canopy cover in the respective catchment or recharge areas. The “water use” indicator is measured by water withdrawal in line with Maurya et al. (2019) and Oţoiu & Grădinaru (2018) to portray the sustainability of the existing water sources and their capacity to serve during disruptions of flooding. The indicator also unveils the existence of plans and functional water withdrawal monitoring programs or activities within the assessed water supply system.

[20] http://www.tawasanet.or.tz/files/Tanzania%20water%20policy%20-%202002.pdf

7.5.2 Environmental capacity

The study refers to this factor as the ability of environmental properties such as water to accommodate particular activities or rate of activities such as rapid population growth or population pressure without unacceptable impacts. Rapid population growth leads to rapid urbanization, and tremendous resources demand, thus, putting more pressure on the available natural resources (URT, 2014). Tanzania, for example, has undergone enormous resource depletion over the past decade, including forests, water and minerals associated with high population growth rates. Resources exploitation has aggravated the magnitude of flood impacts, have led to high levels of contamination, seawater intrusion, low water recharge, and poor water catchment in the water resources (World Bank, 2019). It is therefore important to understand the capacity of the available water resources considering the high population growth rates in most developing countries such as Tanzania.

The findings suggest that "environmental capacity" can be assessed by "population density" indicator. The indicator is intended to reveal the pressure and stresses exerted by rapid population growth on the water resources. It is measured on the basis of the annual per capita internal renewable water resources (Gardner-Outlaw & Engelman, 1997) determining the magnitude of flooding impacts to the communities with respect to water supply systems. For instance, if the communities are living in water-scarce areas, that means they are likely to face higher consequences during flooding. Without reliable water services, poor communities that are unable to afford bottled water or water from vendors may prefer using alternative sources such as traditional wells and lowland waters (Sweya et al. 2019), some of which are prone to contamination and would lead to water-related diseases.

7.5.3 Natural floods attenuation

Natural flood attenuation process is the immediate solution to flooding waters. Flood is controlled through natural processes where flood buffers such as wetlands naturally intercept to reduce the impacts of floods on water sources and the infrastructure. Flooding water is retained in the wetlands and intercepted from causing more harm to the environment (Acreman & Holden, 2013; GLOWS_FIU, 2014), including the communities and resources such as drinking water. Sediments from upstream settle in the wetlands before reaching the water sources. Wetlands also act as natural water treatment media through the filtration and uptake of nutrients and heavy metals by the wetland plants, thereby improving the quality of water flowing downstream to the water sources.

Invasion of human activities such as agriculture, land conversion, water abstraction, livestock keeping, and pollution loads have affected the natural flood buffers leading to an increase of the magnitude of flooding impacts in the country. For instance, the lack of sufficient natural flood attenuation processes has seen a severe level of siltation at Kidongozero along the Ruvu River affecting the river morphology and the quantity of water downstream to the two major treatment plants serving Dar es Salaam city and part of Pwani region. Other examples include the Bus Rapid Transit (BRT) infrastructure built within the Jangwani wetlands in Dar es Salaam, extensive agricultural activities in the upper Ruvu catchments, and the impacts of mining activities in the east Usambara wetland forests in Tanga.

Findings suggest that two indicators can assess the current factor. Loss of naturally occurring wetlands is an important indication related to flooding (Brody et al., 2012). As such, "Protection of wetlands" assesses whether wetlands have been fully identified and protection programs established. Besides, "control of urbanization" assesses the level of enforcement of the Tanzania Water Resources Management Act 2009 regarding the control of human development in catchments and recharge areas designated as protected zones and the restriction of development within 60m from the water sources.

7.5.4 Natural assets

Assets of the natural environment consist of biological, land and water areas, subsoil, and air with their ecosystems. The factor is pertinent to the status or health of the water asset, including quality, accessibility of water, and existing protection strategies. For instance, if there is low *access* to a freshwater resource during flooding, the community uses alternative sources such as shallow wells, boreholes, and water from low-lying areas. These waters are always susceptible to contamination, and salinity levels are higher in the boreholes. Similarly, if the water quality is compromised, the community may face water-related diseases that erupt in various parts of the country during flooding.

Contaminated water resources often result in high water treatment investment; the worst situation arises during flooding where unpredictable levels and types of contaminants reach the water treatment plants. There are places where treatment operations are forced to stop during flooding for that reason. For instance, screens are frequently clogged by floodwater debris and logs, and high turbidity levels require large quantities of “flocculants” chemicals (Sweya et al. 2019). In some cases, the system cannot detect the right dosage to ensure turbidity is reduced to acceptable standards. In areas such as Arusha, Moshi, and Shinyanga, alternative sources, especially groundwater, contain high levels of fluoride that impacts people’s wellbeing.

The study suggests that this factor could be measured using four indicators. Firstly "accessibility of freshwater resources,” which is in line with the SDG 6.1; it assesses the proportion of the population using safely managed water sources. The indicator also aligns with the UNSD criterion of the proportion of the population connected to the public water supply system[21]. Secondly, "quality of water sources" entailing the existence of information about the suitability of both main and alternative water sources during flooding as well as the existing monitoring programs. Thirdly, "reduction of environmental impacts," assessing the efforts put forth into reducing sources of pollution that can affect water supply during flooding. And lastly, "soil erosion protection,” to assess the existence of protection programs to prevent further erosion during flooding that would affect the quality and quantity of water sources.

7.5.5 Implication of the environmental resilience tool

The example indicates that initial scores for the water supply systems environmental resilience assessment can be obtained from the WSSAs in close collaboration with basin water offices. The performance in the example is based on indicative scores from the two water institutions, and an in-depth application of the tool could provide a different view. To operationalize the tool, initial scores are introduced to the tool then aggregated to the FERS. The example shows a medium level of resilience; thus, the system has less than desirable performance, and specific improvements should be prioritized. In particular, the “environmental capacity” is compromised, and immediate measures are needed to lessen the population pressure and stresses on the water resources—such as controlling waste disposal and development in the recharge and catchment areas. Natural asset “water” needs more improvements through the reduction of environmental impacts. More effort for addressing sources of pollution is needed in line with improving the coverage of sewerage systems and consequently lowering the impacts of onsite sanitation on the quality of water. Other aspects have also indicated moderate performance suggesting that measures need to be taken to enhance the overall water supply system environmental resilience. Although the current

[21] https://unstats.un.org/unsd/environment/envpdf/UNSD_UNEP_ECOWAS%20Workshop/Session%2004-4-1%20Introduction%20to%20water%20statistics%20(UNSD).pdf

example is only for demonstration, it still gives an overall picture of the water supply systems environmental resilience and clearly shows how assessors of resilience can apply the tool to assess their systems. A recommendation is drawn for the WSSAs to provide their own weightings of the variables that align with their goals, objectives, and resources for water services provision. Besides, further research should be undertaken to investigate the relevance and contribution of livestock density to the environmental capacity in relation to the general water supply systems' environmental resilience.

7.6 CONCLUSION

The developed tool is qualitative in nature, embracing a management approach that can be used to evaluate the existing water supply systems environmental resilience. The tool will assist with the development of mechanisms to enhance the resilience of water supply systems to better cope with future impacts of floods. Evaluation of the resilience can be conducted by using available data that exists in the WSSAs in collaboration with a relationship that is not uncommon with the basin water offices. The tool's variables were initially founded from existing literature from international and local publications and contain information that can be applied in a range of water supply systems in Tanzania and other developing countries with similar features. Most water supply resilience tools have neglected the influence of environmental aspects. The current study suggests that resilience assessors should take into consideration the environmental factors as they have impacts on the availability, accessibility, quality, and sustainability of the water sources which are at the heart of the water supply systems. Moreover, the tool is designed in such a way that it aligns with the Tanzania National Water Policy (URT, 2002) and contributes to the implementation of the Tanzania Water Resources Management Act 2009 towards meeting the needs of the Paris Agreement and achieving the Sustainable Development Goals.

Despite the evident significance of using the tool to measure the water supply systems' environmental resilience, possible limitations can be drawn. The tool's variables were scrutinized by experts using six criteria; relevance, availability, affordability, reliability, simplicity, and transparency. Results show that data availability and affordability may limit the assessment process, as WSSAs may not have readily available data for conducting the assessment. As noted earlier, this problem can be resolved when the WSSAs collaborates closely with the basin water offices, the Ministry of Water, and Tanzania Forest Services Agency (TFS). The data are obtained from public sectors/institutions so is the assessment. That may increase the degree of bias as information may be exaggerated or downplayed. Moreover, there’s an expected level of subjectivity when assigning scores and weightings, to mitigate this, weightings and scores should be developed in a group setting of knowledgeable and skillful staff. This chapter has shown the dependence of water users on the wellbeing of the water sources, and recharge and catchment areas and vice versa. Aligning with the interplay discussed in chapter four, the next chapter evaluates how water consumers resilience is important for the overall Tanzania water supply systems. As such, it will assess factors leading to significant variables for measuring the social resilience in the Tanzania water supply systems.

Chapter 8
Development of Social variables for Measuring Resilience

The current chapter is based on the following article:

Sweya, L.N., Wilkinson, S., Kassenga, G., Mayunga, J. (2020). A Social Resilience Measurement Tool for Tanzania's Water Supply Systems (Under review: International Journal of Disasters Risk Reduction)

8.1 INTRODUCTION

Previous chapters have revealed that poor communities are the most affected when water supply systems are affected by floods. Thus, understanding their resilience is an important aspect of the current research. The current chapter attempts to examine factors related to water users that can be used to measure the social resilience for the water supply systems.

The systems are social-ecological-technical systems comprising of natural, physical, organizational, and social systems that have direct interaction with the community and the operating organizations (Newman, 2011). Societies need water for their health and wellbeing. Access to safe and clean water is in line with SDG 6.1 requiring universal and equitable access to safe and affordable drinking water for all by 2030. The SDG report (2018) shows that 71% of the population used safely managed water services, while 17% used basic improved water services in 2015. Despite that achievement, 844 million people globally still lacked even the basic service level (UN, 2018) whereas, existing water supply systems are constantly affected by climate change impacts. The risks such as saline-water intrusion and coastal flooding are already causing significant consequences to the livelihood and wellbeing of Tanzanians[22].

Climate variability and change is impacting already water-stressed populations. Projections indicate that poor water security will intensify in the country[23]. The variability affects water quality and quantity. For example, excessive rains cause floods impacting the

[22] https://www.who.int/globalchange/resources/wash-toolkit/tanzania-climate-change-health-wash.pdf
[23] https://www.who.int/globalchange/resources/wash-toolkit/tanzania-climate-change-health-wash.pdf

water sources, treatment plants, water supply infrastructures, and cause gross contamination (URT, 2015). Also, the effects lead to lacking quality water services; one of the weaknesses continuously undermining poverty eradication strategies (Jimenez & Perez-Foguet, 2010). Water contamination leads to water-related diseases, among the top ten diseases causing morbidity and mortality in the country. Furthermore, over 80% of hospital attendants are due to preventable diseases, including diarrhea which is attributable to unsafe water (URT, 2015).

Water supply systems in the country have shown weaknesses needing improvement to combat the snags during business as usual and emergencies. Common response approaches such as reinforcing physical infrastructures (Balaei et al., 2019), cannot eradicate all risks due to financial, construction, and transport constraints caused by the dependency on political influences rather than the need for addressing emergencies. Tanzania like in other developing countries, more effort has been put on increasing service coverage by expanding water infrastructures in compliance with the current National Water Policy (URT, 2002). However, the effort has encountered constraints, including insufficient funding, poor supervision, and climate-related impacts such as flooding. Thus, there is need for strengthening social systems of the communities to foster the water supply systems resilience by increasing their ability to respond and enhance quick recovery aftermath.

While measuring social resilience would assist in determining appropriate measures for improving water supply systems social resilience, more work has been done while lacking clarity and consistency regarding the definition and applicability of the concept (Saja et al. 2019). Also, measuring social resilience for infrastructure such as water supply systems is understudied, and Tanzania cannot be excluded. Therefore, the current chapter proposes a social resilience measurement tool for Tanzania's water supply systems. Expectations are that the tool can identify priority measures that are useful to the water supply authorities' planning and budgeting processes to improve the social aspects of the water supply systems resilience to floods.

8.2 SOCIAL RESILIENCE

Resilience is a concept that has undergone several evolutions without universally agreed definition and measures (Wills, 2015). Organizations dealing with disaster management issues have included the concept in their frameworks indicating the need for involving community sectors in building capacities for locals. For instance, the Sendai Framework for disaster risk reduction (2015-2030) calls for the reduction of disaster risks through an all-of-society engagement and partnership approach (UNISDR, 2015).

The need for engaging societies in the risk reduction activities has led to numerous studies on community resilience, particularly the social aspects. However, there are still variations on how the concept is defined, understood, and applied across communities and disasters (Saja et al. 2019). Most social resilience studies have identified crucial elements that help define the resilience of societies against disasters. About eleven elements were identified by reviewing five definitions; Kwok (2016); Saja et al. (2019); Adger (2000); Mayunga (2007); Cutter (2014). The elements include preparedness, anticipation, mitigation, withstand, resist, absorb, response, coping, accommodate, adapt, and recovery. In all cases, resilience aligns with the ability or capacity in achieving such elements. The elements suggest that most definitions are developed relying on the phases of disaster management; mitigation, preparedness, response, and post-disaster recovery. Furthermore, social resilience depends on the community's social situation in those phases (Khalili et al. 2015).

There is a lack of consistency on the key concepts for measuring social resilience because of the discrepancies of the recovery rate across communities (Saja et al., 2019). Literature portrays two approaches for developing frameworks for measuring social resilience; standard and context-specific frameworks development approaches. Context-specific includes hazard-specific, geographical scope specific, and hierarchical level-specific frameworks. Such frameworks can be a combination; for instance, a hazard-specific framework developed for a specific geographical location (Qasim et al. 2016). The approach is adopted to this study as a framework for measuring social resilience against flood is developed for Tanzania's water supply systems.

Another frameworks classification relies on resilience concepts and dimensions. Saja et al. (2019) clustered several frameworks to four dimension-based categories: capital-based dimensions, coping, adaptive, and transformative capacities (CAT) dimensions, structure, and cognitive dimensions, and social and interconnected community resilience dimensions. Social and interconnected community resilience dimensions frameworks describe social resilience within a holistic multi-dimensional community resilience. For instance, in TOSE (Bruneau et al., 2003) and the five dimensions of community resilience by Sharif (2016) and Cutter (2016), social dimension characteristics are considered as social resilience. Similarly, infrastructure resilience studies have adopted multi-dimensional frameworks integrating social components for measuring resilience (Labaka et al. 2014 and Balaei et al. 2018). Such an approach is adopted in the current chapter to discuss the social aspect of resilience when floods affect water supply systems.

Social resilience is a subject of various factors that answers human factors-related questions, social traditions, power relations and issues, and dimensions largely neglected in ecological studies (Bastaminia, 2017). Lack of consistency has resulted in several factors affecting social resilience, some of which show commonalities. Social demographic, social networks, community engagement, are the three key sub-dimensions in most social resilience frameworks (Saja et al. 2019). Also, Khalili et al. (2015) identify social innovation and learnings as important social resilience factors. **Table 8.1** presents dominant factors that served as building blocks for developing a social tool to measure Tanzania's water supply systems resilience to floods.

Table 8.1: Dominant sub-dimensions for measuring social resilience

Factor/Sub-dimension	Other names	Studies
Social capital	Community bonds, social support and social institutions	Mayunga 2007; Saja 2019; Khalili et al. 2015; Maguire & Hagan 2007; Qasim 2016; Cutter 2016; Sharif 2016; Quandt, 2018.
Social structure	Social demography	Khalili et al. 2015; Cutter 2008
Safety and wellbeing	Access to health, and social safety measures, health insurance	Sharif 2016; Cutter 2016; Cutter 2008; Cutter 2016; Jovanovic et al. 2016
Equity and diversity	N/A	Sharif 2016; Kotzee & Reyers 2016
Learning and innovation	Community competence/education	Jovanovic et al. 2016; Khalili et al. 2015; Kwok 2016; Kusumastuti 2014; Cutter 2008 Jovanovic et al. 2016
Local culture	Beliefs/faith	Sharif 2016; Kwok 2016; Qasim 2016
Inclusion	Community engagement	Jovanovic et al. 2016; Maguire & Hagan 2007; Kwok 2016;
Aspiration	Community aspiration	Jovanovic et al. 2016; Cutter 2016
Leadership	N/A	Maguire & Hagan 2007; Kwok 2016;
Social preparedness	N/A	Kusumastuti 2014; Jovanovic 2016

8.3 METHODOLOGY

The study applied a five-stage process to identify potential variables for measuring social resilience to floods for Tanzania's water supply systems. The processes include literature review, pre-assessment, pretesting, and a three-round Delphi process. Various publications were reviewed to identify key variables that help inform the social resilience for water supply systems. The review also involved other water-related publications for Tanzania and international water supply. The tool's variables needed to be in line with one of the phases of disaster management: mitigation, preparedness, response, and recovery.

The tool was customized to Tanzania's water supply systems through pre-assessment and pretesting processes that took place in Dar es Salaam, followed by a three-round Delphi survey. A questionnaire was developed based on the hypothesized tool and applied during the pre-assessment. The pre-assessment exercise involved ten water supply experts from academia, government and practitioners. The experts had a working experience or research background of at least five years in the water sector. Experts opinions were analyzed and used to improve the indicators. To pretest, the tool, 106 questionnaires were administered to heads of households (HoHs) sampled from Vingunguti, Tandale, and Jangwani wards as presented earlier in chapter 4—**Table 4.2**.

The improved tool was subjected to a three-round Delphi study. To maintain consistency, ten experts who participated during pre-assessment were also included in a list of 22 experts in the exercise. Researchers physically contacted all experts at the beginning of each round, asking them to develop consensus and prioritize the principles and indicators systematically. In the first round, experts were asked to comment on principles and indicators, and add more indicators, whereas during the second and third rounds they were requested to rank the principles and rate the importance of the indicators. The ranking was in the order from 1 for the most important principle to 5 for the least important principle. Six attributes: relevance (Balaei et al., 2018), affordability, availability, reliability, simplicity, and transparency (Morley, 2012 from Villagran's 2006 and Cutter, 2014) were used as guidance in rating the indicators importance and their potential for inclusion in this study.

Each attribute was scored on a five-point Likert scale, from strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4), to strongly agree (5). The agreement was achieved when at least 70% of experts on average, scored 4 or 5 on the six attributes and the standard deviations are between 0.3 and 0.998 (Zhong et al., 2015).

The tool was further evaluated in a hypothetical example "Dar es Salaam" to show how it works. Assessment tools, including measures and measurement scales, were developed. A questionnaire was developed based on the final tool's measures. A survey of 100 HoHs whose houses are constantly vulnerable to floods was carried out where respondents were asked to indicate their position regarding the various measures of resilience.

Thematic analysis was applied manually to analyze the experts' comments from the pre-assessment and first-round of the Delphi study. Standard descriptive statistical analysis was carried out for the pre-assessment, pretesting, second and third rounds Delphi study data, and the evaluation data using a Statistical Package for Social Sciences, IBM SPSS Statistics version 25. The mean ratings (MRs) and median ratings (MeR) established the ranking order of the principles and indicators. Also, MS and standard deviations (SDs) described the group opinions, and convergence of the range of importance ratings of the indicators, respectively. To compare the second and third round results, t-test or non-parametric Mann-Whitney test were used depending on whether the data were normally distributed, with $p < 0.05$ as the level of statistical significance. Furthermore, Kappa statistics were calculated to show the percentage agreement between the two rounds.

Percentages were calculated from the survey of 100 HoHs and used to score the variables initially. The initial scores corresponded to the performance levels of the measures basing on a 5-point Likert scale from 1 = poor performance to 5 = highest performance. All variables were considered having equal weights. The scores were then weighted and aggregated based on Morley's utility index (Morley 2012) to the indicator scores, principle scores, and the final social resilience index. The final index showed the level of resilience from 1 for very poor resilience to 5 for very high resilience.

8.4 RESULTS

8.4.1 Pre-assessment

Existing frameworks were initially reviewed to identify the key characteristics having the potential to measure the water supply systems social resilience. A hypothesized tool with ten indicators was established (see **Appendix 2**). The hypothesized tool was introduced to a pre-assessment process. The exercise comprised of ten water sector experts. Fifty percent of the experts possessed PhD qualifications and had more than ten-year experience in the water industry. The majority also were senior professionals at their workplaces and expressed high disaster management experience. Others were senior associate professionals with experience ranging from 5 to 10 years, and the majority "80%" had disaster management experience. Overall, 80% of the experts had disaster management experience with good research experience.

Results show that experts accepted 7 out of 10 hypothesized indicators. Indicators with close interpretations were merged; for instance, “self-organization” was combined with “community bonds, social support, and social institution.” The two indicators were reorganized to “togetherness” principle within which three indicators were proposed; “the degree of connectedness across community groups,” “volunteering rate,” and “shared water facilities.” “Preparedness” and “responsiveness” indicators were also combined and reorganized to a “preparedness” principle. Also, some indicators were too general. To that understanding, “social structure” was reorganized to a principle with five indicators; “population composition,” “house ownership,” and “connectivity to water supply,” “media of communication,” and “level of education and skills diversity.” “Safety and wellbeing” was revised to a principle whereas “learning and innovation” was modified to “education” principle with “past experience with disasters” indicator.

There were comments such as “inclusion indicator is not only applicable for activities, but also for decision making” to address both staff and the community involvement in water projects and disaster management activities at different levels. Also, “consider using participation instead of inclusion.” The comments were addressed, and the indicator revised to community participation. Similarly, comments such as “what about the people’s awareness on disasters and their impacts to the water supply systems?” and “consider the awareness infrastructures’ users” prompted for an “awareness” indicator under the “education” principle. Thus, five principles and eleven indicators were proposed.

8.4.2 Pretesting

The pretest results portrayed emerging issues (see **Table 8.2**), which prompted to adding six more indicators. As a result, the tool was improved further to five principles and seventeen indicators (see **Table 8.3**).

Table 8.2: Emerging issues during pretesting

Emerging issues	Proposed indicator
Most affected people reside in low-lying areas which are not planned and are known to be vulnerable to floods. For instance, 63.2% of the households are highly likely, and 26.4% are quite likely affected by floods, and the majority are near the urban rivers.	1. Location of houses
According to 88.7% and 83% of the respondents, the public water quality and quantity respectively is affected during flooding.	2. Preventive health measures 3. Water and sanitation disaster response kit
Most respondents (88.7%) had experienced flood impacts in the past, and the majority (67.02%) expressed alternative ways of getting the water service during flooding. Some alternative sources such as wells, valleys, and boreholes are not reliable due to contamination during flooding and contain high salinity	4. Past experience with floods 5. Adoption of water serving technologies
The vulnerability of the community to the failure of public water supply against floods is high; 61% do not receive information or advice regarding the effects of floods on water supply systems whereas 71.7% had taken no action to ensure that future floods impacts are minimized.	6. Water supply centered mitigation plan

Table 8.3: Improved tool from the pre-assessment and pretesting exercises

Principles	Indicators	Code	Reference
1. Social structure	1. Population composition	SI1	Sharif, 2016
	2. House ownership and connectivity to the water supply system	SI2	******
	3. Media of communication	SI3	******
	4. Level of education and skills diversity	SI4	******
	5. Location of houses	SI5	******
2. Togetherness	6. Degree of connectedness across community groups	SI6	Sharif, 2016; Quandt, 2018
	7. Volunteering rate	SI7	Balaei et al., 2018
	8. Shared water facilities	SI8	*******
3. Safety and wellbeing	9. Preventive health measures	SI9	Sharif, 2016
	10. Water and sanitation disaster response kit	SI10	******
4. Education	11. Past experience with disasters	SI11	Sharif, 2016
	12. Cultural and historical prevention: indigenous knowledge and traditions	SI12	Sharif, 2016
	13. Adoption of water serving technologies	SI13	Jovanovic et al. 2016
	14. Community awareness	SI14	*******
5. Preparedness	15. Mitigation plan	SI15	Jovanovic et al. 2016
	16. Disaster preparedness exercises/drills	SI16	Jovanovic et al. 2016
	17. Community participation	SI17	Maguire & Hagan, 2007

****** added based on experts' opinions

8.4.3 Three-round Delphi survey

Twenty-two experts were contacted to participate in the Delphi exercise, 16 completed the first round, among those, 12 completed the second and third rounds. The response rates were 72.7%, 75%, and 100% for the first, second, and third round, respectively. No new expert was invited to participate after the exercise commenced. The education background of the experts ranged from bachelor's degree to PhD, the majority "31.25%" were PhD holders. Half of the experts were senior professionals, whereas the rest were senior associate professionals at their workplaces. Experts were elicited from eight different institutions such as water supply authorities, academic institutions, regulatory authorities, local government authorities, and the Ministry of water, with the majority "68.75%" having disaster management experience.

First-round Delphi survey

Sixteen experts provided feedback during the first round. Experts suggested that social resilience describes *the way water users such as households, communities, institutions, and industries relate, network, bond together to promote cooperation and link up to exchange ideas and resources for the purpose of facilitating rapid recovery aftermath*. The focus is on building people's skills and knowledge to lessen the suffering of negative consequences due to loss of water supply service during flooding.

Specific comments emerged, leading to improving the description of "social structure" principle to accommodate the ability of social groups to *minimize* and *prepare* for flood risks to water supply systems. "Togetherness" principle was refreshed to have a more focus on water supply systems. "Education" principle description was revised to accommodate *formal,* and *non-formal* education used to generate knowledge and innovative skills. Description for "preparedness" principle was also revised to measures taken to improve resilience such that vulnerabilities are minimized, and the society is prepared for water supply problems during flooding (see **Table 8.4**). Experts also suggested modification of the description of "disaster preparedness exercises" indicator to include both practical and non-practical exercises, whereas the description of "house ownership and connectivity to water supply" indicator was amended to the population living in houses with or without house connection to water supply systems.

Table 8.4: Improved principles

Principle	Description
Social structure	The system of societal stratification (e.g., the class structure), or, other patterned interactions between large social groups. It entails the ability of individuals or different social groups to minimize, prepare, respond, and recover from the impacts of floods on water supply systems.
Togetherness: (Community bonds, social support, and social institutions)	The sense of unity within the society that fosters the eagerness of solving common problems of water supply during flooding.
Safety and wellbeing	Access to immediate security and health services regarding epidemic water-borne and water-related diseases such as cholera, diarrhea and skin diseases during flooding
Education: (Local culture, learning, and innovation)	Knowledge and innovative skills passed down the generation through non-formal and formal education to enhance the resilience of the society regarding water supply problems during flooding.
Preparedness	Measures are taken to improve resilience such that vulnerabilities are minimized, and the society is prepared for water problems during flooding.

Second-round Delphi survey

Ranking of principles

The improved tool contained five principles and 17 indicators. In the second round, principles were ranked for their importance between 1 and 5. “Education” was ranked many times as the most important principle associated with the lowest mean rating (MR) = 2.25 and median (MeR) = 2.00. “Preparedness” was ranked second having MR = 2.58 and MeR = 2.00, followed by “social structure” and “togetherness.” “Safety and wellbeing” principle was the least important principle-it was ranked ten times between 3rd and 5th in the order of importance with the highest MR = 3.67. Second round results suggest the order of importance ranking is 1 for education, 2 for preparedness, 3, social structure, 4 for togetherness, and 5 for safety and wellbeing.

Rating of indicators

Applying the six attributes—presented in chapter three, **Table 3.3**—for indicators importance rating, 35.3% of indicators passed all attributes. All indicators except "house ownership and connectivity to the water supply system" and "volunteering rate" passed the relevance attribute. About 13.3% underscored for one attribute, 33.3% underscored for two attributes, 20% underscored for three attributes, and 6.7% for four attributes. Of all indicators that were underscored in at least one of the attributes, 81.8% was due to data availability. Results indicate further that, data availability, reliability, and affordability are the limiting factors for selecting indicators in the country.

Eight indicators "47.1%" were eliminated during this round. The indicators were associated with relatively lower MRs and higher SDs, suggesting that the group opinions for inclusion were low, and the importance ratings had low convergence. On the other hand, 52.9% of the indicators passed this round having MRs ranging from 3.6667 to 4.3333, and SDs from 0.51493 to 0.90034, suggesting that the group opinions were relatively high, and the overall convergence of importance ratings was acceptable.

Results show "community awareness" was the most important indicator according to 91.7% experts with a MR = 4.333, followed by "preventive health measures," "mitigation plan," and "location of houses." The least important indicator was "shared water facilities" supported by only 75% of experts with lowest MR=3.6667 and high SD=0.88763.

Third-round Delphi survey

The revised tool had five principles and nine indicators. In the third round, experts were invited to reconsider their voting for ranking the principles and rating the indicators. The majority "83.3%" were satisfied with the principles and indicators that emerged from the second-round. Nevertheless, 16.7% of the experts reconsidered their voting. Statistical results show the p-values ranging from 0.3485 to 0.5000, suggesting that there was no significant difference between the second and third rounds principles ranking results. However, the ranking order slightly changed, where "safety and wellbeing" mounted to fourth place above "togetherness," having similar MRs = 3.42 but lower MeR = 3.50 than "togetherness" MeR = 4.00. The revised ranking order became 1 for "education," 2 for "preparedness," 3 for "social structure," 4 for "safety and wellbeing," and 5 for "togetherness."

Further statistical results for comparing the importance rating of the indicators revealed p-values ranging from 0.3419 to 0.4876, suggesting there was no significant difference between the second and third rounds. Between 75% and 91.7% of the experts agreed or strongly agreed on the inclusion of the indicators, suggesting experts were satisfied with the indicators and all nine sufficed for inclusion. The MRs ranged from 3.6667 to 4.3333, and SDs ranged from 0.51493 to 0.90034, suggesting the overall convergence of the importance ratings were acceptable. “Population composition” mounted to sixth place in exchange with “adoption of new technologies.” The Kappa values for the variables ranged from 0.742 to 1.000 (mean = 0.9547, median = 1.000). These values suggest there were substantial agreements between the two rounds. The final tool is presented in **Table 8.5**.

Table 8.5: Final tool for measuring social dimension resilience for water supply systems in Tanzania

Principles (MR, MeR) (P-value, Kappa)	Indicators				
	Indicator (MR, SD)	**Code**	**Description**	**p-value, Kappa score**	**Rank**
1. Education (2.25, 2.00) (0.4879, 1.000)	1. Adoption of new technologies (3.833, 0.577)	SI13	Use of new water serving technologies that enable the community to survive the crisis of water supply during flooding	(0.3941, 0.844)	**7**
	2. Community awareness (4.333, 0.651)	SI14	Awareness of risks caused by the flood impacts on water supply systems, and the disaster management facilities such as the early warnings and communications, and the emergency response organizations in their vicinities	(0.4872, 1.000)	**1**
2. Preparedness (2.75, 2.50) (0.4289, 0.890)	3. Mitigation plan (4.167, 0.718)	SI15	Plans prepared and adopted by the community with the primary purpose of identifying, assessing, and reducing water supply problems from flooding hazards	(0.3819, 0.850)	**3**
	4. Community participation (3.917, 0.793)	SI17	Community participation and engagement in water supply projects and disaster management activities to create a sense of ownership for the projects and enhance response capability during flooding respectively	(0.4862, 1.000)	**5**
3. Social structure (3.33, 3.50) (0.4880, 1.000)	5. Location of the house (4.000, 0.603)	SI5	The status of the area where people reside, whether it is planned or unplanned settlement and its vulnerability and exposure to floods	(0.4862, 1.000)	**4**
	6. Population composition (3.917, 0.900)	SI1	Distribution of the population according to characteristics such as age, and cultural diversity, that helps to understand how the community is stratified.	(0.4876, 1.000)	**6**
	7. Level of education and skills diversity (3.75, 0.965)	SI4	The maximum level of education achieved and the diversity of skills within the community to pull together in response to flooding events and fasten the rate of recovery	(0.4871, 1.000)	**8**
4. Safety and wellbeing (3.42, 3.50) (0.3494, 0.891)	8. Preventive health measures (4.083, 0.515)	SI9	Measures for preventing the eruption of waterborne and water-related diseases due to using contaminated water during flooding	(0.4848, 1.000)	**2**
5. Togetherness (3.42, 4.00) (0.4644, 0.891)	9. Shared water facilities (3.667, 0.888)	SI8	Water facilities such as boreholes, water trucks, water storage tanks, etc. that are jointly owned within the community	(0.4862, 1.000)	**9**

8.4.4 Operationalization of the social resilience tool

Development of assessment tools relied on existing literature. The measures and measurement scales for the current tool depict the resilience level of the society regarding water supply during flooding. Each indicator contains at least one measure scaled using a 5-point Likert scale from 1 for a poor condition to 5 for better condition. For instance, “population composition” is measured by assessing the age distribution within the community. As such, it contains measurement scales from 1 = 0-14 years (more population are young dependent), 2 = Above 64 years (More population are elderly dependents), 3 = 15-24 years (more population are just entering the labor market after education), 4 = 55-64 years (more population are approaching retirement), to 5 = 25-54 years (more population are in their prime working lives).

The percentages analyzed from the HoHs survey were useful inputs in the initial scoring process of the tool. The percentage corresponded to at least one of the conditions of the measures. The score of the measure equaled the score of the indicator, in some cases indicators had two measures; thus, the average was calculated. Indicator scores ranged between 1 and 4. “Shared water facilities” was the least scored followed by “mitigation plan,” and “population composition.” “Adoption of new technology” was the highest scored indicator, followed by ‘preventive health measures.” The indicators weightings ranged from 33.33% to 100% depending on their number in a principle whereas, principles had 20% weighting each. Aggregation results show that “safety and wellbeing” principle scored higher (4.0) than others, followed by social structure (3.0), whereas “togetherness” principle scored the lowest (1.0) than other principles. Further aggregation led to a final social resilience index of 2.6 ≈ 3.0.

8.5 DISCUSSION

The current tool has a generality nature comprising of variables from different frameworks applied to assess the social resilience in both developing and developed countries. Most variables had rarely been tested to assess the social resilience of infrastructures like water supply systems. Therefore, they were made appropriate to Tanzania’s water supply systems through pre-assessment, pretesting, and a three-round Delphi survey. Pre-assessment findings suggest that elimination, merging, and splitting processes are useful in improving the tool variables. That is to say; some indicators were eliminated, too similar indicators were merged whereas, too general indicators were reconsidered as principles and split into several indicators.

Emerging issues during pretesting were analyzed and new indicators proposed. Firstly, most affected people reside in low-lying areas which are unplanned, have proximity to urban rivers and are vulnerable to floods. Secondly, the public water quantity and quality are affected during flooding due to failure of the infrastructures and post-contamination. Thirdly, most respondents had experienced flood impacts in the past, whereas the majority expressed alternative ways of getting water service during flooding, some of which are not reliable due to contamination during flooding and high salinity. Fourthly, the vulnerability of the society to the failure of public water supply systems is significant since the majority do not receive information or advice regarding flood risks on water supply systems; thus, they had taken no action to prepare for future floods risks. These issues prompted to additional indicators such as the "location of the houses," "preventive health measures," "water and sanitation kit," "past experience with floods," "adoption of new technology," and "water supply-centered mitigation plan."

The rate of responses in the three-rounds Delphi survey improved linearly across the rounds. The improvement concurs with (Gargon, Burnside, & Williamson, 2019) whose study suggest that small size panels are likely to have better response rates. The response rates further improved due to the recruitment method, and participants contact as experts were contacted directly at the beginning of each round and regularly reminded to provide feedback. Most experts were satisfied with the tool containing five principles and nine indicators after the second round and did not revise their voting. Reaching consensus in two-rounds is common, as some studies such as Suwaratchai et al. (2011) applied two rounds to obtain consensus in developing trauma care indicators.

Assessment of the six attributes for indicators importance rating suggests data availability is the critical attribute needing close attention. The attribute impacts Tanzania and most developing countries due to low awareness, inadequate capacity in terms of financial and human resources, and technology. Other attributes needing close attention are data affordability and reliability. The findings suggest that these three attributes are the significant factors when selecting and refining indicators for resilience assessment in the country.

Principles ranking showed no significant difference between the second and third rounds suggesting there was reasonable consensus and that, ranking results from either round could be used. Similarly, the importance rating results for indicators showed no significant difference between the two rounds. The MSs and SDs values suggest that there were better group opinions, and the overall convergence of the importance ratings is acceptable. Furthermore, the Kappa statistic results suggest there were substantial agreements between the two rounds, and that the consensus was reached.

The study suggests that the social resilience for Tanzania's water supply systems can be affected by five key factors. "Education" is the most important factor, followed by "preparedness," "social structure," "safety and wellbeing," and "togetherness." In all cases, "community awareness" is the most important indicator, showing the awareness of the community to flood risks on water supply systems. Also, it assesses the awareness of the community to early warnings and communications, alternative water services, and the emergency response organizations in their areas. The second is "health preventive measures" assessing the health and wellbeing of the community from water-related diseases when water supply systems fail, as the diseases are common in most developing countries (McCrickard et al. 2017) especially when faced with floods. The third is "mitigation plans" prepared and adopted by the community with the primary purpose of identifying, assessing, and reducing flood risks to water supply systems. Others are the "location of houses" and "community participation."

In the current tool, survey data from the residents is useful in the initial scoring process to determine the water supply systems social resilience. Aggregated variables had almost similar values to the average values of the variables suggesting that weightings did not affect the resilience scores of the variables. The cross-principles comparison suggests the influence of the weightings to the weighted variables. For instance, large weightings for indicators with low score improved the weighted values sometimes surpassing the indicators with high scores having small weightings. This situation is consistent with the number of indicators in the principles.

When evaluated in a hypothetical example, the tool showed a medium social resilience, suggesting that the residents have less than desirable resilience level and specific improvements should be prioritized. There were no shared water facilities in the area, indicating the residents have no desire to resolve water supply issues jointly during crises. Although Dar es Salaam is culturally diverse with for example about 31 different tribes in the sampled area, and somehow a dominant Muslim group, it seems to lack togetherness. Lack of cohesion in a culturally diverse community such as this lowers the ability to withstand shocks and adapt to new circumstances. In this case, there is a need for improving the sense of unity within the society and create programs for integrating new residents to foster the eagerness of solving water supply common problems.

Also, Dar es salaam is characterized by people aged between 0 to 14 years “43.9%” a group of young dependents, suggesting that introducing awareness and preparedness learning programs in primary schools would help the majority to understand and prepare for flood risks on water supply systems. Moreover, they can pass the knowledge to the parents and guardians who did not attend school and the majority whose education level is limited to primary education.

There is limited preparedness regarding flood risks on water supply systems, and this is evident from the lack of awareness on the hazard mitigation and responsive plans. In addition, residents have not attended or represented to preparedness training regarding flood risks on water supply systems. Also, there is medium community participation in water-related projects and other disaster management activities, that said, about half of the residents have not participated in any water projects and water-related disaster management activities. The findings highlight the need for creating awareness among the community regarding the hazard mitigation and responsive plans and introducing water-related disaster preparedness part for the communities during the implementation of water projects. This should be in line with involving as many society members as possible to understand the value of the water projects, so they can stop conducting any illegal activities that would increase water supply systems’ vulnerability to floods.

Most sampled houses are in unplanned settlements; this is not uncommon as most houses in Dar es Salaam “about 70%” are in unplanned settlements. Such a situation has increased their vulnerabilities to flooding risks due to blocked waterways, and most water pipes are partially exposed to the ground. In some areas, pipes have been cut for illegal water tapping or broken due to traffic escalating the post contamination risk during flooding. Residents experience hardships obtaining water as some pass ways and roads become impassable during flooding. Careful settlements planning measures are suggested to ensure that such areas are accessible all times, and waterways are cleared to reduce flood risks. The WSSAs also may need to improve the construction approaches such as making sure that the top soil-cover to pipes is at least 0.6m according to the Tanzania design manual for water supply and wastewater disposal.

Although residents expressed better coping with new technologies, yet it is limited to the use of household treatment methods—such as boiling and waterguard chemicals application—to reduce the impact of flood contamination risks to water. A recommendation could be drawn from the current assessment that, the community members are sensitized to use rain water harvesting technologies to ensure that they do not extremely suffer from flood risks to the conventional water supply systems. The tool provides a starting point for broad agreement regarding the key components of the social resilience for water supply systems in the country. It evaluates and informs the priority practices assisting water supply authorities in Tanzania and other developing countries to address social issues that can affect water supply systems in future flood risks.

8.6 CONCLUSION

The study portrays a fundamental basis for comprehensive agreement about the components of water supply systems social resilience against floods in Tanzania. It was possible through considering numerous water supply systems international resilience characteristics presented in various frameworks into a comprehensive tool comprising of five principles and nine indicators for measuring social resilience of Tanzania's water supply systems. Until now, studies on water supply field in Tanzania are focused on water management, climate change studies, and floods risks analysis with limited attention on the resilience against floods. The current tool, covering a suitable range of indicators is useful in assessing the social resilience of Tanzania's water supply systems.

The tool can be applied by water supply practitioners and managers to assess the social resilience of the water systems using a simple set of questions developed from the assessment measures. The questions, when administered to the water users, provide important information that is used in the initial scoring process. WSSAs can use their billing and communication systems to obtain the information from the water users, for a more reliable assessment process. Results from the tool provide the resilience level of the residents when faced by flood risks to water supply system. The tool works further as a checklist to identify vulnerabilities of the society and set priority measures in addressing social-water-related issues for future floods. The tool provides suitable information for planning and budgeting for resilience enhancement in the country's water supply system and other developing countries as agreed variables originated from general concepts in the literature. The next chapter answers the question of economic issues related to water supply systems and their essentiality during disasters such as floods.

Chapter 9
Development of Economic Variables for Measuring Resilience

The current chapter is based on the following article:

Sweya, L.N., Wilkinson, S. (2020). Tool Development to Measure Resilience of Water Supply Systems in Tanzania: Economic Dimension (Under review: Jamba Journal of Disaster Risk Studies)

9.1 INTRODUCTION

Resilience building in all aspects of the water supply systems depends on the economic capacity and how the water organizations well spend funds in implementing appropriate measures to ensure continuous services at all times. Thus, the current chapter assesses economic factors leading to essential variables for measuring the economic capacity of the water supply systems to survive the impacts of floods in the country.

Human civilization has become a superorganism changing the environment from which it evolved and inducing new hazards with no analogue. With increasing complexity and interaction of human, economic, and political systems within ecological systems, the risks become increasingly systemic (UNDRR, 2019). The worst scenario is the contributions to the already changing environment expected to yield more frightening impacts on the economy and human lives if serious interventions are lacking. The ability to exacerbate the impacts of environmental-related disasters is a notable concern; from the 1960s to date there has been an exponential increase in natural disasters' frequency, magnitude and impacts in terms of human lives and economic losses (EM-DAT). UNDRR (2019) indicates further that, 68.5% of all global economic losses in the period from 2005 to 2017 were attributed to extensive risk events and heavily absorbed by the low-income households and communities particularly in the low-and-middle-income countries in Asia, Pacific, and Africa. Such countries that have the least capacity to prepare, finance, and respond to disasters and climate change.

Globally, too much has been already lost "approximately USD 3.5 trillion” due to natural disasters since 1900 based on the relatively few internationally reported disasters and the damages caused (EM-DAT). The equivalent money is more than the global infrastructure development investment in 2014 estimated to USD 3.4 trillion (Bhattacharya et al., 2016). Besides, USD 5.2 billion and approx. USD 136.8 billion spent on DRR and disaster response (humanitarian financing), respectively between 2005 and 2017 (UNDRR, 2019) aggravates to the wounded economy. The disasters' reporting data are imperfect, particularly in developing countries, and disaster losses remain significantly unreported compromising accurate calculations of impacts and affect the preparedness and mitigation plans for future events.

For instance, in Tanzania, only 5.7% of the internationally reported disasters had information that represented the total damage caused for the past century (EM-DAT). The country was the first in the top ten countries by disaster damages in 2016 (%GDP), which accounted for 0.97billion USD (Guha-Sapir et al., 2016). Moreover, the country incurs an estimated 4.5 trillion TZSH (appx. USD 2Billions) annually on flooding hazard—two times the state budget for the Ministry of Health, Education, Home Affairs and Environment combined for financial year 2017/2018[24]. During the course, infrastructures suffer the consequences. With the increased risk of coastal flooding in many parts of the world which is projected to have more significant damage than riverine floods, infrastructure (such as water supply) and assets that stand to be damaged are increasing (UNDRR, 2019). Thus, there is a need for investing in resilience building to 1. Avoid losses when disasters strike; 2. Stimulate economic activity from reduced risks, and 3. Develop co-benefit, or uses of a specific disaster risk management investment (UNDP 2019), including for water supply systems.

The possibility to measure economic changes at the regional level triggered by disasters is a crucial step towards disaster risk reduction (Renschler et al., 2010) so is for infrastructure resilience (Willis, 2015) in which economic dimension plays a crucial role. The economic dimension involves economic factors in the restoration process of urban infrastructure, they drive recovery before, during and after disasters, and they need to be determined to select optimal resources allocation and prepared measures right after an extreme event (Martinelli et al. 2014). Worldwide, researchers have shown the importance of economic factors and their measurements for the performance of infrastructures (Bruneau et al., 2003; Vugrin et al., 2010; Balaei et al., 2018; de Bruijn et al. 2017; Bhattacharya et al., 2016) during disasters. However, the difference in economic patterns and their consequences on infrastructure such as water supply systems pose a quest for localized approaches that would precisely apply in measuring

[24] https://www.dailynews.co.tz/news/floods-cost-tanzania-us-2billion-annually.aspx

the economic factors and enhance the resilience of overall water supply system—that is missing for Tanzania. The current study applied Delphi techniques to try to fill the gap through developing a resilience tool to floods, with economic components/factors that can be used in the water supply organizations' planning processes and budgeting to improve overall water system resilience.

9.2 ECONOMIC RESILIENCE

Resilience is a multi-dimensional concept applicable in various fields such as ecology, social sciences, engineering, and economic, mainly to describe how the systems are better prepared to withstand, respond, recover, and adapt when stricken by disasters. Since the advent of resilience by Holling (1973), several studies have tried to define the concept without consensus on a universal definition (Vugrin et al., 2010) even in specific areas of research. Some definitions try to define the concept at a general perspective while others are context-specific while focusing on specific dimensions such as social dimension, economic dimension, and organizational dimension. In all cases, the resilience concept is defined based on some or all four phases of disaster management; mitigation, preparedness, response, and recovery. A meta-definition which comprehensively defines resilience is by Stephenson et al. (2015) *"The ability to absorb the effects of a disruptive event, minimize adverse impacts, respond effectively post-event, maintain or recover functionality, and adapt in a way that allows for learning and thriving, while mitigating the adverse impacts of future events."* The definition was developed by drawing together common words from 120 literature-based definitions (Stephenson et al., 2015). This definition provides an excellent platform for understanding the general concept of resilience as applied in the current research.

Economic resilience is a more complex concept than others (social, technical, and environmental) because the long-term investment in rehabilitation is complicated and is a unique post-disaster task (Bastaminia et al. 2017). The review of a few definitions shows discrepancies on how economic resilience is defined 1. As the analysis of economic success with respect to the processes involved in disaster management (Christopherson et al., 2010), 2. The capacity of an institution or a system to maintain its functions during crises (Rose, 2004), 3. Reconfiguration of economy, adaptability, and infrastructure, and sustain acceptable growth in production, employment, and welfare in the long-term (Martin, 2011), 4. The ability of an economy or a local community to absorb and adapt to the negative effects of economic shock and move towards pre-disaster equilibrium or stability (Bastaminia et al., 2017) and 5. The inherent ability and adaptive response that enables individual business firms and entire regions to avoid maximum potential loss (Rose & Liao, 2005). The common attributes apply to the economic resilience with respect to water supply systems, encompassing economic factors that affect the functionality and recovery process aftermath. Also, determine water service options for households, communities, firms, and water supply authorities during flooding/disasters.

Likewise, measuring resilience is complex, and there is no universal approach (Willis, 2015). Various methodologies have been developed to operationalize the concept to remove its ambiguity (Sharifi, 2016). In that regard, more studies have examined economic resilience empirically or with the use of simulation studies (Rose & Krausmann 2013; Cutter 2016) which have undergone evolutions from Tierney (1997) to Rose & Liao (2005) who applied a computable general equilibrium (CGE). Others have used evidence-based such as the FEMA's estimation tool, and survey (Kajitani & Tatano, 2009). Some studies have treated economic aspects as a dimension/component to community resilience (Cimellaro et al. 2016; Mayunga 2007) while others incorporating it in infrastructure resilience (Bruneau et al., 2003, Vugrin et al., 2010, Balaei et al., 2018) within which several indicators apply to examine the resilience.

Rose (2007) indicates that economic resilience divides into *static* resilience and *dynamic* resilience; the former refers to the efficient use of resources at a particular point and time, while the latter implies to the repair and reconstruction affecting the time-path of the economy (focused on speed of recovery). In each case, resilience emanates from both internal motivation (*internal resilience*) and the stimulation of private or public policy decisions (*adaptive resilience*). Moreover, economic resilience takes place at three levels; individual household or firm (*microeconomic level*), sectors (*mesoeconomic level*) and general economy (*macroeconomic level*) (Rose 2007; Rose & Krausmann, 2013; and Rose, 2017). The current study evaluates economic factors, at the society level and water organizations level thus it is important to analyze the internal economic capacity of individuals/society, and water supply organizations, and their interaction with external stakeholders aligning with micro and mesoeconomic levels.

The dominant economic factors that could be useful for the assessment of economic resilience include the economic structure, efficient use of resources to prepare and mitigate disasters, and repair and reconstruction aftermath (Sharifi, 2016; Rose, 2007, 2016). Moreover, the water supply systems' resilience to flood hazards in Tanzania seems to be directly related to microeconomy and mesoeconomy. Thus, **Table 9.1** presents the common factors that could affect the economic resilience: those studies were fundamental during the development of the current tool.

Table 9.1: Common factors used in assessing the economic resilience

Principles	Indicators	Authors
1. Structure (Sharifi 2016)	Employment rate and opportunities	Sharifi 2016, Cimellaro 2016, Bastaminia 2017, Alshehri et al. 2015, Mayunga 2007
	Income (equality, multiple sources,..), poverty	Sharifi 2016, Cimellaro 2016, Bastaminia 2017, Cutter 2016, Alshehri et al. 2015, Mayunga 2007
	The age structure of the working population	Sharifi 2016
	Qualification of the working-age population	Sharifi 2016
	Individuals with high and multiple skills; literacy (education)	Sharifi 2016, Cimellaro 2016
2. Static/security (Rose 2007; Sharifi 2016; Bastaminia 2017 Cimellaro 2016)	Individual and community serving	Sharifi 2016, Mayunga 2007
	Collective ownership of community resources	Sharifi 2016
	Insurance (domestic and non-domestic) and social welfare	Sharifi 2016, Alshehri et al. 2015
	Financial instruments (contingency funds, operating funds, and capital funds)	Sharifi 2016
	Stability of prices and incomes, property value	Sharifi 2016, Mayunga 2007
3. Dynamism (Rose 2007; Sharifi 2016; Bastaminia 2017; Cimellaro 2016)	Inward investment	Sharifi 2016, Mayunga 2007
	Connection with the regional economy	Sharifi 2016
	Business cooperation (inter and intra)	Sharifi 2016
	Openness to micro-enterprises and micro-finance services, entrepreneurialism	Sharifi 2016
	Public-private partnership	Sharifi 2016
	Locally owned business and employers	Sharifi 2016

NOTE: Most factors come from Sharifi (2016), whose study reviewed 36 tools for measuring community resilience.

9.3 METHODOLOGY

This study was conducted to identify potential elements of the tool that can be applied to assess the economic resilience for water supply systems against floods in Tanzania. The tool in the current study is referred to as a framework of potential principles and indicators suitable for measuring the economic resilience for water supply systems in the country. The development of the tool is through an extensive review of literature, a pre-assessment, and a three-round Delphi process. The experts took part voluntarily based on their understanding of the objectives of this research. Ethical approval was obtained from the ethics committee of The University of Auckland, New Zealand (approval number 019619), participant information sheets (PIS) were provided to experts and consent forms (CF) signed by the participants.

A literature review was conducted to identify key factors/indicators that had potential and could help inform the economic resilience for water supply systems. The review was also reinforced with the water-related publications for Tanzania and international water supply systems, particularly from developing countries with similar characteristics. Moreover, indicators were considered based on their adherence to one of the phases of disaster management: mitigation, preparedness, response, and recovery. Thus, a tool with nine indicators was proposed.

The proposed tool was made appropriate to Tanzania water supply systems through a pre-assessment which took place between September and October 2017 in Dar es Salaam, Tanzania followed by a three-round Delphi survey from October 2018 to January 2019. A questionnaire was developed based on the proposed tool and later on used for the pre-assessment exercise-the pre-assessment involved ten water supply experts from the public, private, and research institutions. The experts had a working experience or research background of at least five years in the water supply industry. Experts were requested to comment, modify, and add more indicators and rate their importance. Based on the experts' opinions, the tool was improved to three principles and 12 indicators.

A three-round Delphi study was introduced to improve the tool further and make it more appropriate to Tanzania water supply systems. For more consistency, the exercise included the ten experts who participated in the pre-assessment. Besides, 12 experts whose involvement was for the first time were invited to participate in the study and make an overall panel of 22 experts. Initially, in each round, experts were physically contacted and asked to develop consensus and prioritize the components of the tool. In the first round, participants were asked to comment on the principles and indicators and add more indicators. Whereas during the second and third rounds, experts were asked to rank the principles and rate the importance of indicators. The ranking was in the order from 1 for the most important principle to 3 for the least important principle. Rating of the indicators was based on six key attributes: relevance, affordability, availability, reliability, simplicity, and transparency as useful guidance in rating the importance of the indicators and their potential for inclusion in the study.

Each attribute was scored on a five-point Likert scale that ranged from strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4) strongly agree (5). The agreement was considered to be reached when at least 70% of experts, had scored 4 or 5 on the six attributes for agreeing or strongly agreeing to the inclusion of the indicator (Wakai et al., 2013) and the standard deviation of the ratings are between 0.3 and 0.998 (Zhong et al. 2015).

Thematic analysis was firstly applied manually for the comments given by respondents during the pre-assessment exercise and first-round of the Delphi study. Secondly, standard descriptive statistical analysis for second and third round data of the Delphi study was carried out using Statistical Package for Social Sciences, IBM SPSS Statistics 25. The MSs and MeRs were used to establish the ranking order of the components of the tool, whereas, MRs and SDs were used to describe the group opinion and the convergence of the range of importance ratings of the indicators respectively as provided by the experts. Depending on whether the data were normally distributed and using $p < 0.05$ as the statistical significance level, t-test or non-parametric Mann-Whitney test were analyzed to compare whether there was a significant difference between the second and the third round. Furthermore, Kappa statistics were calculated to show the percentage agreement between the two rounds.

9.4 RESULTS

The chapter presents the development of a tool that has variables suitable for assessing the economic resilience for water supply systems in Tanzania. A three-stage approach was employed; literature review, pre-assessment, and a three-round Delphi survey. The chapter encompassed a review of several publications to establish key factors of the tool that are relevant and could be used to assess economic resilience for water supply systems. Thus, the review resulted in a hypothetical tool with nine indicators (see **Appendix 2**).

9.4.1 Pre-assessment

The proposed "hypothetical" tool went through a pre-assessment exercise. The pre-assessment involved ten water experts. 50% of the experts possessed PhD qualifications, had more than ten-year experience in the water-related fields and were ranked as senior professionals at their workplaces. Others were senior associate professionals with experience ranging from 5 to 10 years. 80% of all experts had experience in disaster management and better research background. Results show that only four indicators; "availability of funding for all elements of resilience," "qualification of the working-age population," "individuals with high and multiple skills; literacy (education)," and "public, private partnership (PPP)" were accepted by at least 70% of the experts for inclusion in this study and had SDs of their ratings between 0.3 and 0.998. Among omitted indicators, three were because less than 70% of the experts agreed or strongly agreed on their inclusion and two were because both less than 70%

of the experts agreed or strongly agreed on their inclusion and the standard deviation of their importance ratings was above 0.998 (see **Table 9.2**).

Table 9.2: Screening process for indicators during pre-assessment

Assessment criteria	Number of indicators	Comments
1. At least 70% of experts agree or strongly agree 2. Standard deviation between 0.3 and 0.998	4	Passed
Less than 70% of experts agree or strongly agree	3	Rejected
1. Less than 70% of experts agree or strongly agree 2. Standard deviation above 0.998	2	Rejected

Two indicators, "insurances for hazard events," and "stability of prices and incomes" while omitted during the exercise, were restored to the next stage of assessment by researchers. That is because the first influences the security of affected populations, infrastructures and organizations that run the infrastructures, whereas the second affects the ability of the people to obtain the water service from alternative sources. Along with insurances, it was suggestive that there was a need to assess the serving behaviors of individuals and the cost recovery of organizations, thereby incorporating indicators such as "individual and community servings," and "cost recovery." Together with public-private-partnership (PPP), "business cooperation (intra and inter)" was added to assess the business-oriented interaction within and outside the organizations that run water supply systems.

It is not uncommon to see massive investments in parts of the water supply systems than others in most developing countries such as Tanzania. For instance, by 2015 the production component of the Dar es Salaam water supply systems had expanded to twice the previous capacity while the distribution part remained the same, suggesting that there is heavy investment in the production system than in the distribution system. The situation has seen more water "with high pressure" released into the lowly-developed distribution system leading to pipe bursting and high levels of NRW. To that understanding, researchers proposed an additional indicator, namely "system investment proportionality." Moreover, researchers were curious about the community water service economic consequences as such, proposing another "expenditure on water services" indicator to assess water services expenditures before and after flooding. Another notable addition was the 'inward investment,' intended to assess how investors are interested in investing in the water supply industry. Overall, the improved tool comprised of 12 indicators grouped into the most dominant principles for assessing economic resilience; structure, static/security, and dynamic/dynamism (see **Table 9.3**).

Table 9.3: Improved tool from the pre-assessment exercise

Principles	Indicators	Code	Reference
1. Structure	1. Employment rate and opportunities	EI1	Sharifi, 2016
	2. Income	EI2	Sharifi, 2016
	3. Expenditure on water services	EI3	******
2. Security	4. Individual and community savings	EI4	Sharifi, 2016
	5. Insurance	EI5	Sharifi, 2016
	6. Stability of prices and incomes	EI6	Sharifi, 2016
3. Dynamism	7. Inward investment	EI7	Sharifi, 2016
	8. Business cooperation (intra and inter)	EI8	Sharifi, 2016
	9. Public-private partnership	EI9	Sharifi, 2016
	10. Funding	EI10	Hughes & Healy 2014
	11. Cost recovery	EI11	******
	12. System investment proportionality	EI12	******

****** Indicators added by researchers based on experts' opinions

9.4.2 Three-round Delphi survey

The improved tool comprising of three principles and 12 indicators passed a three-round Delphi study. The researcher contacted twenty-two experts participate in the exercise. Sixteen completed the first round, among those, 12 completed the second round and the third round. The response rate in the three rounds was 72.7%, 75%, and 100%, respectively. There was no new invite of new expert to participate after the exercise had commenced. Chapter three presented the selection criteria and qualifications of the experts who participated in the three-round Delphi study.

First-round assessment

In the first round, experts commented on the significance of the potential principles and indicators and modified or added more indicators that seemed significant for the study. All 22 experts were invited to participate in the exercise. Of those, 16 responded in this round, including eight "equivalent to 50%" whose participation was for the first time. The analysis shows that 75% of the experts had comments on the tool, which strongly reflected in the current study.

Experts' opinions emerging from this round, were analyzed and summarized as for latter addition, revision, or integration in the study. Results suggest that the economic dimension is *the ability of an economic entity such as individuals, households, societies, water* *supply authorities, and firms. to use their economic resources to quickly recover or adjust to the loss of water supply services due to flooding impacts*. Such description aligns with three principles (see **Table 9.4**). There were no significant changes concerning the indicators; a few specific comments entailed minor changes or improvement of the descriptions. For instance, system investment proportionality description changed from equality to proportionality of investment from the system production and transmission to system distribution such as to ensure uniformity in services and reduce losses.

Table 9.4: Improved principles for economic dimension resilience

Principle	Description
Structure	The composition and patterns of various components of the economy “trade, income, employment” ranging from water users to the organizations that run the water supply systems.
Security/Static	The ability of an entity or system “household, society, or organization” to maintain functions by making the best use of available resources. It is essentially concerned with the efficient allocation of resources, and it principally involves users (customers).
Dynamism	The efficient use of resources over time for investment in repair and reconstruction focusing on the speed of recovery of water supply from the impacts of flooding

Second-round assessment

The tool improved from first-round assessment comprised of three principles and 12 indicators. In the second round, experts ranked the dimensions and principles and rated the indicators based on their importance. The principles were ranked accordingly between 1 and 3; 1 for the most important and 3 for the least important. “Dynamism” was ranked as the most important principle with higher frequency (5 times) than any other principle in this dimension. It was also associated with the lowest MR (1.75) and MeR (2.00) than others. Other principles had relatively higher means and medians. Besides, the “structure” principle had a higher mean (2.25) and median (2.50) than “security/static” 2.08 and 2.00 for MR and MeR, respectively. Results suggest that the importance ranking order is 1 for dynamism, 2 for security, and 3 for structure.

Rating of indicators

The six attributes—presented in chapter three—applied as useful guidance in rating the importance of the indicators and their potential for inclusion in the study. Despite all indicators passing for relevance attribute, no indicator that passed for all six attributes. The majority (75%) were underrated for at least three out of the six attributes. “Stability of prices and incomes,” and “business cooperation (intra and inter)” were the lowest-rated indicators; they were underrated for five out of the six attributes. Only “public-private-partnership,” “system investment proportionality,” and “cost recovery” indicators underscored for one of the six attributes. In most indicators’ ratings “83.3%,” availability attribute was a major concern.

Nine indicators equivalent to 75% were excluded from the study, which also prompted for the omission of two principles: “structure,” and “security/static.” Excluded indicators were associated with relatively low MSs and higher SDs, suggesting that the group opinions for their inclusion were low, and the importance rating by the experts was low. The lowest rated indicators were “business cooperation (intra and inter),” “individual and community savings,” and “stability of prices and incomes,” to which less than 50% of the experts argued that they are important for the study.

The three criteria-at least 70% agreeing or strongly agreeing on the importance of the indicator, MSs, and the SDs of the ratings applied in assessing the ranking of the indicators. Only three indicators were included in this study at this stage; “public-private-partnership,” “cost recovery,” and “system investment proportionality.” The importance of all three indicators was supported by 75% of the experts, whereas “system investment proportionality” emerged as the most important indicator due to higher MR (3.7500) and lower SD than others. The second important was public-private-partnership, whereas cost recovery was the least important indicator.

Third-round assessment

The improved tool from the second round encompassed one principle and three indicators. Experts were invited to reconsider their voting and re-rate the indicators. Most (83.3%) experts did not revise their opinions because they were satisfied with the components of the tool that had emerged from the second round. Some experts provided the following responses; ‘I have gone through the indicators, and I find at the stage you have reached all suffice the assessment; that said I have no additional input to it,’ ‘yes please, kindly proceed with further steps, I do not have different opinions,’ ‘I think there are no changes, you can proceed.'

In contrast, 16.7% of the experts reconsidered their voting for re-ranking the principles and re-rating the indicators. Statistical results comparing the second and third-round ratings for the principle show that the p-value was 0.4875, suggesting that there was no significant difference between the rounds. Similarly, statistical analysis was conducted to compare the importance rating of the indicators between the second round and third round. Results showed p-values ranging from 0.3949 to 0.4862, suggesting that there was no significant difference between the rounds.

In the third round, 75% of the experts agreed or strongly agreed on the inclusion of the three indicators. The results suggest that there was enough consensus, and experts were satisfied with the indicators. The MRs ranged from 3.667 to 3.750 and SDs from 0.754 to 0.888. Such results indicate that the overall convergence of the importance ratings can be considered acceptable. The Kappa values for the components of the tool (principle and indicators) ranged from 0.852 to 1.000 (MR = 0.9507, MeR = 1.000). Those values suggest that there was a substantial agreement between the two rounds. The final tool, including one principle and three indicators, is presented in **Table 9.5**.

Table 9.5: Variables for measuring the economic resilience for water supply systems in Tanzania

Principle (MR, MeR) (P-value, Kappa)	Indicators			
	Indicator (MR, SD)	Description	p-value, Kappa score	Rank
4.1 Dynamism *(1.75, 2.00)* *(0.4875, 1.000)*	4.1.1 System investment proportionality *(3.750, 0.754)*	Proportionality of investment for the system from production and transmission system to distribution network such as to ensure uniformity in services and reduce losses	(0.4862, 1.000)	**1**
	4.1.2 Public-private partnership (PPP) *(3.667, 0.888)*	The partnership between the water supply authority and private sector including private water services companies in the delivery of water service during flooding	(0.3949, 0.852)	**2***
	4.1.3 Cost recovery *(3.667, 0.888)*	Recovering the costs of any given expense regarding operation and maintenance of the water supply system through the billing	(0.4862, 1.000)	**2***

Key: MR = Mean Rating, MeR = Median Rating, SD = Standard Deviation

9.5 DISCUSSION

The study adopted a three-stage approach-literature review, pre-assessment, and Delphi survey to develop a tool suitable for assessing the economic resilience for water supply systems in Tanzania. A tool comprising of nine indicators was initially proposed from literature. The tool first derived from literature included features that could assess the internal and external economic resilience of the water supply systems at the microeconomic and mesoeconomic levels. The tool later passed through a pre-assessment exercise involving ten water supply experts. Expert's opinions were analyzed, and the results used to improve the tool. The improved tool comprising of three principles/sub-dimensions; “structure,” “static,” and “dynamism” and 12 indicators was further subjected to a three-round Delphi exercise. The experts who provided feedback were between 16 and 12, which are considered minimally sufficient participants (Hsu & Sandford 2007) for a successful Delphi exercise. The rate of response increased from 72.7% in the first round to 100% in the final round which is in line with (Gargon et al., 2019) who suggest that small size panels are likely to have significantly better response rates. The rates were enhanced by participants contact at the beginning of each round and regular reminders to provide feedback.

Results show that there was no substantial changes or modifications that emerged from the first round-the only comments were associated with “expenditure on water services,” and “system investment proportionality” indicators. Experts suggested that the description of the expenditure on water services should consider other unpaid-resources such as volunteering works, whereas for the systems investment proportionality they suggested changes in the description from *equal* investment to *proportional* investment. Most of the excluded indicators during the second round were associated with data availability, affordability and reliability. Indicators which underscored for those three attributes, could not qualify for inclusion in this study. The three attributes have expressed concerns in Tanzania; for instance, URT, (2008b); World Bank (2018); UN-WATER, (2013) and Nobert and Skinner (2016) concur with the current findings that the lack of consistent and accurate data is a particular limitation in the country. The findings suggest that the three attributes are key factors when choosing indicators in the country and other developing countries.

Most experts were satisfied with the tool, including one principle and three indicators after the second round such that they did not revise their voting in the subsequent round. Consensus building in two iterations is not uncommon as other studies such as Suwaratchai et al. (2011) were able to obtain consensus during the second round. Some experts reconsidered their voting during the third round. Statistical results indicate that the importance ratings for indicators between the second and third rounds had no significant difference. The MSs and SDs suggest that there were better group opinions and that the overall convergence of the importance ratings can be considered acceptable. Moreover, the Kappa statistic values of the tool's components ranged from 0.852 to 1.000. Thus, according to Zhong et al. (2015), the agreement between the two rounds was significant, and consensus had been reached.

The tool underwent significant changes at the end of the Delphi exercise. Excluded indicators (75%) prompted for an automatic omission the "structure," and "static/security" principles/sub-dimensions. That said, dynamism principle associated with how fast the system could recover from flood hazards and return to its normal condition (repair and reconstruction), was in favor of the experts and remained the only principle for the tool. Besides, three indicators "system investment proportionality," "cost recovery," and "public-private partnership" were included in the dynamism principle/sub-dimension of the tool. The first two indicators assess the internal economic resilience; for instance, cost recovery indicates the capacity of the organizations to generate their financial resource through billing, which could facilitate rapid recovery of water services aftermath. The system investment proportionality depicts the efficient use of the financial resources in such a proportion that could not affect the system functionality. The last indicator "public-private-partnership" assesses the external economic resilience describing the adaptive capacity that could be enhanced by assistances from other partners during flooding. In all cases, system investment proportionality is the most important indicator followed by both public-private-partnership and cost recovery indicators. Overall, the findings suggest that the economic function of the water supply at the organizations level is vital for building water supply systems' economic resilience against flood hazards.

The current study was conducted through a review of various international economic resilience attributes from different frameworks and made relevant to Tanzania through experts' judgement elicitation-Delphi survey. Thus, the study entails a more needed beginning for broad agreement about the components of water supply systems' economic resilience against floods in Tanzania. To date, studies on the water supply field in Tanzania focus on water management, climate change studies, and flood risks analysis with limited focus on economic resilience. Thus, the current tool is useful in evaluating the economic dimension of resilience for water supply systems in Tanzania. The tool encompasses a management approach of enabling water supply organizations to provide water supply services sustainably when faced with flood hazards.

The tool can be used by water supply professionals and managers to assess the economic resilience for water supply systems using their internal data. The tool is also useful in identifying priority activities that can assist in enhancing resilience and consequently address future floods. Finally, the tool can work in other developing countries since the agreed measures originated from general concepts of the economic resilience from the literature.

9.6 CONCLUSION

The study developed a tool with a principle and key indicators of the economic dimension resilience for water supply systems in Tanzania. It provides a potential beginning for broad agreement regarding the key components of the economic resilience of water supply systems in Tanzania. The tool can be used for evaluating and informing the priority practices that can assist water supply organizations in Tanzania and other developing countries to address future impacts of flood hazards. After discussing the findings from the previous chapters and the current chapter, it is therefore evident that a multi-dimensional tool incorporating all variables from the five dimensions is much needed. The next chapter attempts to combine the variables into a multi-dimensional tool to measure the resilience of water supply systems in a single assessment.

Chapter 10
A Multi-dimensional Tool for Measuring Resilience of Water Supply Systems in Tanzania

The current chapter is based on the following article:

Sweya, L. N., Wilkinson, S., Mayunga, J., Joseph, A., Lugomela, G., & Victor, J. (2020). Development of a Tool to Measure Resilience against Floods for Water Supply Systems in Tanzania. *Journal of Management in Engineering*, *36*(4), 05020007.

10.1 INTRODUCTION

The rate and magnitude of weather-related disasters such as floods are increasing and are expected to escalate due to climate change impacts (IPCC, 2014). Lifeline systems such as water supply are frequently affected, leading to a lack of water services during and immediately after the events. The most affected population is the poor, particularly in developing countries, including Tanzania (Sweya et al., 2019). As an integral part of the community disaster recovery, the continuity of water supply systems service is required to ensure people's health and wellbeing. Resilience measures cannot be ignored when developing water supply systems in flood-prone countries as they prepare infrastructures, organizations, and communities to be able to survive the impact of the disasters

Holling et al. (1973) first introduced the concept of resilience and defined it as "the measure of the persistence of systems and their ability to absorb change and disturbance and adapting their internal dynamics if needed." To date, the concept has undergone evolutions and applied in various areas of research, including in infrastructures such as water supply. Water supply systems are complex socio-ecological-technological systems comprising of natural, physical, organizational and social networks (Newman et al., 2011), making them more susceptible to disasters (Karamouz et al., 2010). Applying the concept of resilience in the water supply systems needs a better understanding of the multi-dimensional nature of the system to address issues in infrastructure, Organizations, water users, funding systems, and water sources and catchments.

The broader perspective of the water supply in Tanzania, as in other developing countries, shows that systems face diverse resilience problems such as aging infrastructure, imbalanced investment, insufficient rehabilitation or maintenance, lack of understanding of system connectedness, lack of community support, to mention a few (Sweya et al. 2018). In addition, poor planning, poverty, weak infrastructure, poor stormwater drainage systems, and rapid urbanization (Sakijege et al., 2012; Kebede & Nicolls, 2011) in the country exacerbate flooding impacts putting more pressure on the organizations operating the systems. According to D'Lima & Medda (2015), measuring resilience is a suitable approach to help develop appropriate measures to improve systems resilience. Globally, resilience measurement tools have been developed for ecological systems, engineering systems, organizational, community systems, and social systems, but a universal tool that can be used across all systems or all specific systems, e.g. engineering systems is currently non-existent. Such a tool would benefit Tanzania and is the subject of this thesis.

Bruneau et al. (2003) first described the multi-dimensional concept of measuring resilience, and several studies have built on that work to develop tools that meet their requirements. The most recent water supply multi-dimensional tool was developed to address the impacts of earthquakes (Balaei et al., 2018). However, the impacts of earthquakes on water supply systems differs from floods impacts, so the variables of the assessment tools, especially the indicators and measures need to be tailored. For instance, the environmental dimension was regarded as less significant in Balaei et al. (2018) work and did not feature during the assessment, although it is an important aspect and has strong implications on water supply system during flooding. Moreover, the tool was focused and tested in a developed country. Thus, water supply organizations in developing countries such as Tanzania are unable to fully adapt the existing assessment tools to systematically assess their current resilience and be able to develop intervention measures, plan, and prepare for future flood events.

A multi-dimensional assessment tool is proposed to measure water supply system's resilience to the country's flood impacts. The tool helps managers/practitioners in the water sector evaluate resilience weaknesses in the systems, based on which appropriate measures can be developed to enhance the overall system resilience. Development of the tool is discussed in five main sections of this chapter. The following section examines the challenges of defining and measuring resilience. The third section concerns the development of the resilience tool, including the development of the conceptual framework and assessment tools. The tool is operationalized to show how it works in the fourth section, whereas conclusions are drawn in the fifth section.

10.2 THE AMBIGUITY OF THE DEFINITION AND MEASUREMENT OF RESILIENCE

In infrastructure systems, resilience tends to be thought of as the system's ability to reduce the chances of a shock, absorb and recover quickly after the shock (Agarwal, 2015). The efficacy of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event (Soldi et al., 2015). This implies that the concept is dynamic and undergoes many long-term refreshment and redefinition changes (Prior, 2015).

Researchers have presented various options for describing resilience. While resilience has not adopted standard definition given its continued implementation and use in new areas, the typical application is in the understanding of complex systems (Barnes et al., 2012). Several disciplines use the term resilience (Agarwal, 2015; Perry 2013; Eid & El-Adaway, 2016; Hughes & Healy, 2014). Analysis of 32 definitions from various publications and disciplines reveals that there are nine different terms that are frequently used to describe resilience. The terms include anticipate, resist, reduce, withstand, recover, bounce on, adapt, organize itself, and timely recovery: in all cases stability is the key characteristic, in line with Barnes et al. (2012).

Most resilience definitions include the terms absorb/withstand, adapt, and recover, meaning that, the general focus of the definitions is on preventing failure, recovering from the failure and adapting to the new system state after a failure. This is consistent with the general resilience characteristics in the form of absorptive capacity, adaptive capacity, and restorative capacity. Barnes et al. (2012) discuss the definition of resilience into technical, ecological, and social-ecological aspects, with more emphasis on the characteristics, focus, and context. In conjunction with the multi-dimensional nature of water supply infrastructure, any effective resilience definition needs to include stability, recovery, and adaptation across the physical parts, organizations operating systems, customers and the environment within which water sources and catchments exist.

The resilience concept remains ambiguous unless it is measured (Prior, 2015) to bridge the gap between theory and application. "As there is no standard definition, there is no standard resilience measure" (Willis, 2015). Its measurement is complicated by the number of factors required in terms of physical, social, organizational, and cultural aspects (Prior, 2015) and needs a better understanding of the unpredictable events (Hughes & Healy, 2014). A framework (TOSE: technical, organizational, social, and economic resilience) by Bruneau et al. (2003), was the first multi-dimensional framework for measuring resilience against seismic impacts with emphasis on a holistic approach to social and economic systems beyond physical and organizational systems. Various tools have been developed from TOSE (Chang & Shinozuka, 2004; Cimellaro et al., 2016; Hughes & Healy, 2014; Tierney & Bruneau, 2007; Vugrin, 2010) including for the measurement of water supply system resilience, such as Balaei et al. (2018) and Pagano et al. (2017). These studies were used as relevant extracts to inform the current study tool for measuring the water supply systems resilience to floods in Tanzania.

10.3 TOOL DEVELOPMENT

Resilience assessment helps develop appropriate solutions that can be used to reduce systems vulnerabilities to disasters. There are a variety of hazards and failure modes that can affect water supply systems. Resilience assessors require awareness regarding the assessment boundaries. According to Hughes and Healy (2014), the nature of assessment could be an all-hazard assessment based on an event due to any known or unknown hazard. Another is a hazard-specific assessment of resilience to a known hazard. The assessment may further be undertaken at different scales or geographical scope such as regional, local, societal, distal, and networks. Moreover, the assessment may include short-term shock events such as earthquake, tsunamis, and floods or longer-term stresses such as climate-related events (Hughes and Healy 2014).

Generally, two principal approaches for the assessment of resilience are presented in most literature: qualitative assessment and quantitative assessment (Hossein et al., 2016; Hughes & Healy, 2014; Perry, 2013). Qualitative approach refers to resilience assessment methods without numerical descriptions. These methods are divided into conceptual frameworks and semi-quantitative indices; the former provides conceptual insights without quantifying system resilience while the latter consists of a set of questions designed to measure different resilience-based system characteristics on a Likert scale 0-1 or 0% to 100% (Hossein et al., 2016) or 1 to 5 (Hughes & Healy 2014; Morley 2012). If semi-quantitative methods are used, assessment of the characteristics can be made from experts' opinions and further aggregated to obtain a resilience index.

Hossein et al. (2016) classify quantitative approaches as 1. general resilience methods of assessment providing domain-agnostic measures to quantify application-wide resilience; examples are probabilistic approaches and deterministic approaches. 2. Structural-based modelling approaches modelling domain-specific representations of the components of resilience, including optimization models, simulation models, and fuzzy logic models.

Both qualitative and quantitative approaches have been applied to assessing resilience. Hughes and Healy (2014) contrasted the two approaches; quantitative approaches are less flexible, time-consuming, and appropriate to a narrow network and systems assessments, data-intensive and hard to implement. Perry (2013) also indicates that quantitative approaches are confined to small theoretical networks and are somewhat unrealistic and difficult to implement in complex networks. Based on the comparison it is concluded that, although qualitative approaches are subject to interpretation, they are flexible in terms of scale and context, focused on people (operators and managers), information, technology, and facilities, thus, providing a broader process or organizational benefits.

The current study is supported by a management approach aiming to enhance resilience against the impacts of floods in Tanzania urban water supply systems. The study applies a context-specific approach, including hazard-specific nature of assessment for short-term shock events (floods) in Tanzania's urban water supply systems. With a management approach in mind, as it focuses on people, a qualitative tool provides a more suitable assessment. Besides, the qualitative tool is flexible and easy to implement, allowing for application in more than 20 urban water supply systems in the country, and in other developing countries. Moreover, Tanzania, like other developing countries, faces a data deficit, making qualitative assessment a good candidate for this study. The proposed qualitative tool entails two parts; a conceptual framework, and assessment tools. The assessment tools comprise of a semi-quantitative assessment approach with specific measures and scores to be able to quantify the resilience into an index; the second part includes processes such as 1. Developing measures and measurement scales, 2. Weighting of the variables, and 3. Variables aggregation (see **Figure 10.1**)

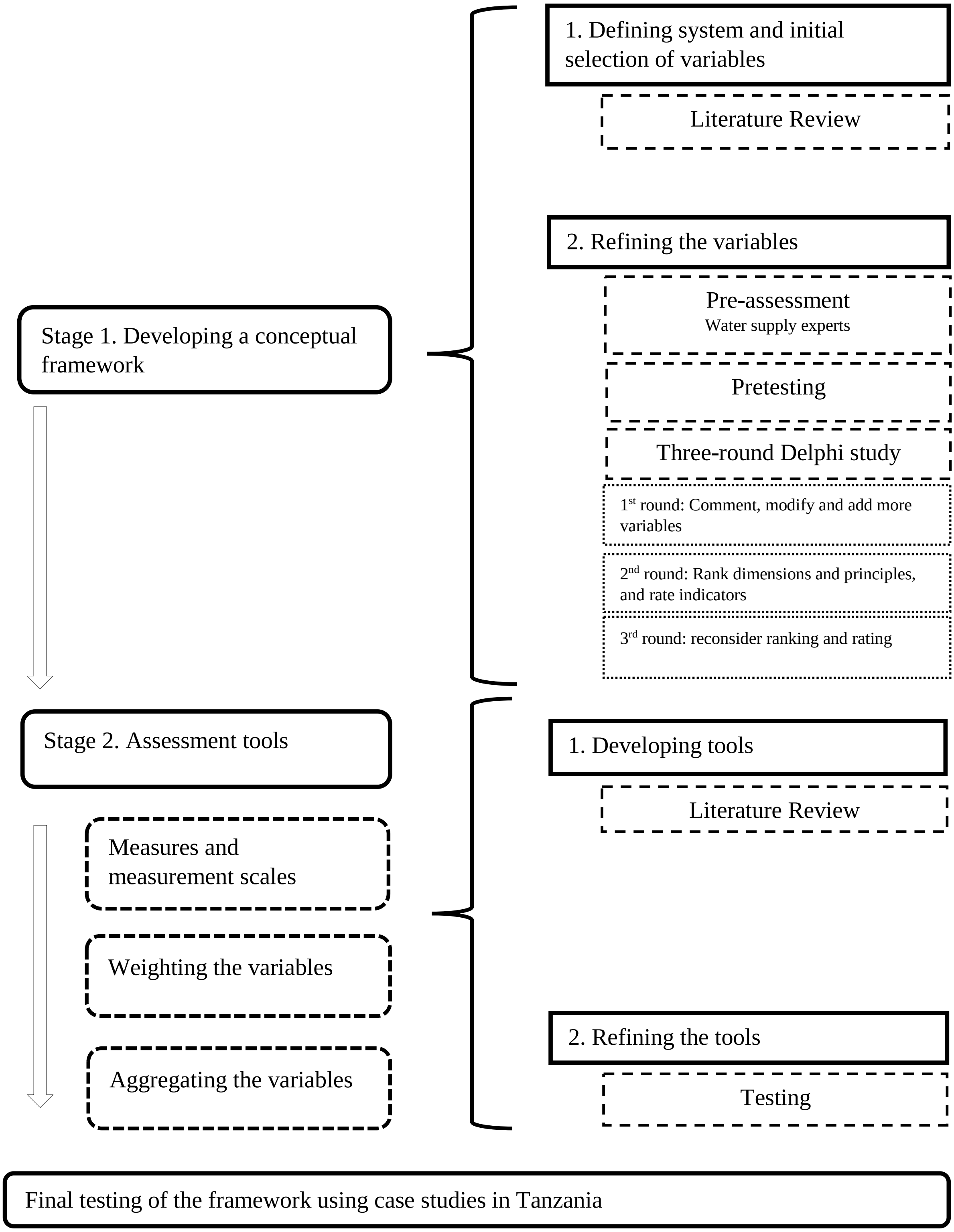


Figure 10.1: Resilience tool development processes for water supply systems in Tanzania

10.3.1 Developing a conceptual framework

Most frameworks conceptualize resilience in the same way, focusing on similar attributes that reduce vulnerability and enhance resilience (Mayunga, 2007). Development of frameworks as such is closely linked to that phenomenon. There are two main approaches to frameworks development: a bottom-up approach, and a top-down approach, and most studies have used one or both approaches. Bottom-up approaches are designed to engage communities or experts to develop resilience goals and increasing capacity to achieve them (Cutter 2016). The conceptual frameworks developed through this approach, are not easily generalizable, and indicators can vary in different locations (Balaei et al., 2018). On the other side, top-down approaches involve initial extensive literature review to identify common principles that can guide the resilience assessment process. Through the process, dimensions of resilience are established, which then allows an indicator identification process. Subsequently, experts are involved in identifying indicators that practitioners and policymakers consider important (Cox and Hamlen 2014).

Different frameworks also include different assessment levels; for instance, frameworks that use a single level assessment consisting of a set of indicators (Cabell & Oelofse, 2012), and frameworks that have two assessment levels consisting of dimensions/capital/principles and performance measures/indicators/measurements (Bruneau et al. 2003; Mayunga 2007; Perry, 2013). Others are frameworks with three assessment levels such as dimensions, principles/capacities and categories/indicators (Hughes & Healy 2014; Balaei et al., 2018), domains, dimensions, and indicators (Cox & Hamlen 2015), and frameworks with four assessment levels including defining system in analysis, dimensions, quantitative measurements, and capacities (Vugrin 2010). Level differences suggest that there is no consensus on the appropriate level of assessment. Comparison of information on which assessment level is the most useful is limited. The higher levels, however, are likely to further appreciate the resilience concept.

The current study adopts the top-down framework development approach that uses literature review to identify variables and Delphi study to involve experts in refining the variables and defining key indicators. The proposed conceptual framework comprises of four assessment levels, including 1. Defining the system in analysis, 2. Identification of dimensions, 3. Identification of principles, 4. Selection of indicators.

Defining system in the analysis

Water supply systems are a combination of natural, technological and socio-economic elements consisting of physical infrastructure (Van Leuven, 2011), water sources (Karamouz, Sadaati & Ahmadi, 2010), and have a direct relationship with the community and managing organizations (Newman et al. 2011). The primary function of the water supply systems is *water service* provision. Water supply and sanitation authorities (WSSAs) in Tanzania are the lawful organizations for *operating* the physical infrastructures with a principle goal of providing customers with *water service* of acceptable standards. WSSAs, through systems development and maintenance, are responsible for ensuring the *functionality* of the physical infrastructure. Functionality is also enhanced by ensuring the *wellbeing of the environment* through the protection and maintenance of water sources. Moreover, the WSSAs are accountable for ensuring *revenue collection* and creating a harmonious relationship with other stakeholders.

Water supply systems in Tanzania depend on primary aspects such as the functionality of the physical infrastructure, organizational ability to operate the infrastructures, environmental wellbeing, and revenue collection, to achieve an acceptable standard of service provision. Service provision is the output of the water supply systems and has been used by researchers such as Balaei et al. (2018), Choi et al. (2019) and Perry (2013) as a measure of resilience. In the current study, the acceptable service standard is consistent with the Tanzania Water and Wastewater Design Manual 2009 referring to the water quality standard based on international standards or criteria set by WHO, and a minimum pressure of 5m at the draw of points.

If flood hazards strike the water supply systems, they disrupt all or part of the primary aspects. System disruption is referred to as the lack of service associated with the failure of the above mentioned four aspects. Depending on the magnitude of the hazards, the systems would need rapid water service restoration and recovery after interruption. Recovery is needed when major disruptions have occurred. Recovery includes restoring water service through the recovery of system functionality, the organization’s ability to operate the system and collect revenue, and environmental restoration or adaptation. The concept of resilience, therefore, contains both *strength* and *restorability* attributes (Balaei et al., 2018); although these attributes may not be enough to include the long-term environmental restoration needs. Sometimes water sources, catchments, and recharge areas are affected such that could barely be restored, making *adaptation* a crucial requirement. Thus, in the current study, the water supply system resilience refers to—the ability to continue providing water service with acceptable standards to consumers during flood emergencies, restoring service or undertaking recovery and adaptation activities if major disruptions occur.

Identification of suitable dimensions

Bruneau et al. (2003), used four interrelated dimensions for measuring community resilience: technical, organizational, social, and economic (TOSE). The TOSE dimensions have not been used consistently throughout; they have been modified to suit the researchers' requirements. For instance, for measuring the resilience of 18 different infrastructures and economic systems, Vugrin et al. (2010) added two more dimensions (environmental and ecological). Based on a narrowly focused transport system, Hughes and Healy (2014) used only two dimensions; technical and organizational to measure the resilience of New Zealand's transport infrastructure.

Regarding water supply, Barnes et al. (2012) indicate that any careful assessment of water supply system resilience requires three domains to be regarded as key aspects; ecological, technical, and socio-technical. Howe et al. (2011) cited in Johannessen & Wamsler (2017) suggest that the water supply systems involve multiple scales such as consumers, institutions "service providers and regulators," technologies, and ecosystems. Both studies are useful and relevant for understanding the high level of dimensions of resilience. In assessing the resilience of water supply systems, both studies consider technical, organizational, social, and ecological aspects as potential dimensions. Balaei et al. (2018) further propose that water systems can be influenced by economic factors at both country and individual levels and use five dimensions; *technical, organizational, social, economic, and environmental* to measure water supply resilience to the impact of earthquakes. To classify water systems resilience problems in Tanzania, a similar combination of dimensions was used (Sweya et al. 2018). Thus, because of the broadness and interactive nature of water supply systems, these dimensions seem adequate and comprehensive enough and are proposed to measure the resilience of water supply systems against the country's flood impacts.

Identification of suitable principles

According to Bruneau et al. (2003), for different systems, the dimension of resilience can be assessed by various performance measures. Certain researchers refer to these measures as aspects of measuring resilience (Agarwal, 2015), determinants of resilience (Tierney & Bruneau, 2007), and principles of resilience (Hughes & Healy, 2014). The measures are consistently referred to as principles of resilience in the current study. These principles are specific mechanisms and behaviors that can make a system resilient. Such principles apply in the comprehensive resilience measurement process and provide insights into how organizations can improve the systems' resilience.

The principles applied to measure the resilience of different systems are common. Robustness and redundancy are the most used principles for enhancing the physical systems' performance (Bruneau et al., 2003). Also relevant are other emerging principles such as reliability (Proag, 2016), safe to fail (Hughes & Healy, 2014), and flexibility (Mugume et al., 2015). Reliability, remain functioning (de Bruijn et al., 2017), and safe-to-fail seem to have the same focus; since safe designs of urban water systems have largely focused on enhancing systems' reliability 'to keep the system in operation.' The focus is on ensuring systems remain functioning during extreme events while acknowledging that the possibility of failure cannot be eliminated altogether and is typical for resilience thinking (de Bruijn et al., 2017). Thus, *robustness*, *redundancy, flexibility*, and *safe-to-fail* principles are proposed for assessing the resilience in the technical dimension of the water supply.

McManus (2008) identified three key principles to determine an organization's resilience; situation awareness, management of keystone vulnerabilities, and adaptive capacities. The principles were reorganized to *change ready*, *networks and relationships*, and *leadership and culture* (Resilient Organizations, 2012 cited in Hughes and Healy, 2014). Such principles were further applied by Hughes and Healy (2014) to measure the organizational resilience for transport infrastructure. Similar principles are proposed to measure the organizational resilience for water supply systems in Tanzania.

The economic resilience takes place at three levels; microeconomic level, mesoeconomic level, and macroeconomic level (Eid & El-adaway, 2016; Rose, 2007, 2013 & 2017). It is further classified as static and dynamic; the former refers to the efficient use of resources at a particular point and time, while the latter refers to the repair and reconstruction that affect the economy's time-path. Sharif (2016) describes structure, security/static, and dynamism as useful principles to assess economic resilience. The current study is best suited at the microeconomy and mesoeconomy levels, which can be assessed based on the *structure, security/static*, and *dynamism* principles in each context.

Moreover, a proposed list of principles of social dimension includes *social structure, togetherness*, *safety, and wellbeing* (Sharif 2016), *education, and preparedness* (Jovanovic et al., 2016). Sharif (2016) also identified *natural assets* (environment and resources) as a sub-domain for measuring the environmental dimension of resilience. Others are *environmental capacity*, ecosystem sensitivity, and water resources sensitivity, which Brenkert & Malone (2005) referred to as sectors. The last two can be reorganized to produce one principle known as *environmental resources sensitivity.* Furthermore, *natural floods attenuation* can be added to the environmental dimension principles list considering the amount of land which is wetland and its capacity to combat floods.

Selecting Appropriate Indicators

The use of indicators is one of the most prominent approaches for assessing resilience (Cutter, 2016). Several assessment methods use indicators due to difficulties in quantifying absolute terms without external validation (Cutter, 2008). In this regard, various studies have tried to define indicators in different ways, in which ambiguity and complications exist in understanding the general concept of indicators (Birkmann, 2006). A review of Balaei et al. (2018), Birkmann (2006), and Cutter (2010; 2016) suggest that indicators are representations of the reality such as a systems' characteristic, a situation, quality, or serviceability. Such representations can affect a system's resilience to disaster impacts such as floods. Indicators can, therefore, be defined as "variables that are the operational representation of serviceability, quality, or a characteristic of a system either in technical, organizational, social, economic, or environmental aspects that could potentially affect its disaster resilience (Balaei et al., 2018)" which is floods for the current study.

According to Cutter (2008), indicators are typically used to assess relative resilience levels, either to compare places or to analyze resilience over time. In that regard, indicators have three major functions (Birkmann, 2006); 1. Knowledge and understanding which involve identifying and visualizing different characteristics or evaluating political strategies and monitoring their implementations 2. Knowledge for action, involving the provision of relevant information to disaster managers for a sound decision-making process and 3. Reducing vulnerability or "enhancing resilience." Most other functions, including "priority-setting," "awareness-raising" "background for actions," and "trend analysis" (Birkmann 2005; Cutter 2016), come under these three categories.

Selecting the right indicators for use in assessing a system's resilience is a vital process. Indicators from literature need to meet the three main functions listed earlier and must be able to represent one of the four phases of disaster management: mitigation, preparedness, response, and recovery. Moreover, based on the current conceptual framework, indicators need to represent the specific mechanisms and behaviors that make a system resilient, referring to this study to principles of resilience. Based on these conditions, 52 indicators were derived from literature and proposed to measure Tanzania water supply systems resilience across the five dimensions.

More criteria could be used to refine the indicators and make them relevant to the study area. Various criteria have been established as guidelines for refining indicators. Transparency, data availability, data affordability, relevancy, reliability, validity, sensitivity, and simplicity are the most used criteria. Of these, Morley (2012) applied five to evaluate the resilience in the water sector, making them good candidates for the current study. In addition, the relevance of the indicators is important to ensure literature derived indicators are made appropriate to the system. For the current study, six criteria are proposed including *relevance*, the degree to which indicators are appropriate to this study, *affordability* referring to data accessibility or generated at reasonable cost or level of effort, *availability* meaning data is easy to collect and measure, *reliability* data is consistent over time, *simplicity* indicator is decision-makers' ease of understanding, and *transparency* referring to the possibility of reproducing and verifying data.

Moreover, Birkmann (2006) and Cutter (2008) suggest validity as an important criterion indicating the representation of resilience dimension of interest (Cutter 2008). In a nutshell, validity is a mother criterion that all other criteria will apply to. If a thorough assessment is conducted using the previous six criteria, then the indicator will be considered valid. Processes such as those involving experts review would be useful in offering a basis for assessing the validity using the six criteria as presented in the next section.

Refining the conceptual framework variables

Originally, the literature extracted five dimensions and 52 indicators; the variables passed through pre-assessment and pretesting in Dar es Salaam. The results were used to improve the dimensions and indicators; as such, the number of indicators improved to 69, which were also grouped into 19 principles across the five dimensions. A three-round Delphi assessment using 12 to 22 water sector experts, was carried out to refine and make the indicators, principles, and dimension further relevant to Tanzania water supply systems. The experts ranked the importance of the principles and dimensions and rated the indicators' importance. The experts applied the six attributes "relevance, availability, affordability, reliability, simplicity, and transparency" as useful indicator rating guidelines. Indicators were eligible for inclusion when at least the average of 70% of experts scored agree (4) and strongly agree (5) across the six attributes. At the end of the third round, experts reached a consensus, on five dimensions, 18 principles, and 47 indicators. The consensus was attributed with p-values ranging from 0.3419 to 0.4876, suggesting that there was no significant difference in the importance of the dimensions, principles, and indicators between the second round and the third round. The mean indicator ratings ranged from 3.667 and 4.1667 with standard deviations from 0.38925 to 0.96531, suggesting that the overall convergence of the importance rating could be acceptable. Moreover, elements were characterized by kappa scores between 0.742 and 1.000 (mean = 0.9474, median 1.000); the values suggest a substantial agreement between the second and third rounds. The refined variables of the conceptual framework are presented in **Table 10.1.**

10.3.2 Developing the assessment tools

This section addresses specific tools for measuring the water supply systems resilience based on the "conceptual framework" developed earlier. It comprises a detailed assessment using a variety of measures combined to generate a resilience score from 5 (very high resilience) to 1 (very low resilience): (5) Very high resilience – meets all the requirements (4) High resilience – acceptable performance in relation to a measure (s), some improvements could be made, (3) Moderate resilience – less than desirable performance and specific improvements should be prioritized (2) Low resilience – poor performance and improvement required (1) Very low resilience – very poor performance and extensive improvement measures required.

Table 10.1: Refined variables of the conceptual framework for assessing the resilience of water supply systems in Tanzania

Dimensions	Principles	Indicators
1.0 Technical	1.1 Robustness	1.1.1 System maintenance
		1.1.2 System renewal
		1.1.3 System design
		1.1.4 Standards/ codes
	1.2 Redundancy	1.2.1 System decentralization
		1.2.2 System redundancy
	1.3 Flexibility	1.3.1 System future expansion capability
		1.3.2 Critical spare parts and equipment availability
		1.3.3 Connectedness of the system
	1.4 Safe-to-fail	1.4.1 Design approaches in guidelines
2.0 Organizational	2.1 Change readiness	2.1.1 Awareness
		2.1.2 Emergency Response Plan (ERP)
		2.1.3 Communication and warning
		2.1.4 Planning strategies
		2.1.5 Proactive posture
	2.2 Leadership and culture	2.2.1 Leadership
		2.2.2 Political will
		2.2.3 Engagement and involvement
		2.2.4 Decision making
		2.2.5 Innovative and creativity
	2.3 Legal framework and institutional set-up	2.3.1 Organizational structure
		2.3.2 Laws and policies
	2.4 Network and relationships	2.4.1 Learning
		2.4.2 Effective partnership
		2.4.3 Leveraging knowledge
		2.4.4 Internal resources
3.0 Environmental	3.1 Environmental resources sensitivity	3.1.1 Human encroachment
		3.1.2 Water use
	3.2 Environmental capacity	3.2.1 Population density
	3.3 Natural floods attenuation	3.3.1 Protection of wetlands
		3.3.2 Control of urbanization
	3.4 Natural assets	3.4.1 Accessibility of freshwater resource
		3.4.2 Quality of water sources
		3.4.3 Reduction of environmental impacts
		3.4.4 Soil erosion protection
4.0 Economic	4.1 Dynamism	4.1.1 System investment proportionality
		4.1.2 Public-private partnership (PPP)
		4.1.3 Cost recovery
5.0 Social	5.1 Education	5.1.1 Adoption of new technologies
		5.1.2 Community awareness
	5.2 Preparedness	5.2.1 Mitigation plan
		5.2.2 community participation
	5.3 Social structure	5.3.1 Location of houses
		5.3.2 Population composition
		5.3.3 Level of education and skills diversity
	5.4 Safety and wellbeing	5.4.1 Preventive health measures
	5.5 Togetherness	5.5.1 Shared water facilities

Scaling the indicators

Each indicator consists of at least one literature derived measure. Other measures were developed in line with international and local needs in achieving water supply goals. For instance, the measure for "accessibility of water resources" is developed based on the internationally accepted Sustainable Development Goals (6) "the proportion of the population using safely managed water resource." The measure for "public-private-partnership" aligns with the achievements of the *Tanzania Water Policy 2002* sections 3 (x) and 4.4 (URT, 2002), and the *Water Supply and Sanitation Act 2009* section 4, 1(f). The measure for assessing "control of urbanization" comply with the enforcement of the *Water Resources Management act 2009* section 34&37 for water sources protection such that no human activities exist within 60 meters from the water sources.

Each indicator measure includes five (5) criteria, generally representing the graduated level of performance. That's to say, the initial scoring criteria for the measures are based on the Likert values of one to five; (1) describe conditions leading to poor resilience level, and (5) describe conditions for high resilience levels (Morley, 2012). Some example measures and measurement scales for "flexibility principle" in the technical dimension are shown in **Table 10.2**, whereas more measures and measurement scales are in **appendix 4**. The average scores can then be calculated for each indicator's measure, followed by the weighted average score and aggregated score for a principle, or dimension (Hughes & Healy, 2014; Morley, 2012).

Table 10.2: Examples of resilience measures and measurement scales (from "flexibility" principle in the technical dimension)

Indicator	Measure	Measurement scale
System future expansion capability	Percentage of components with an option for future expansion	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%
Critical spare parts and equipment availability	Evidence that spare parts are readily available and accessible during emergencies	1. No clear information 2. Most are ordered from abroad and takes a few weeks 3. Most are ordered from abroad and takes a few days 4. Most are locally available but impeded by the purchasing procedures 5. Most are locally available, and simple purchasing procedures are followed during emergencies
Connectedness of the system	1. Percentage of the service area that is likely to receive service from more than one scheme.	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%
	2. The proportion of looped distribution network versus dead end distribution network in the service areas (LS/DeS)	1. No information 2. <40% large part of the service areas has a dead-end distribution network 3. 40 – 60% the two networks co-exist in nearly the same proportion 4. 60 - 80% Improved efforts for implementing the looped system 5. 80 – 100% The looped distribution network is dominant

Weighting the Variables

Cutter et al. (2010) suggest that there is no theoretical or practical justification for allocating differing importance across indicators. Nonetheless, assigning weights to variables is important because it allows the user to determine which variable is important than the other (Mayunga 2007; Hughes & Healy 2014). Mayunga indicates that there are at least five approaches that can be used to assign weights to variables: weights driven by theoretical consideration, empirical weighting approaches, weights determined by policy relevance, consensus-determined weights, and weights that are entirely arbitrary in which assigning equal weights falls. In all cases, there is no a direct answer for which one is the best method due to a limited discussion on the advantages and disadvantages of the methods; although, it would be more beneficial to combine methods (Mayunga, 2007).

Choosing the weighting approach, as indicated earlier, is tricky as it depends only on the factors and the situation where the method is applied. The current study applies a combination of methods by grouping the weighting of attributes in three categories: assigning indicators weights, assigning principles weights, and assigning dimensions weights. In the first category, weights are assigned based on experts' consensus whereas in the second category weights are assigned based on the experts' consensus and empirical approaches, and in the third category an arbitrary method is applied, and dimensions are assigned equal weights.

Assigning weights to indicators

The percentages during the final round of the Delphi exercise determined the consensus for inclusion of the indicators and formed a basis for understanding the importance of the indicators, thus, were used to determine the weightings. In this case, the indicator that a large percent of experts included is considered the most important and weights more than others. For instance, "dynamism" principle in the economic dimension has three indicators; all indicators were accepted during the final round by a score of 75% of experts each. That means they can be considered to have equal weights, 33:3%:33.3%:33.3%. A simplified equation to this approach is presented below.

$$w_i = \frac{X_i}{\sum_{i=1}^{n} X_i} x100 \qquad (10.1)$$

Where, X_i = the percentage (%) of experts who reached consensus for inclusion of the indicator *(i)* in the study

w_i = the weight assigned for indicator *(i)*

and n = the number of indicators in the respective principle.

Equation (1) can be applied to assign weights to all indicators in each principle across the whole tool.

Assigning weights to principles

In this category, two approaches are applied-the experts' consensus and empirical equation. The principles importance ranking results based on experts' consensus provide a basis for establishing the ratios of importance between the variables. The ratios are then used in the equation to calculate variables weightings. Morley (2012) equation (4) was updated to suit the current study's requirements, which contain a different number of variables (i.e., principles) for different dimensions. In this study, each level of importance is considered as a separate group and is assigned a ratio. For instance, five principles are included in the "social" dimension, the level of importance is from 1 for the most important principle to 5 for the least important principle, which is equivalent to five groups. The modified equation 2 and 3 can be used to calculate the weights for principles in respective dimensions.

$$w_j = \frac{X_1(Y_1)_j + X_2(Y_2)_j + X_3(Y_3)_j + \cdots X_n(Y_n)_j}{N} \tag{10.2}$$

Where, X_1, X_2, X_3, and X_n = Ratios of importance of the groups depending on the number *(n)* of principles in the dimension. The ratios are obtained based on the experts' consensus on ranking scores, and their sum should be 100%.

Y_1, Y_2, Y_3, and Y_n = the number of times the principle *(j)* is assigned to ranking levels from 1 the highest level to *n* the lowest level.

N = Total number of assignments

w_j = weight of the j^{th} principle

Equation (2) can be reorganized to equation (3) which is universal and could be used to calculate the weightings for all principles across the tool.

$$w_j = \frac{\sum_{i=1}^{n} X_i(Y_i)_j}{N} \tag{10.3}$$

Assigning weights to dimensions.

According to Balaei et al. (2018), assigning different weights to dimensions leads to a situation such as the second-ranked dimension's most important variable being more important than the first-ranked dimension's least important variable. As such, an arbitrary approach is applied to assign weights for dimensions. Assigning equivalent weights to dimensions prevents double-weighting of the principles and indicators, leading to poor ranking.

Aggregating the variables

Water supply systems' overall resilience level is derived by aggregating the weighted attributes across four levels: indicators level, principles level, dimensions level, and water supply overall resilience level. The initial score corresponds to each measure. If the indicator has more than one measure, it uses the average score to establish the particular indicator's unweighted average score. For instance, "connectedness of the system" indicator from the technical dimension has two measures; thus, the average unweighted score must be calculated. The unweighted score is then multiplied by the indicator weight to establish the indicator resilience (R_I). In the second level, the principle resilience (R_P) is calculated as the sum of the weighted indicator resilience, depending on the number of the indicators in the respective principle. In the third level, dimension resilience (R_D) is derived from the sum of the weighted principle resilience depending on the number of principles in that dimension. Lastly, the overall system resilience (OSR) is the sum of the five-dimensional weighted resilience; technical, organizational, social, economic, and environmental. The following are simplified equations indicating the resilience score and aggregation at each level. The summary of the tool is presented in **Figure 9.2**.

Leve 1: *Indicator Resilience (R_I)*

$$R_{Ii} = w_{Ii} R_{UIi} \tag{10.4}$$

$$R_{Ii} = w_{Ii} \left(\frac{\sum_{i=1}^{n} S_{ci}}{n} \right) \tag{10.5}$$

Where, R_{Ii} = the indicator resilience (weighted average),

w_{Ii} = the weight of the indicator i

R_{UIi} = the average unweighted score of an indicator i

S_{ci} = the individual score of a measure for an indicator

n = number of measures in the indicator i

Level 2: *Aggregated principle resilience (R_P)*

$$R_{Pi} = \sum_{i=1}^{n} R_{Ii} \tag{10.6}$$

Where, R_{Pi} = the principle resilience,

R_{Ii} = the indicator resilience,

Level 3: *Aggregated dimension resilience (R_D)*

$$R_{Di} = \sum_{i=1}^{n} w_{Pi} R_{Pi} \tag{10.7}$$

Where, R_{Di} = the aggregated dimension resilience,

R_{Pi} = the aggregated principle resilience,

w_{Ii} = the weight of the principle i

Level 4: *Overall system resilience (OSR)*

$$OSR = (w_{TD}R_{TD} + w_{OD}R_{OD} + w_{SD}R_{SD} + w_{ED}R_{ED} + w_{ENVD}R_{ENVD}) \tag{10.8}$$

Where, OSR = the overall system resilience,

w_{TD} = the weight of the technical dimension

R_{TD} = the aggregated resilience for technical dimension

W_{OD} = the weight of the organizational dimension

R_{OD} = the aggregated resilience for organizational dimension

w_{SD} = the weight of the social dimension

R_{SD} = the aggregated resilience for social dimension

w_{ED} = the weight of the economic dimension

R_{ED} = the aggregated resilience for economic dimension

w_{ENVD} = the weight of the environmental dimension

R_{ENVD} = the aggregated resilience for environmental dimension

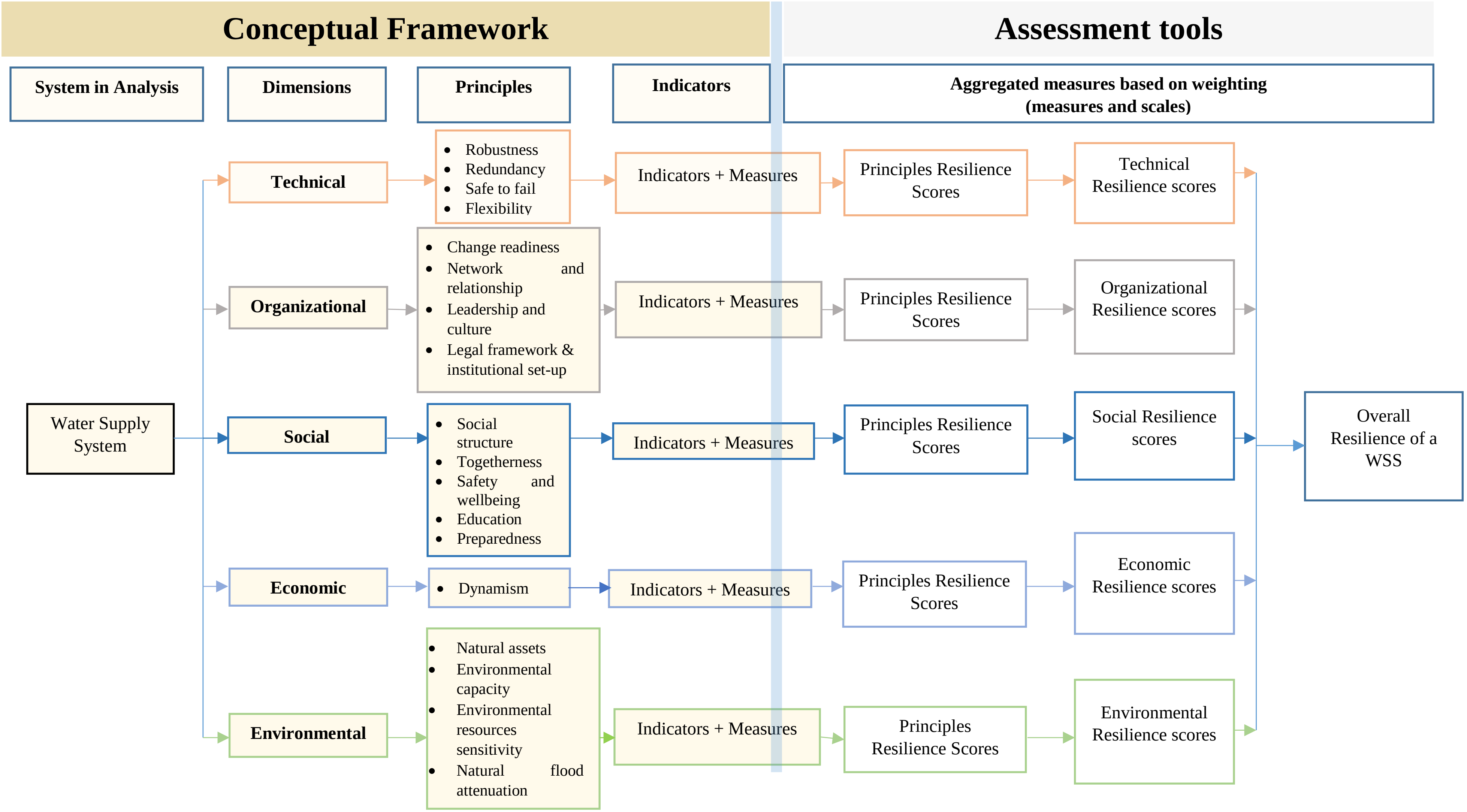


Figure 10.2: Summary of the tool for measuring the resilience of water supply systems in Tanzania

10.4 PUTTING THE TOOL INTO OPERATION

The tool was evaluated in two Tanzania water supply authorities to determine the tool's workability in the technical, organizational, economic, and environmental dimensions. One hundred questionnaires were conducted to head of households whose houses are regularly affected by floods. The questionnaires were used to evaluate the validity of the tool in the social dimension. One senior technical staff from each WSSA was asked to initially score the measures based on the five performance criteria. The staff also coordinated the information required from other departments, as to inform all four dimensions: technical, organizational, economic, and environmental (TOEE). Questionnaires were analyzed for the percentages that were later used in the social dimension initial scoring process.

The initial scores were used to initiate the assessment process; they represented the unweighted indicator resilience; the average score was calculated for indicators that had more than one measure. The unweighted principle resilience (R_{UP}) was calculated as the average of unweighted indicator resilience (R_{UI}), so is the unweighted dimension resilience (R_{UD}) as the average of unweighted principle resilience. Assigning weights for the indicators and principles followed the application of the simple equations 1 & 3, respectively, as presented in the previous section. For instance, the "flexibility" principle has three indicators: "system future expansion capability," "critical spare parts and equipment availability," and "connectedness of the system." The percentages of experts reached consensus for inclusion of those indicators during final round Delphi study are 91.7%, 83.3%, and 83.3% respectively; these percentages were used to deduce the weightings w_1, w_2, and w_3 by using equation 1. Thus, $w_1 = 36\%$, $w_2 = 32\%$, and $w_3 = 32\%$ (see an example for w_1 below)

$$W_1 = \left(\frac{91.7}{91.7 + 83.3 + 83.3}\right) X100 = 36\% \qquad (10.9)$$

An example of the technical dimension is used for assigning weights to principles, which has four principles ranked from 1. Robustness, 2. Redundancy 3. Flexibility to 4. Safe-to-fail. The ranking levels relating to the importance groups for the principles were used to establish the ratios (*X*). Depending on the number of groups, the hypothesized ratios in **Table 10.3** were used. For four groups like in the technical dimension, the ratios are 40%, 30%, 20%, and 10%. Values of (*Y*) correspond to the number of times the principle (*j*) was assigned to a group of importance (1) to (4) and (*N*) is the total number of experts involved in the ranking process. Out of 12 experts, three (3) could not complete the ranking properly, thus, *(N = 9).*

Taking an example of "robustness," the number of times the principle was assigned to the four groups are $Y_1 = 4$, $Y_2 = 2$, $Y_3 = 3$, $Y_4 = 0$. Thus, applying equation (3) the weighting for "robustness" is $w_1 = 31\%$ (see the example below). When the same process is conducted for "redundancy," "safe-to-fail," and "flexibility," their weightings become $w_2 = 26\%$, $w_3 = 23\%$, $w_4 = 20\%$ respectively. All other weightings for the principles across the whole tool followed the same process.

$$w_1 = \frac{(0.4x4) + (0.3x2) + (0.2x3) + (0.1x0)}{9} = 0.31 = 31\% \qquad (10.10)$$

Table 10.3: Hypothetical ratios (X) for different groups of importance

	Ranking (importance groups)					
	1	**2**	**3**	**4**	**5**	
Ratios (5 groups)	30	25	20	15	10	100
Ratios (4 groups)	40	30	20	10		100
Ratios (3 groups)	50	30	20			100
Ratios (2 groups)	60	40				100
Ratios (1 group)	100					100

The arbitrary approach was adopted to assign weights to dimensions thereby assigning equivalent weights: 20%, 20%, 20%, 20%, and 20% for technical, organizational, social, economic, and environmental dimensions. Weighted resilience was then calculated and aggregated across the four levels. For instance, the unweighted indicator resilience (R_{UI}) were multiplied by the weightings to obtain the weighted indicator resilience (R_I). The aggregated principle resilience (R_P) were deduced by calculating the sum of the weighted resilience of indicators. Similarly, the aggregated dimension resilience (R_D) were deduced by calculating the sum of the weighted principle resilience. Lastly, the overall system resilience (OSR) was calculated as the sum of the weighted dimension resilience (see an example in **Table 10.4**).

Table 10.4: An example taken from the technical and economic dimensions for aggregating the variables

Principle	Indicators	Indicator score: Mean score R_I	Indicator score: Weights w	Indicator score: Weighted score $w \times R_I$	Principle score: Aggregated score R_P	Principle score: Weights w	Principle score: Weighted score $w \times R_P$	Dimension score: Aggregated score R_D	Dimension score: Weights w	Dimension score: Weighted score $w \times R_D$	OSR Aggregated score
Technical dimension											
1.1 Robustness	1.1.1 System maintenance	2	0.28	0.56							
	1.1.2 System renewal	1	0.26	0.26							
	1.1.3 System design	3	0.23	0.69							
	1.1.4 Standards/ codes	3	0.23	0.69	2.20	0.31	0.68				
1.2 Redundancy	1.2.1 System decentralization	4	0.53	2.12							
	1.2.2 System redundancy	2	0.47	0.94	3.06	0.26	0.79				
1.3 Flexibility	1.3.1 System future expansion capability	5	0.36	1.80				2.45	0.20	0.49	
	1.3.2 Critical spare parts and equipment availability	4	0.32	1.28							
	1.3.3 Connectedness of the system	2	0.32	0.64	3.72	0.20	0.74				
1.4 Safe-to-fail	1.4.1 Design approaches in guidelines	1	1.00	1.00	1.00	0.23	0.23				
Economic dimension											
1.1 Dynamism	1.1.1 Public-private partnership	3	0.33	0.99							
	1.1.2 Cost recovery	5	0.33	1.67							
	1.1.3 System investment proportionality	3	0.33	0.99	3.66	1	3.66	3.66	0.2	0.73	

Note: OSR = Overall System Resilience

Using the same approach, other dimensions' weighted scores were calculated and then aggregated to the OSR = 2.8 ≈ 3.0 using equation eight as shown below.

$$OSR = (0.2\ x\ 2.45) + (0.2\ x\ 2.3) + (0.2\ x\ 2.4) + (0.2\ x\ 3.66) + (0.2\ x\ 3.2) \\ = 2.8 \qquad (10.11)$$

Most information used for the initial scoring process in the technical, organizational, and economic dimensions came from internal data. The only information that was needed from other agencies is the existence and effectiveness of the early warning systems, in this case, the assessor needs to liaise with the Tanzania Meteorological Agency (TMA) to obtain the most up-to-date information. There will be a need for close cooperation between the WSSA and the respective Basin water office, which is not uncommon, to enhance the scoring process in the environmental dimension as most information is available at the Basin water office. The measure for "accessibility of water resources" such as the proportion of the population using safely managed water sources is available at the Ministry of Water and EWURA, whereas, measures for "human encroachment" such as the percentage loss of forest cover of natural landscape can be obtained from the Tanzania Forest Agency (TFS). Moreover, the information for scoring the social dimension is readily available by conducting user surveys through WSSAs billing and communication systems.

The current tool variables cannot have equal level of importance; this is evident from the experts' opinions gotten during the Delphi study. The introduction of weightings is basically for that reason; variables with bigger weights tend to have a strong influence on the resilience index and need more priority than small weights variables. Unweighted variables and weighted variables also varied. The discrepancy was attributed to the weighting's differences; in some instances, less important variables with high initial scores ended up with higher weighted values than high important variables that were lowly scored. This suggests that the influence of weightings should be looked at individual variables to understand the importance of one variable over another. That influence may not be useful and could mislead when trying to compare the weighted values. The aggregated values did not differ significantly when compared to unweighted average values, meaning that, the weightings did not affect the results. While the weighting scheme used in the current study is highly reliant on experts' opinions, it may not effectively reflect the priorities of the individual WSSA. Thus, the organization may need to establish weightings depending on their own priorities.

The tool's result indicates the water supply system's resilience level. It clearly outlines the areas requiring decision-making for improvement. For instance, the technical dimension scored 2.45 ≈ 3.0, meaning that, the system has moderate resilience with less than desirable performance, and specific improvements should be prioritized. In this case, "robustness" is the principle that needs immediate intervention and most specifically by improving the "system renewal" through establishing renewal and upgrade plans linked to resilience for critical assets and making sure they are effectively implemented. Also, by improving "system maintenance" through the establishment and implementation of audited annual inspection processes for critical assets and ensuring that corrective maintenance is completed when required. Similarly, the economic dimension scored 3.66 ≈ 4.0, meaning that, there is high resilience and acceptable performance in relation to a measure, however, strong public-private-partnership (PPP) with long-term contracts is needed, and system components require the same proportion of investment.

The tool addresses the direct and indirect flood risks, which are diverse due to the broadness nature of water supply systems. For instance, resilience improvement in the technical dimension lowers the flood risks such as damaging the physical infrastructure, water-shortage and post-contamination in the pipe networks. This ensures uninterrupted water service in regular and unusual situations. Strengthening the social dimension increases the water users' awareness and preparedness to flood impacts. Awareness reduces the extent of pollution and environmental degradation, thereby lowering both at source and post-contamination risks of floods to water. It also entails water users' preparedness to better cope and avoid the risk of using alternative water sources that are vulnerable to flooding and could lead to water-related diseases.

Resilient organizations increase the skills and ability of the staff to anticipate risks and ensure rapid water service restoration and system recovery. Aspects of the environment are also significant. Improving the environmental variables increases the floods natural attenuation capacity and lowers the pollution loads resulting from human encroachment. It also enhances water sources sustainability by lowering the risk of siltation and at source water scarcity, and preventing damage to intakes, pumps and treatment plants. Moreover, economic resilience means the WSSA can invest in the water system at an appropriate proportionality, has enough funds to plan, prepare and respond to flood risks, and collaborates with other WSSAs, government agencies, and private organization to mitigate water supply flood risks. The tool's final results allow resilience thinking to be embedded in future water supply system decision-making in Tanzania.

10.5 CONCLUSION

Water supply systems are complex, and measuring their resilience requires a multi-dimensional tool. The contribution of the current chapter is to integrate engineering with organizational, social, economic, and environmental aspects in the tool, to provide operational decision-making in managing water supply systems in the face of flood hazards. The tool is qualitative in nature comprising of the conceptual framework and assessment tools, which is an advantageous approach as it is reliant on operators and managers, is flexible, requires minimum computational requirements, making it suitable for developing countries such as Tanzania. Moreover, the tool is easy to implement; thus, it can be useful in assessing resilience across a wider range of urban water supply systems, which are more than 20 across the country.

The variables of the tool were developed from international literature and then made relevant to Tanzania through the experts' involvement process. Some indicators, measures and measurement scales, were developed in line with local policies, regulations, and design guidelines, and international goals (SDGs), suggesting that the tool will also be able to improve levels of achievements on other areas locally and internationally. The approach used clearly leads to a tool that's generalizable and could be used in other developing countries with similar characteristics to Tanzania.

Most information required during the assessment is from the WSSA's internal data. In some instances, the assessor will need to liaise with other agencies to smoothen the assessment process. For instance, strong cooperation with the respective basin water office will be needed to obtain current information regarding the environmental dimension resilience assessment. The WSSA, could use their billing or communication systems to collect consumers' information to assess social resilience. The weighting process of the variables relied entirely on the experts' opinions, revealing the importance of one variable over another. However, it would be useful for the WSSA to establish their own weightings based on the company's priorities. To avoid biases, the company can establish ratios of the importance of the variables and use the simple equations developed in this study to deduce the weightings.

The overall system resilience (OSR) will indicate the specific needs for improvements in different aspects of the systems. The improvement needs will be useful to the WSSA to identify the appropriate measures for enhancing the water supply systems overall resilience. Resilience improvement needs can then be applied during the planning process, including allowing the allocation of funds for immediate intervention and planning for future enhancement of system resilience.

Chapter 11

Assessing the Validity of the Tanzania Water Supply Systems Resilience Measurement Tool.

The current chapter is based on the following article:

Sweya, L.N., Wilkinson, S. (2020). Validity Assessment: An Example of Tanzania Water Supply Resilience Measures. (Under review: Journal of Applied Water Engineering and Research).

11.1 INTRODUCTION

The unpredictability nature of disasters and the influence of climate change to weather-driven disasters indicate the need for resilient water supply systems that can withstand the risks. Influenced by climate change, floods are already affecting the water supply systems, putting more pressure to water supply managers on developing measures to ensure service continuation in communities. Social-technological systems such as water supply are complex (Newman et al., 2011), such that building resilience needs a better understanding of interactions between the infrastructure, managing organizations, social networks, funding systems, and environmental systems (Sweya et al. 2018). Putting together these aspects into a set of resilience measurement variables is appropriate for developing measures that can help improve the capacity of the systems to cope with disasters (Sweya et al., 2020a).

Tanzania being a tropical country in the East Africa region, is vulnerable to flooding, and its water supply systems have been affected. With some regions located on the coast of the Indian ocean, worse impacts could happen due to storm surges, coastal flooding, and cyclones (Sweya et al., 2020b). For instance, earlier 2019 the southern part of Tanzania and the neighboring country “Mozambique” experienced two cyclones at different times, indicating the vulnerability of the regions, and the need for more resilient water supply systems. Despite the ambiguity, measuring resilience still is an appropriate approach that helps to identify feasible resilience enhancement measures, whereas operationalizing resilience through measurements also makes the concept more understandable and achievable.

Appropriate measures ensure funds well spent on prioritization, planning, development, and implementation of resilience improvement measures. However, most existing resilience measures do not contain validation processes to ensure appropriateness to the assessed systems. Validation is complex by itself (Stevenson et al., 2015) and complicates the concept of resilience as several studies fail to demonstrate the relevance of their measures to the respective systems. Usually, validation comes to the end of the tools development processes and receives little or no attention before applications (Tate, 2011 and Bakkensen et al., 2017). Besides, most existing measures have not been operationalized and validated with real data ending up with anticipations of the possible enhancement strategies against future risks (Irajifar et al., 2013). The current chapter, therefore, tries to examine the validity of variables developed in the current tool to measure the resilience of water supply systems in Tanzania. Validation followed a six-process analysis approach: 1. Assessment of the group opinions 2. Assessment of the convergence of opinions, 3. Reliability analysis, 4. Inter-item correlations, 5. Level of agreements, 6. Applicability and generality testing. Such processes align with the content validation and tool evaluation for applicability and generality testing as presented earlier in chapter 3). The validated set of variables will be suitable for assessing resilience weaknesses in the water supply systems through which, appropriate improvement measures can be prioritized for effective planning, development and implementation to enhance the systems' resilience. Variables can also be useful in other developing countries with similar disaster risks and exposures as for Tanzania.

11.2 VALIDATION PROCESS IN RESILIENCE MEASURES

Resilience is a complex concept applied in multiple fields without consensus on the universal definition and measures. The idea is to enhance the capability of systems to resist, respond and recover from disasters. To realize its potential, one must be able to undertake measurements. Measuring resilience is influenced by several attributes of natural, social, economic, and environmental aspects. One way of ensuring data quality is by use of validated resilience measures (Windle et al., 2011). Measures development needs a validation process, one that has been skipped by most resilience indices developers. Validation refers to the comparison of model predictions with the real-world to determine whether the model is suitable for its intended purpose (Mayer and Butler, 1993). Moreover, a measure is valid if it assesses the intended measure (Mayunga, 2009)

More often, the literature on resilience measurements has indicated that validation is a complex process (Cutter and Finch, 2008) due to unavailable or expensive in-depth field surveys to obtain empirical data required for validation (Mayunga, 2009). Most resilience indices depend on meta-data analyses of literature and theoretical justification in drawing indices in the existing knowledge base (Bakkensen, 2017), and limited to hypothetical situations considering equal risk distributions across populations (Stevenson, 2015). Despite their importance, meta-data analyses do not ensure the appropriateness of the indices to specific outcomes of interest (Bakkensen, 2017). Also, resilience is a concept not directly observable needing proxies for validation. Unfortunately, there is existing antagonism as resilience measures rely on pre-disturbance, whereas validation proxies rely on outcomes (Tate 2011). Until a disaster event occur, resilience efforts cannot be measured, a key reason for lack of investment for resilience. Moreover, infrequent events constrain validation, where specific community and disaster conditions are never the same (Marzi et al., 2019).

Despite the challenges, the literature indicates many ways of validating resilience measures. Validation can be by comparing the measures obtained to previously well-established indices (Stevenson et al. 2015 and Assad et al., 2019) such as Bruneau et al. (2003) and Mayunga (2009) for community resilience and Cutter et al. (2003) for social vulnerabilities. On the other hand, validation of measures can be through comparison with an independent dataset collected in the field or field measurements, especially in physical sciences (Tate, 2011). Also, validation can take place by applying the index to produce measurements between at least two points in time whereby comparing the end-line assessment with a baseline assessment and possibly mid-term assessments (Irajifar et al., 2013). In a similar idea, Hodliffe (2014) suggests that validation can be performed through tool testing with organizations from different sectors and context to examine its generality. Some studies consider empirical validation as the most useful approach to resilience indices. Bakkensen et al. (2017) for example state that empirical validation assesses the explanatory power of an index using real-world observations, although the method faces data availability issues associated with expensive in-depth field surveys (Mayunga, 2009). Some qualitative methods, such as in-depth surveys and case studies, are also useful in validating the indices (Irajifar et al., 2013). Yang et al. (2019) developed a framework through a methodological approach and tested it in experts' judgement elicitation. They noted that, unless effectively applied and demonstrated in real cases, expert judgement frameworks cannot be entirely validated. They went on to applying two case studies to demonstrate the framework's applicability and practicability. Similarly, Oktari et al. (2020) applied experts' judgements to conduct content validity in their study. In addition, the validation process can be through testing the tool against real disasters (Klise et al., 2015) —especially the recurring disasters.

In all cases, the classification of validation processes is into several groups-some important examples are content validity, construct validity, and predictive validity (Mayunga, 2009). The study assessed the validity of the community disaster risk index (CDRI) using both content and construct validity. Content validity refers to whether or not the measure captures the various aspects of the construct. Mayunga (2009) indicates that in psychometric literature, content validity assessment is through a panel of experts evaluating the various components of the measure and determining if they capture the aspects pertinent to theoretical concepts. Also, it assesses the inter-rate agreement regarding the components' relevance, guiding the initial development of the measure, and ensuring the inclusion of all aspects of the concept. Usually, seven or more experts can perform content validation (DeVon et al., 2007). Studies such as Oktari et al. (2020) used a panel of 14 experts to conduct content validity testing through which 23 items had excellent content validity. Among other parameters, they calculated kappa statistics to show the assessment tool's inter-rate reliability at an item level. Due to limited resources, Mayunga (2009) suggests that two raters working within formalized operationalization procedure itself should provide a degree of content validity.

Construct validity assesses the relationship pattern among the measures of concepts anticipated by literature, and the ability to predict potential expected outcomes (Mayunga 2009). It is an integration of any evidence that bears on the interpretation or meaning of the test scores (Messick, 1987). The emphasis is on developing models explaining processes regarding performance on various tests and the relationship to other phenomena (Teglasi, 1998). The correlations between test scores and the criterion measures contribute to the construct validity (Teglasi, 1998) where performance ratings are the most commonly used criterion measures (Ispas and Borman, 2015). In a nutshell, indices of content/criterion validity contribute to the meaning of the scores, and they too pertain to construct validity, suggesting that, construct validity includes all other forms of validity evidence. Irajifar et al. (2013) state further that, the best way that any sort of disaster metric could be validated would be continuously testing and refining after major events.

11.3 METHODOLOGY

Sweya et al. (2020a) developed a qualitative resilience tool to measure the resilience of water supply systems in Tanzania. In the current study, the validity of the tool was assessed in three stages: content validation on the hypothesized variables, content validation on the improved variables, and the construct validation. The three stages encompassed six validation analysis processes such as 1. Assessment of the group opinions 2. Assessment of the convergence of opinions, 3. Reliability analysis, 4. Inter-items correlations, 5. Level of agreements, and 6. Applicability and generality testing.

11.3.1 Content validity on the hypothesized variables

At this stage, content validity was conducted to validate the variables of the hypothesized tool. In this case, expert judgement was carried out through a pre-assessment process. The pre-assessment exercise consisted of ten experts whose experience is at least five years in the water supply industry. The experts involved were stakeholders representing government and non-government practitioners and academics with adequate experience in disasters and climate change. Moreover, experts possessed at least a bachelor's degree and were either associate senior or senior professionals at their workplaces. A questionnaire was developed from the hypothesized variables from which experts were asked to comment on, modify and criticize the appropriateness of the variables or add extra variables that seemed important for the study. In addition, they were asked to rate the variables on a five-point Likert scale from 1=strongly disagree to 5=strongly agree on the inclusion of the variable. All basic information regarding the variables was clearly defined and explained to experts through personal information sheets (PIS), and experts accepted to participate in the study by signing the consent forms (CFs). Researchers addressed the comments and modified the variables accordingly. A standard descriptive method using SPSS BM25 was used to analyze the ratings. Mean ratings (MR) described the importance rating of the variables and the group opinion, whereas, standard deviations (SD) were calculated and used to assess the convergence of the range of importance ratings. Also, the reliability test was performed by calculating the Cronbach's alpha coefficient.

11.3.2 Content validity on the improved variables

The improved variables were subjected to another expert judgement process. A three-round Delphi study was carried out, using water supply experts to develop consensus on the validity of the resilience measurement variables for Tanzania water supply systems. Similar criteria as in the previous content validity section were used to identify the experts. The ten experts who assessed the hypothetical variables were included in the list of 22 experts that were invited to participate in the Delphi process. Initially, experts were invited to comment, modify or criticize the variables and add more variables that had a potential impact on the study. Comments were analyzed, and the variables modified accordingly. In the second round, experts rated the variables, whereas, in the third round, reconsidered their voting. Six attributes: relevance, availability, affordability, simplicity, reliability, and transparency were used as guidelines to the experts in the rating process. Each attribute was rated from 1 for strongly disagree to 5 for strongly agree to the inclusion of the variable. A statistical analysis using SPSS BM25 was carried out. MSs and SDs were calculated to determine the overall group opinions and convergence of the ratings in both second and third rounds. Cronbach's alpha coefficients were calculated and used to conduct the reliability test. The ratings from the two rounds were compared to show the level of agreements. The comparison was performed using the t-test or non-parametric Mann-Whitney test depending on the distribution of the data, with p-value < 0.05 as the statistical significance level. Kappa statistic was further carried out to investigate the percentage of agreements between the two rounds.

11.3.3 Applicability and generality

The expert ratings were further applied to calculate the inter-item correlations using a 2-tailed statistical test (p-value 0.05, 0.01). Results were used to assess the relationship pattern in the respective principles and dimensions. The variables were finally evaluated in three of Tanzania's water supply systems. The evaluation was conducted to portray the practicability and applicability of the variables in the country's water supply systems. Also, the evaluation assessed the generality of the variables to various water supply systems in the country. The water supply and sanitation authorities (WSSAs) rated the performance of the variables. The criterion measures depicted the level of performance based on the five-point Likert scale. Each value from one to five corresponded to the position of the water supply system based on that particular variable ranging from 1 for poor performance to 5 for highest performance. The variables were rated accordingly; the scores were used to describe the resilience of the water supply systems ranging from 1 for very low resilience to 5 for very high resilience. Each resilience level related to certain criteria that could lead to resilience improvements. To assess the practicability and applicability of the variables, each test score was described in terms of the criterion measures/performance ratings, which were used further to identify resilience improvement needs in the water supply systems. The generality of the measures was measured by the practicability and applicability of the variables in the three WSSAs.

11.4 RESULTS AND DISCUSSION

11.4.1 Assessing the group opinions and convergence of opinions on the inclusion of variables

The agreement was attainable when at least 70% of the experts agree or strongly agree to include the indicator, and the standard deviation was less than 0.998. Based on the first criterion for inclusion of indicators, during pre-assessment, all technical indicators and environmental indicators were rated between agree and strongly agree by at least 80% of the respondents. During the exercise, more than 80% organizational indicators and social indicators were rated between agree and strongly agree by at least 70% of the experts. Poor results emerged in the economic dimension, where only 44.4% of the indicators were considered suitable for inclusion in the study by at least 80% of the experts. In the second-round Delphi survey, 94.12% of the organizational indicators qualified for inclusion in the study as at least 75% of the experts rated them between agree and strongly agree. In other dimensions, 81.8% environmental indicators, 62.5% technical indicator, 46.67% social indicators, and only 25% economic indicators were qualified for inclusion by at least 75% of the experts. In the third-round Delphi survey, all the indicators were considered suitable for inclusion since they were rated between agree and strongly agree by at least 75% of the experts. The percentages during the Delphi survey relied on the average ratings from the six attributes: relevance, affordability, availability, reliability, simplicity, and transparency used as indicators rating guidelines.

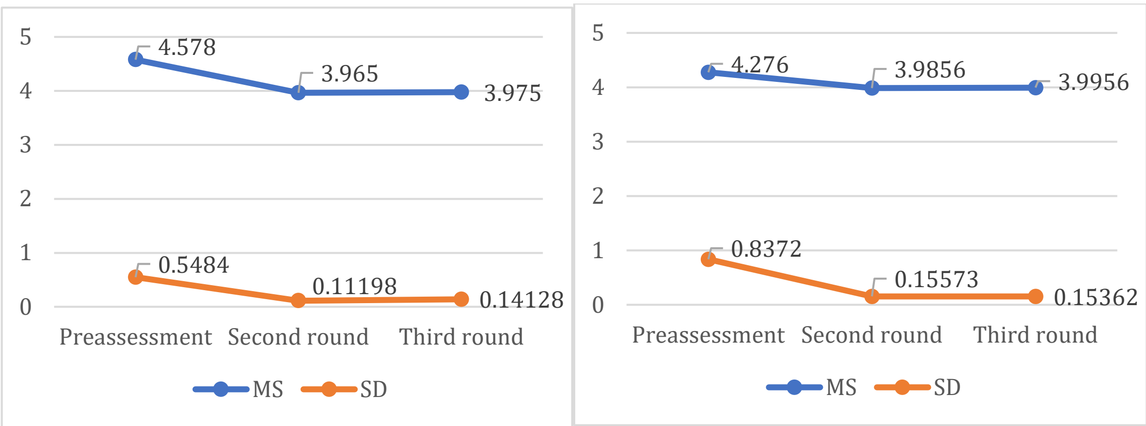
Results show that all technical indicators were *relevant* to this study. 93.8% were passed for *reliability, transparency, and simplicity* criteria, whereas 68.8% of the indicators passed for *affordability* and *availability* criteria. For all underrated indicators, in each case, either *affordability* or *availability* or both were involved. Similarly, in the organizational dimension, all indicators were considered *relevant*, 11.8% were underrated each for one of the attributes and 17.6% each one for three attributes. In all underrated organizational indicators *availability* was among the attributes. Most social indicators “86.67%” were *relevant*, 13.3% underrated on one attribute, 33.3% on two attributes, 20% on three attributes, and 6.7% on four attributes. Of all underrated social indicators, 81.8% involved data *availability*. Despite results indicating that all economic indicators were *relevant*, no indicator met all six criteria. The majority “75%” were underrated on at least three criteria, *availability* still being the major concern for most indicators “83.3%”. Good results emerged in the environmental dimension, where 81.8% of the indicators passed all criteria. The remaining percent relates to indicators that underscored at least one of the six attributes and were associated with simplicity and transparency. The criteria profoundly affected the inclusion of indicators was *availability*; most excluded indicators suffered data availability. Such an attribute impacts Tanzania and most developing countries, probably due to low awareness, insufficient capacity in terms of funding and human resources, and technology. Other criteria are *affordability* and *reliability*. The findings suggest that indicators underrated for the three criteria, also scored low for their importance and potential for inclusion in this study; thus, the majority did not feature in the study.

Although the average MRs shown in **Table 11.1** are relatively high, yet as indicated earlier, some indicators were excluded/rejected. Indicators considered for inclusion at all stages: pre-assessment, second-round Delphi survey, and third Delphi survey, had their average ratings between agree and strongly agree by at least 70% of the experts suggesting that the group opinions for inclusion were significant. The MRs as representatives of the group opinions and the standard deviations measuring the convergence of opinions both describe what happened in the pre-assessment and the Delphi surveys. For instance, all MRs are close to four, suggesting that the group opinions are level four “agree.” Their standard deviations significantly changed from high in the pre-assessment to low in the second and third round Delphi processes suggesting that the panel finally was in strong agreement that the indicators within the dimensions are level four.

Table 11.1: Average MRs and standard deviations of the importance ratings

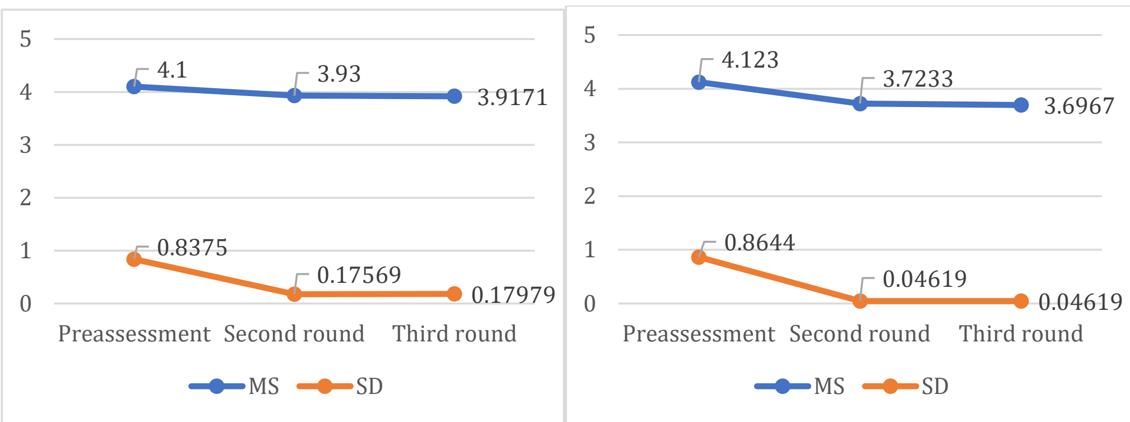
S/N	Dimension	Pre-assessment		Second-round		Third-round	
		MR	**SD**	**MR**	**SD**	**MR**	**SD**
1	Technical	4.578	0.5484	3.9650	0.11198	3.9750	0.14128
2	Organizational	4.276	0.8372	3.9856	0.15573	3.9956	0.15362
3	Social	4.100	0.8375	3.9300	0.17569	3.9171	0.17979
4	Economic	4.123	0.8644	3.7233	0.04619	3.6967	0.04619
5	Environmental	4.390	0.7505	4.0467	0.08471	4.0656	0.09167

Graphical representation of the MRs and standard deviations illustrates the story beyond the statistics. The plots in **Figure 11.1** through **11.3** indicate that based on Greatorex and Dexter (2000), there were relatively stable group opinions in all dimensions throughout the study. On the other hand, the amount of agreement increased sharply in the second Delphi survey and then stabilized during the third-round Delphi survey. The sharp increase is because pre-assessment was the initial process that took place almost a year earlier. Also, the number and descriptions of the indicators had significantly changed after pre-assessment, pretesting, and first-round Delphi surveys which provided opportunities for the experts and the researchers to make changes on the variables. The graphs in the second and the third-round Delphi processes suggest that the panel were of reasonably stable opinion across the rounds with more agreement (convergence).



(a) Technical dimension (b) Organizational dimension

Figure 11.1: Dimension graphs showing the group opinion and agreement in the technical and organizational dimensions



(a) Social dimension (b) Economic dimension

Figure 11.2: Dimension graphs showing the group opinion and agreement in the social and economic dimensions

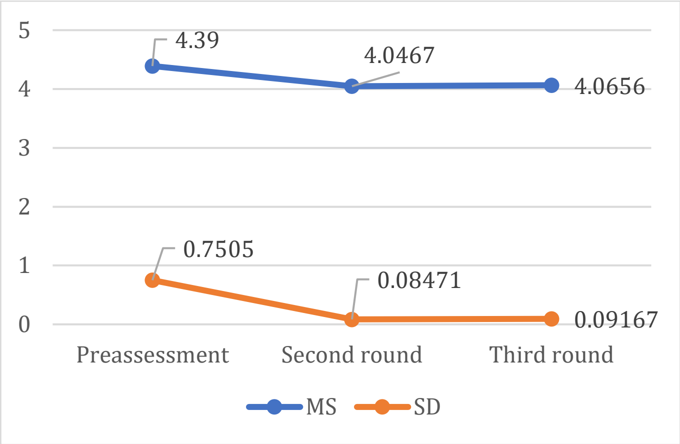


Figure 11.3: Dimension graph showing group opinion and agreement in the environmental dimension

11.4.2 Reliability assessment

Reliability refers to the consistency of a set of measurements and is assessed by examining the internal consistency of the individual indicators in relation to the overall index (Mayunga, 2009). According to Norusis (2005) cited in Mayunga (2009), a greater consistency suggests that the measure is more reliable. When tested for reliability, results in **Table 11.2** indicate that the Cronbach's alpha coefficients ranged from 0.519 to 0.963. Lowest alpha coefficient emerged in the indicators in the technical dimension during pre-assessment, whereas the highest Cronbach's alpha coefficient was for the Organizational dimension during the third-round Delphi survey. The Cronbach's alpha coefficients in the technical, organizational, and environmental dimensions increased linearly towards the third-round of the Delphi survey. In the social and economic dimensions, the values increased during the second-round of the Delphi survey and slightly dropped in the third-round. Except for the pre-assessment of the technical dimension, alpha values were above 0.700 indicating that according to Mayunga (2009) from Norusis (2005) there is a high degree of internal consistency implying that the measures are reliable. Overall, the tool for measuring water supply systems resilience exhibited a high level of Cronbach's alpha coefficient "0.975" suggesting that the tool is a reliable measure.

Table 11.2: Cronbach's alpha coefficient for reliability test

S/N	Dimension	Cronbach's alpha		
		Pre-assessment	**Second-round**	**Third-round**
1	Technical	0.519	0.881	0.857
2	Organizational	0.810	0.948	0.963
3	Social	0.885	0.928	0.835
4	Economic	0.902	0.922	0.805
5	Environmental	0.852	0.900	0.918

11.4.3 Inter-item correlations

This part examines the inter-item correlations among indicators for each dimension during the pre-assessment, second Delphi survey and third Delphi survey. The Pearson correlation results for the third-round Delphi survey appear in **Table 11.3** through **11.7**. **Table 11.3** presents the inter-item correlations in the technical dimension. Results indicate that most indicators correlated positively, and the correlations were statistically significant ($p \leq 0.05$, $p \leq 0.01$). The strongest correlation ".903" exhibited between "system maintenance" and "system renewal." This correlation affirms the suggestion that both indicators measure the robustness of the system. On the other hand, some correlations were negative, although not statistically significant. The weakest correlation is "-.667" between system redundancy and the connectedness on the system. This is not uncommon as according to Sweya et al. (2020a) systems redundancy is intended to measure the redundancy of the water supply system, whereas connectedness of the systems assesses flexibility in the system.

Table 11.3: Inter-item correlations among technical dimension indicators

Technical indicators	1	2	3	4	5	6	7	8	9
System maintenance **(1)**									
System renewal **(2)**	.903**								
System design **(3)**	.629*	.529							
Standards/codes **(4)**	.729**	.466	.753**						
System redundancy **(5)**	-.174	.075	-.317	-.502					
Design approaches in guidelines **(6)**	.522	.406	.722**	.770**	-.467				
System decentralization **(7)**	.554	.319	.672*	.829**	-.236	.424			
The connectedness of the system **(8)**	.000	-.225	.380	.502	-.667*	.600*	.177		
System future expansion capability **(9)**	.561	.506	.241	.605*	-.293	.527	.414	.293	
Critical spare parts and equipment availability **(10)**	.432	.390	.529	.466	-.225	.586*	.319	.451	.506

Note ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed)

Results of inter-item correlations of the indicators in the organizational, social, economic and environmental dimensions are presented in **Table 11.4** through **11.7**. There were no negative correlations for indicators in these dimensions. The lowest was zero correlations which emerged in the social dimension and environmental dimension. For instance, the “location of houses” showed zero correlation to “shared water facilities” that means the location of the houses does not influence the sharing of water facilities. Also “soil erosion protection” was found to have a zero correlation to the “population density” and the “water use” showing that soil erosion protection does not influence the population density/increase in population and has no further impact on the water use. Other lowest correlations are such as “.066” for the “shared water facilities” against the “preventive health measures,” and “.212” for the “effective partnership” against the “organization structure.” Other indicators exhibited a Pearson correlation of at least “.212”.

Highest Pearson correlations for the indicators emerged in the environmental dimension. For instance, a Pearson correlation of “1.000” emerged for “population density” against “water use,” and “human encroachment” against “protection of wetlands,” suggesting that population density has a very strong influence on the water usage, whereas human encroachment strongly influences the programs for wetlands protection. Other correlations of 0.903 indicate that “protection of wetlands” influences the “reduction of environmental impacts” whereas “control of urbanization” influences the “reduction of environmental impacts.” Majority of indicators correlations “83.3%” in the organizational dimension were more than “.800”. “Internal resources” seemed to have the strongest correlation “0.938” to “engagement and involvement” in this dimension. In the social dimension “location of houses” had a strong influence “.878 correlation” to “preventive health measures” this is probably due to the reason that most people residing in unplanned settlements, or vulnerable areas need more attention as they are highly exposed to the impacts of flooding and are likely to be attacked by water-related diseases. Also, “population composition” influences “.845 correlation” the “adoption of new technologies,” suggesting that the adoption of new technology aligns with the profiles of the people in the community including the age and cultural groups. Moreover, in the economic dimension, there is a strong correlation “.769” between the “system investment proportionality” and the public-private-partnership.

Table 11.4: Inter-item correlations among social dimension indicators

Social indicators	1	2	3	4	5	6	7	8
Population composition **(1)**								
Level of education and skills diversity **(2)**	.601*							
Location of the house **(3)**	.335	.781**						
Shared water facilities **(4)**	.645*	.318	.000					
Preventive health measures **(5)**	.409	.594*	.878**	.066				
Adoption of new technology **(6)**	.845**	.408	.261	.414	.357			
Community awareness **(7)**	.362	.289	.463	.210	.723**	.403		
Mitigation plan **(8)**	.305	.459	.630*	.095	.697*	.293	.648*	
Community participation **(9)**	.753**	.802**	.570	.474	.686*	.563	.587*	.506

Note ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed)

Table 11.5: Inter-item correlations among economic dimension indicators

Economic indicators	1	2
System investment proportionality **(1)**		
Public-Private partnership PPP **(2)**	.769**	
Cost recovery **(3)**	.408	.543

Note: ** Correlation is significant at the 0.01 level (2-tailed).

Table 11.6: Inter-item correlations among environmental dimension indicators

Environmental indicators	1	2	3	4	5	6	7	8
Soil erosion protection **(1)**								
Accessibility of freshwater resources **(2)**	.076							
Quality of water sources **(3)**	.371	.378						
Reduction of environmental impacts **(4)**	.286	.640*	.242					
Population density **(5)**	.000	.775**	.586*	.676*				
Human encroachment **(6)**	.051	.674*	.255	.903**	.783**			
Water use **(7)**	.000	.775**	.586*	.676*	1.000**	.783**		
Protection of wetlands **(8)**	.051	.674*	.255	.903**	.783**	1.000**	.783**	
Control of urbanization **(9)**	.586*	0.387	.293	.902**	.500	.783**	.500	.783**

Note ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed)

Table 11.7: Inter-item correlations among organizational dimension indicators

Organizational indicators	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Emergency response plan **(1)**															
Communication and warning **(2)**	.761**														
Proactive posture **(3)**	.629*	.735**													
Planning strategies **(4)**	.804**	.612*	.666*												
Awareness **(5)**	.322	.293	.411	.454											
Effective partnership **(6)**	.661*	.721**	.842**	.664*	.732**										
Leveraging knowledge **(7)**	.817**	.847**	.801**	.809**	.446	.799**									
Learning **(8)**	.727**	.761**	.827**	.804**	.564	.826**	.817**								
Internal resources **(9)**	.817**	.847**	.526	.506	.446	.685*	.739**	.629*							
Leadership **(10)**	.640*	.776**	.776**	.514	.378	.645*	.737**	.640*	.737**						
Engagement and involvement **(11)**	.827**	.880**	.711**	.666*	.587*	.842**	.801**	.827**	.938**	.776**					
Decision making **(12)**	.510	.529	.329	.600*	.278	.285	.624*	.510	.461	.552	.500				
Innovation and creativity **(13)**	.731**	.798**	.722**	.756**	.370	.759**	.939**	.731**	.650*	.653*	.722**	.676*			
Political will **(14)**	.739**	.672*	.672*	.594*	.491	.671*	.766**	.739**	.766**	.866**	.807**	.638*	.707*		
Organizational structure **(15)**	.729**	.520	.371	.727**	.052	.212	.585*	.554	.464	.410	.499	.743**	.502	.474	
Laws and policies **(16)**	.510	.357	.329	.410	.278	.285	.461	.510	.461	.552	.500	.797**	.496	.797**	.592*

Note ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed)

Overall results of Pearson correlations indicate that majority of the indicators revealed statistically significant positive correlations ($p \leq 0.05$, $p \leq 0.01$). This finding emerged for indicators in all dimensions for all stages of pre-assessment, second Delphi survey and third Delphi survey (see **Table 11.8**). Better correlation results are evident in the third-round of the Delphi survey, where all indicators in all dimensions except for the technical dimension exhibited positive correlations. During the third-round of the Delphi process, there were only 20% negative indicators correlations in the technical dimension, although they were not statistically significant. Having at least 74% positive correlations for all three stages of the variables/indicators' development, and at least 80% positive correlations in the final stage "third Delphi survey," the current study portrays better correlations than Mayunga (2009) who's some capitals had lower positive correlations such as 23%-39% yet conclusively had a reasonable consistency. The current findings suggest that most of the indicators are consistent with each other, indicating that there is an adequate positive relationship pattern in the respective dimensions. Findings suggest further that the proposed indicators are relevant measures of the water supply systems resilience construct at the dimensional level and show an acceptable level of confidence of appropriateness when applied to measure the overall water supply systems resilience.

Table 11.8: Percentages of positive correlations

S/N	Dimension	Percentage of positive correlations		
		Pre-assessment	**Second-round**	**Third-round**
1	Technical	100	82.5	80
2	Organizational	74.9	98.5	100
3	Social	86.7	96.2	100
4	Economic	100	98.5	100
5	Environmental	78.6	94.6	100

11.4.4 Level of agreement between second and third rounds

Comparison results between the second and third rounds of the Delphi assessment indicate that the p-values for all dimensions ranged between 0.170 and 0.673 (see **Table 10.9**). The lowest value was for the environmental dimension, while the highest value was for the technical dimension. The values are higher than 0.05; thus, suggesting there was no significant difference in the ratings between the second and third round. The results suggest further that the experts had achieved a consensus regarding the variables for assessing the resilience of water supply systems in Tanzania.

Table 11.9: Comparison test between second and third-rounds Delphi survey

S/N	Dimension	Significance level	p-Value
1	Technical	0.05	0.673
2	Organizational	0.05	0.364
3	Social	0.05	0.356
4	Economic	0.05	0.423
5	Environmental	0.05	0.170

The level of agreement between the second round and third round was further assessed by calculating the kappa statistics. The overall kappa value for the water supply system resilience tool was 0.605, whereas kappa values for individual indicators ranged from 0.765 to 1.000. All values are positive, which, according to Wynd, Schmidt & Schaefer (2003) they indicate that the interrater agreement occurred more frequently than would be expected. Moreover, the values according to Landis & Koch (1977); Cicchetti (1984); Fleiss (1971) and Zhong et al. 2015 suggest that there was good to excellent agreement between the ratings in the second and third rounds. In particular, Kappa values for most of the indicators "98%" ratings depicted excellent agreement between the two rounds.

11.4.5 Evaluation results from Case I, Case II and Case III

The tool's indicators development relied on adopting a methodological approach involving experts judgement elicitation. The method used "Delphi study" is iterative and consensus-based. The basic themes from the literature were clearly explained to experts to enhance the unified approach of judging the variables. According to Yang et al. (2019), expert judgement alone cannot completely validate frameworks/resilience tools unless they are applied and demonstrated in real cases. This section employs three cases to assess further the validation and the claim that the developed tool would be suitable for measuring the resilience of water supply systems in Tanzania. The cases are three water supply systems managed by Tanzanian WSSAs, as presented in chapter three. The cases differ from their technical capacities, water production capacities, population served, nature of the water sources and financial capabilities, representing about 26 other WSSAs across the country.

Resilience evaluation in the cases

The resilience tool was evaluated in all three cases; initial scores came from the WSSAs. Opinions on the efficacy of the measures for evaluating the resilience of the water supply systems were also enquired. In all cases, the scores were aggregated to the final resilience indices. In all dimensions, the initial scores were able to indicate the level of indicator performance based on the five qualitative statements representing the measures from 1 for very poor performance to 5 for highest performance. Aggregating the indicator scores, portrayed the position of principles in terms of their resilience. From the aggregated results, it was easier to draw recommendations to suggest the extent of improvements required and the areas that required improvements.

Similarly, principles resilience results when aggregated to dimensional resilience; it was possible to identify the dimension whose resilience was wanting and requiring immediate attention. Moreover, one could also suggest the principles or factors within the dimension that needed immediate intervention. The dimension results when aggregated, they led to an overall water supply system resilience from which any need for improvement was identifiable from the principles down to the specific indicators and measures. In all cases, the tool demonstrated the ability to identify resilience improvement needs that could easily advise on appropriate measures to enhance the overall resilience of the water supply systems. The WSSA found the tool easier to work with as only initial scores when plugged in the tool could draw all conclusions and recommendations for the system's resilience. Aggregation of scores and determination of the resilience needs work antagonistically, as while aggregation starts from specific measures to the overall system resilience, resilience needs are better determined from the overall system resilience towards the specific measures.

When comparing the scores across the three cases, the Pearson correlation results indicate that there are mixed positive and negative correlations among the indicators' scores. The technical dimension indicators' scores revealed a positive Pearson correlation "0.547" between case I and case II, and "0.541" between case II and case III. A negative Pearson correlation "-0.269" emerged between case I and Case II, although it is not statistically significant—as there is no large discrepancy between their infrastructures. In the organizational dimension, results show a significant negative correlation "-0.462" of the scores between case II and case III. For the economic dimension, there was a positive correlation "0.866" between case II and case III. Moreover, a significant positive correlation emerged in the environmental dimension between Case II and case III. The positive correlations suggest that the cases experience similar resilience issues in their water supply systems. For instance, case I and case III, and case II and case III have similar technical resilience issues, case II and case III have similar economic and environmental issues. On the other hand, case I and case II experience different technical resilience issues, although the difference is not significant, whereas, case II and case III experience significantly different organizational resilience issues.

The similarities in resilience issues are attributable to the existing similarities of technical, economic and environmental issues and the nature of shocks to which the systems are exposed. For instance, most urban water supply systems in some parts consist of old infrastructures, they have low redundancy to dampen failures during crises, and use the same design guideline "Design manual for water supply and wastewater disposal (URT, 2009)" from which there are minimum resilience considerations. Besides, most WSSAs struggle to collect revenue from their clients and have limited participation among themselves and other private organizations on resilience building issues and emergency responses. Also, the majority of the water supply systems have unbalanced systems' investment as there is massive investment in production than other parts of the systems. Environmental aspects are cross-cutting all over the country, human encroachment, for example, is prominent, the annual per capita renewable water resource is decreasing across the country due to rapid population growth, and the snags in enforcing the Water Resources Management Act 2009[25] to reduce the environmental impacts on water sources are for most WSSAs. The differences in organizational resilience issues are pertinent to their different capacities in human resources. For instance, whereas some water supply authorities are strategic and having the behavioral readiness to respond to internal and external early warnings of changes before they become crises, others lag. Similar issues are evident in decision making, learning, and innovation and creativity.

Suggestions can, therefore, be drawn that firstly, most WSSAs in the country are likely to have similar technical, environmental and economic resilience issues and secondly, organizational resilience issues are likely to differ from one WSSA to another significantly. These suggestions lead to recommendations that, there is a need for a joint approach for addressing water supply systems resilience problems. If the WSSAs within the country work in pulling together knowledge and experiences regarding resilience issues and the way they address them, there will be a very high chance of resilience enhancement in their water supply systems. It is also recommendable to adequately discuss the resilience approaches in guidelines, national and local WSSAs policies, and implement them to prepare the water supply systems against future floods/crises.

Following the tool evaluation in the cases, some improvements are suggestive; for instance, the measures for the "cost recovery" indicator will otherwise consist of the working ratio and the operating ratio. The two measures assess the WSSAs' financial sustainability. The

[25] http://extwprlegs1.fao.org/docs/pdf/tan142669.pdf

working ratio below “1.0” implies that the WSSA is able to recover operation costs, whereas the ratio above “1.0” reflects the company’s inability to do so. On the other hand, the operating ratio relates to the costs to operate the water supply system compared to the income brought by the water supply system services. The ideal levels of the operating ratio are between 0.6 to 0.8, where lower values are highly recommendable. The measures are in line with the measurements for cost recovery set by the EWURA (2018) recommending that the working ratio and the operating ratio should be less than 1.0. Another recommendation is that assessors of the resilience may need to cooperate with the municipal council-planning department to be able to obtain consolidated information on the control of urbanization and human encroachment in the water catchments and recharge areas. There is also the need to integrate the assessment tool’s variables in the EWURA’s plans for regulating water utilities in the country. That could mean expanding from EWURA’s performance-based indicators “traditional practices” to include resilience-based indicators to evaluate the capacity of the overall systems to operate in both normal conditions and disruptions.

11.5 CONCLUSION

The chapter presents the processes to validate the Tanzania water supply system’s resilience tool through three stages, encompassing five analysis processes. The first two stages involved experts’ judgment elicitation, followed by tool evaluation in cases. There is adequate evidence that the tool’s validity is sufficient, and the variables can be used to assess the resilience of water supply systems in Tanzania. For instance, there was significant group opinions and convergence of the opinions for the inclusion of the indicators forming the final tool. There was at least .700 Cronbach’s alpha for the final variables in all dimensions with an overall value of .975, indicating that the tool is a reliable measure. Most indicators showed a positive correlation meaning that they are consistent with each other with adequate relationship pattern in the dimensions. The level of agreement between the second and the third Delphi survey was significant showing that the experts reached a consensus regarding the tool’s variables. That means the content validity of the tool can be acceptable at this stage. The tool is applicable for Tanzania water supply systems as the evaluation results met the objective of the tool “to assess the resilience and examine the improvement needs.” The tool’s generality is adequate as it was able to reveal the resilience position of all cases showing similarities of resilience issues across the dimensions except for the organizational dimension. The water supply systems exhibited different organizational resilience issues, thus meaning that the improvement needs, and implementation priorities may differ from one WSSA to another. Generally, in a joint-working environment, WSSAs would pull together the knowledge, and experience needed to enhance their capacities against the impacts of flooding.

Chapter 12
Resilience improvement measures and tool implementation plan

12.1 INTRODUCTION

In previous chapters, the tool evaluated the resilience in selected Tanzania water supply systems. The evaluation of the tool revealed that there are areas that need improvement to enhance the resilience of the water supply systems. This Chapter 12 assesses the appropriate measures that are used to address the resilience problems and improve the resilience of the water supply systems as a whole. Besides, the chapter presents guidelines that are applicable for effective implementation of the resilience tool both for Tanzania water supply systems and in other developing countries. The assessment for the appropriate measures was conducted based on the needs to enhance the absorptive capacity, adaptive capacity, coping capacity, and learning capacity (AACL). As such, measures presented in the current chapter aligns with the enhancement of the AACL capacities leading to enhanced water supply systems resilience. Moreover, the implementation plan was developed based on the best practices existing in the literature and follows the general trend for implementing risk management. The guidelines in the plan point to a committed culture for resilience assessment and improvements. It involves evaluation that is carried out by regulatory bodies to ensure that improvement measures are effective and efficient in all dimensions of the water supply system, obtaining further information to improve the resilience, analyzing and learning lessons, detecting changes in the external and internal context, and identifying emerging risks.

12.2 RESILIENCE PROBLEMS FROM THE EVALUATION RESULTS

Evaluation of the tool in selected Tanzania water supply systems has been discussed in chapter 5 through 11. Evaluation results show that the water supply systems experience moderate resilience with less than desirable performances, needing prioritized measures for enhanced resilience in all dimensions. Chapter 11 has indicated that as resilience aggregation proceeds from the initial scores to the overall resilience index, the identification of problems starts from the overall resilience index for water supply systems down to the assessment measures. By using this principle—aligning with the measures and assessment scales presented in **appendix 4**—all variables with wanting performances were traceable in the previous chapters. In each dimension, the following **Table 12.1** indicates the summary of the critical issues needing immediate interventions in order to improve the resilience of water supply system.

Table 12.1: Summary of the resilience problems from evaluation results

Dimension	Principle	Resilience problem
1.0 Technical	1.1 Flexibility	Only 20-40% of physical components have options for future expansion
		Most spare parts and equipment are ordered from abroad and take a few weeks.
		Less than 20% of the service areas receive water from more than one scheme.
	1.2 Safe to fail	The safe-to-fail concept is not included in the current design approaches, although there are plans to include in future.
	1.3 Robustness	There are no existing plans and controlled renewal or upgrades of assets, especially for MORUWASA.
		Only less than 20% of the critical assets are above the current design codes -MORUWASA.
2.0 Organizational	2.1 Leadership and culture	No strategy exists to encourage and reward staff for using their creativity and innovative ability in addressing issues during floods
		No procedures in place to assign authority to make quick decisions, reduce excessive bureaucracy in relation to deployment of staff and resources during flooding
		There is no resourcing to resilience planning, and roles and responsibilities not clearly defined with regular meetings and documented processes for implementing the improvements.
		There is no resilience culture, although plans are in place to initiate and promote the culture within the water authorities.
		Staff have limited engagement and involvement in internal resilience discussion, training or exercises.
	2.2 Change readiness	Staff have only some awareness of the possible disruptions caused by the impacts of floods. Also, taking only ad hoc processes to reward staff for identifying new hazards, weak links and warning signs.
		Plans are still under development for robust risk identification and assessment practices, including planning for unforeseen risks.
		Discussions are still ongoing to establish cross-sector and authority emergency plans.

Dimension	Principle	Resilience problem
		Ad hoc contingency plan drafted to identify ahead of time alternative water pipelines and other facilities required for response, rehabilitation and protection from further disasters
	2.3 Network and relationship	Only some information sharing takes place across sector or utilities, and there is no updated cross-sector infrastructure register containing structural information important in crises.
3.0 Environmental	3.1 Environmental capacity	The annual per capita internal renewable water resources are 1000-1700m3/yr.c-water stress with intermittent or localized water shortage
	3.2 Natural assets	There is less evidence of reducing the environmental impacts on the water resources as less than 20% of the population still uses off-site sanitation
	3.3 Environmental resources sensitivity	The mean annual percentage of the tree cover removed for urbanization, commodity production, and agriculture is 0.5-15%
4.0 Social	Togetherness	Less than 20% of the households within the communities have joint ownership on water facilities such as boreholes, water tracks, water storage tanks/facilities
	Social structure	More populations “43.9%” are young dependents aging between 0-14
		At least 70% of the houses are within unplanned settlements.
	Preparedness	The community lacks awareness on the existence of either mitigation or responsive plans to reduce flooding impacts on the water supply systems.
		Medium community participation or engagement in water supply projects and water-related disaster management activities
5.0 Economic	Dynamism	Heavy investments on some components of the water supply systems, e.g. production components than distribution components
		There is only ad hoc public-private-partnership, MoUs underdevelopment and contracts are not signed.

As discussed in chapter 4 & 10 water supply systems are multi-dimensional. The interactive nature of the dimensions suggests that resilience problems in one dimension can affect other dimensions as well; for instance, a technical problem such as failure of securing spare parts on time during flooding can affect both technical and social resilience, as such, failure will affect the timely recovery of water services in the communities. Also, organizational problems such as lacking strategies to encourage and reward staff for using their creativity and innovative ability in addressing issues during floods will affect the efficiency of the physical infrastructure in terms of operation, while affecting further the revenue collection-economic dimension, service delivery-social dimension, and the environmental sustainability-environmental dimension. Similarly, social problems will affect the revenue collection-economic dimension, environmental wellbeing due to rapid urbanization and living in informal settlements-environmental dimension. Also, the functionality of the physical infrastructure, as lacking awareness on the existence of either mitigation or responsive plans to reduce flooding impacts on the water supply systems. Moreover, less community participation or engagement in water supply projects and water-related disaster management activities means that the community lacks the sense of the ownership of the infrastructure leading to uncontrollable vandalization, and illegally tapping escalating the vulnerability of the physical infrastructure.

12.3 RESILIENCE IMPROVEMENT MEASURES

Chapter 2 discussed different capacities that can improve resilience: absorptive capacity, adaptive capacity, coping capacity, and learning capacity (AACL). These capacities include absorptive measures-related to mitigation measures, including any physical or nonphysical actions taken to reduce the frequency, magnitude, or duration of a specific threat/flooding. Adaptive measures are the form of modification of a particular element or property of the system to enhance the ability to deliver the same level of service in variable conditions continuously. Coping measures are any preparations or actions taken to reduce the frequency, magnitude, or duration of an impact or recipient. And learning-referring to embedment of experience and new knowledge in the best practices. Similarly, the current measures are categorized such that they lead to enhancing the AACL capacities. The AACL measures are applicable across the five dimensions; that means, the problems in each dimension are addressed by the AACL measures and working together to enhance the overall water supply systems resilience.

12.3.1 Interaction of resilience improvement measures

As discussed in the previous section, the multi-dimension nature of the water supply systems suggests that measures deployed to improve the resilience in one dimension will have an impact on other dimensions. That means technical measures will improve the technical dimension, the social dimension, economic dimension, organizational and environmental dimension. In this case, improving the technical dimension implies sustainable service delivery to the community, high revenue collection, and fund availability to invest in resilience planning and environmental protection. Social dimension measures will enhance revenue collection, environmental sustainability, and lessen physical infrastructure vulnerability. Environmental measures will ensure water resources availability in terms of quantity and quality, improving infrastructure functionality and improve the community's health and wellbeing. Likewise, Organizational measures will improve the efficiency of the physical infrastructure, improve service delivery and revenue collection, and environmental sustainability. Economic measures mean funds well spent on systems development and improving all other dimensions, whereas strong partnership will ensure continuity of the services at all times.

Of all measures, learning is a crosscutting measure needed in improving the Tanzania water supply systems since resilience is still a theoretical concept to most water supply organizations in the country. As such, learning measures such as 1. learning from past events, 2.generating pilot schemes to generate knowledge for the best practices, 3. learning to get the right data and efficient communication strategies, and 4. learning from other water supply organizations whose performance is high and practice resilience culture in their systems "this may go beyond systems other than water supply that embrace resilience approaches" will catalyze the desire to develop resilience culture and enhance the resilience in the water supply systems. **Table 12.3** presents other specific improvement measures. In this case, one of the measures or a collection of measures will enhance the principle resilience; for instance, "control of urbanization" is an absorptive measure that will reduce the mean annual percentage of the tree cover removed—especially in water resources protected areas—thereby improving the "environmental resources sensitivity" principle resilience. Also, establishing and accelerating assets replacement/renewal strategy, and accelerating assets upgrade strategy, thereby introducing updated design with resilience approaches are both absorptive measures that can enhance the "robustness" of the infrastructure. Collectively the improved principle resilience can enhance the dimension resilience, whereas the dimension resilience can jointly enhance the overall water supply system resilience.

12.3.2 Prioritization of the measures

Prioritization of the measures is pertinent to the discussion in previous chapters where the importance of the tool's variables was discussed, and variables ranked by experts according to their significance. The overall assessment suggested that the technical dimension is the most important dimension with low mean and median close to 1 than other dimensions followed by organizational and environmental dimension in the third place. Social dimension was ranked the least important many times than any other dimension and scored the mean 4.417 and median 5.000 very close to 5 and higher than for any other dimensions (see **Table 12.2**).

Table 12.2: Importance ranking of dimensions

Description	Technical		Organizational		social		Economic		Environmental	
	F	(%)	F	(%)	F	(%)	F	(%)	F	(%)
Most important	4	33.3	3	25.0	1	8.3	1	8.3	5	41.7
Important	4	33.3	4	33.3	-	-	3	25.0	1	8.3
Fairly important	2	16.7	3	25.0	-	-	3	25.0	2	16.7
Somehow important	1	8.3	2	16.7	3	25.0	3	25.0	2	16.7
Least important	1	8.3	-	-	8	66.7	2	16.7	2	16.7
Mean	2.250		2.333		4.417		3.167		2.583	
Median	2.000		2.000		5.000		3.000		2.500	
Rank	**1**		**2**		**5**		**4**		**3**	

Further importance ranking results from previous chapters indicate that; principles for technical dimension rank from 1-*robustness*, 2-*redundancy,* 3-*flexibility,* and 4-*safe-to-fail*; for organizational dimension, 1- *change readiness*, 2-*leadership and culture,* 3- *legal framework and institutional set-up*, and 4-*networks and relationships*. For the environmental dimension, the importance ranking for the principles is 1-*environmental resources sensitivity,* 2-*environmental capacity,* 3-*natural flood attenuation,* and 4-*natural assets.* Social dimension's principles rank from 1-*education*, 2-*preparedness*, 3-*social structure*, 4-*safety and wellbeing,* and 5-*togetherness*, whereas the economic dimension has only one "dynamism" principle. Such ranking results and the indicators ranking results presented in **Table 10.1** from chapter 10 suggest the priority setting for the measures to enhance the resilience of Tanzania water supply systems. In **Table 12.3**, the dimensions and principles are presented in the order of their priorities, whereas the enhancement measures' priorities are presented based on the color codes in the capacities' column.

Table 12.3: Specific improvement measures to the resilience problems

	Very high priority		High priority		Medium priority		Low priority		Very low priority

Dimension		Resilience problem	Improvement measures	Capacity
1.0 Technical	1.1 Robustness	There are no existing plans and controlled renewal or upgrades of assets especially for MORUWASA.	Establish and accelerate assets replacement/renewal strategy	Absorptive
		Only less than 20% of the critical assets are above the current design codes -MORUWASA.	Accelerate assets upgrade strategy thereby introducing updated design with resilience approaches	Absorptive
	1.2 Flexibility	Only 20-40% of physical components have options for future expansion.	Adapt planning and designing approaches allowing projected systems development with options for expansion to cope with ever-increasing demand due to rapid population growth, and contingency demands during crises.	Adaptive and Coping
		Most spare parts and equipment are ordered from abroad and take a few weeks.	As much as possible use equipment and facilities whose spare parts are locally available or are readily available and obtained within a short time	Adaptive
		Less than 20% of the service areas receive water from more than one scheme.	Modify operation by connecting service areas to multiple water schemes	Adaptive
	1.4 Safe to fail	The safe-to-fail concept is not included in the current design approaches, although there're plans to include in future.	Introducing resilience design approaches in the design guidelines "Water supply and wastewater disposal design manual" acknowledging that failure cannot completely be eliminated-safe to fail	Adaptive
2.0 Organizational	2.1 Change readiness	Staff have only some awareness of the possible disruptions caused by the impacts of floods. Also, taking only ad hoc processes to reward staff for identifying new hazards, weak links and warning signs	Promote staff awareness on a range of flood risks to water supply systems, and establish procedures to reward staff who manage to identify new risks, weak links, and warning signs	Adaptive and learning

Dimension		Resilience problem	Improvement measures	Capacity
		Plans are still under development for robust risk identification and assessment practices, including planning for unforeseen risks.	Establish plans and procedures for robust risks identification aligning with planning for unforeseen risks	Adaptive
		Discussions are still ongoing to establish cross-sector and authority emergency plans.	Establish joint planning such that to review emergency plans for other agencies and sectors identify required actions and incorporate into plans of the Water authorities as required. Moreover, establish cost-sharing agreements in place for significant requirements by others.	Adaptive
		Ad hoc contingency plan drafted to identify ahead of time alternative water pipelines and other facilities required for response, rehabilitation and protection from further disasters	Establish and implement contingency plans to identify ahead of time alternative water pipelines and other facilities required for response, rehabilitation and protection from further disasters	Adaptive
	2.2 Leadership and culture	No strategy exists to encourage and reward staff for using their creativity and innovative ability in addressing issues during floods	Establish strategies for technological innovations including in advanced data collections and prediction models; also reward staff using their creativity and innovative ability in bringing positive results for the organization	Absorptive and adaptive
		No procedures in place to assign authority to make quick decisions, reduce excessive bureaucracy in relation to deployment of staff and resources during flooding	Establish non-bureaucratic procedures for authorizing staff to make quick decisions in deploying resources in response to flooding impacts on water supply systems	Adaptive
		There is no resourcing to resilience planning, and roles and responsibilities not clearly defined with regular meetings and documented processes for implementing the improvements.	Establish resilience planning strategy and allocate resources in line with clearly defined roles and responsibilities, and regular meetings set to implement the improvements.	Adaptive
		There is no resilience culture, although plans are in place to initiate and promote the culture within the water authorities.	Promote resilience culture in the organizations	Absorptive

Dimension		Resilience problem	Improvement measures	Capacity
		Staff have limited engagement and involvement in internal resilience discussion, training or exercises.	Establish procedures to involve staff in internal resilience discussion, training or exercises	Adaptive
	2.4 Network and relationship	Only some information sharing takes place across sector or utilities, and there is no updated cross-sector infrastructure register containing structural information important in crises.	Establish inter-utilities and cross-sectoral information sharing strategy to enhance learning among utilities and accelerate joint solving of cross-cutting problems	Adaptive
3.0 Environmental	3.1 Environmental resources sensitivity	The mean annual percentage of the tree cover removed for urbanization, commodity production, and agriculture is 0.5-15%	Control urbanization	Absorptive
	3.2 Environmental capacity	The annual per capita internal renewable water resources are 1000-1700m3/yr.c-water stress with intermittent or localized water shortage	Enforcing/Establish strategies for monitoring water abstraction based on proper water balance activities	Absorptive
	3.4 Natural assets	There is less evidence of reducing the environmental impacts on the water resources as less than 20% of the population still uses off-site sanitation	Promoting the use of off-site sanitation systems in line with increasing the sewerage system networks	Adaptive
4.0 Economic	4.1 Dynamism	Heavy investment on some components of the water supply systems, e.g. production components than distribution components	Investing in developing the distribution networks to balance the investments	Absorptive
		There is only ad hoc public-private-partnership, MoUs underdevelopment and contracts are not signed	Promote PPP, establish MoUs and signed contracts	Adaptive
4.0 Social	4.2 Preparedness	The community lacks awareness on the existence of either mitigation or responsive plans to reduce flooding impacts on the water supply systems	Implementation of awareness creation campaigns	coping

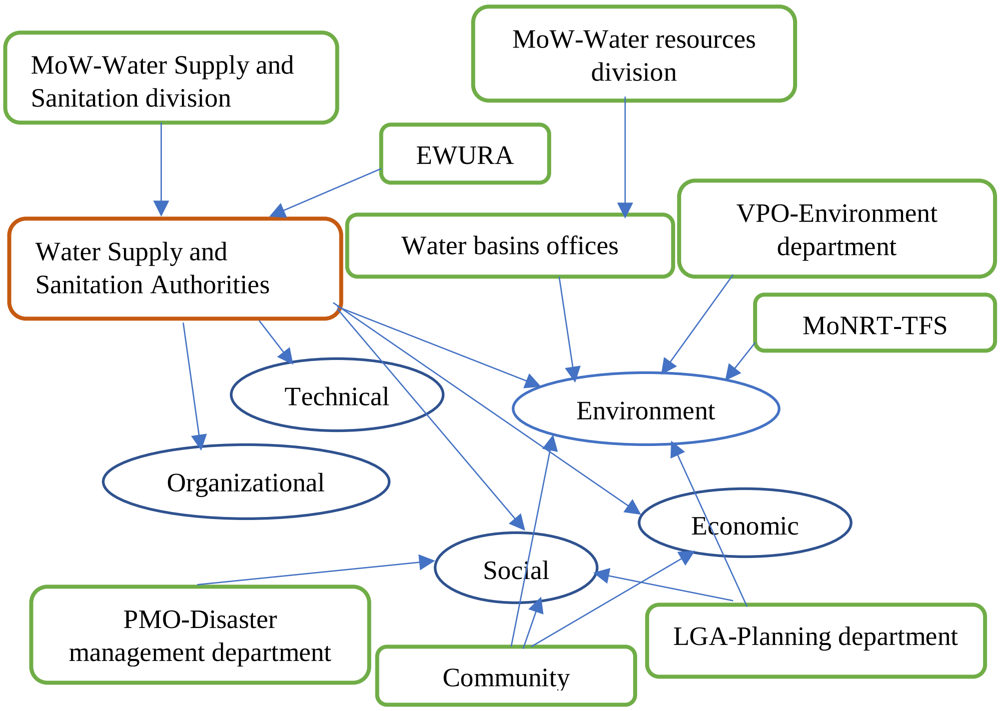
Dimension		Resilience problem	Improvement measures	Capacity
		Medium community participation or engagement in water supply projects and water-related disaster management activities	Involving the community in water projects planning and development of emergence and preparedness plans	Adaptive
	4.3 Social structure	More populations “43.9%” are young dependents aging between 0-14	Introducing awareness and preparedness learning programs in primary schools that would help the majority to understand and prepare for flood risks on water supply systems	Coping
		At least 70% of the houses are in unplanned settlements.	Promote informal settlement improvements and proper planning for new settlements such that no construction of houses takes place in areas that are considered vulnerable to flooding impacts.	Adaptive
	4.5 Togetherness	Less than 20% of the households within the communities have joint ownership on water facilities such as boreholes, water tracks, water storage tanks/facilities	Promote cohesion within the communities through the establishment of strong water user associations (according to WRMA 2009)	Absorptive

12.4 PROPOSED RESILIENCE TOOL IMPLEMENTATION PLAN FOR TANZANIA WATER SUPPLY SYSTEMS

This section proposes guidelines for the implementation of the tool for measuring the resilience of water supply systems. Without such guidelines, stakeholders will not be able to carry out the resilience assessment in a consistent manner. Consequently, outcomes from different tool users may be hardly comparable, affecting the effectiveness of the water organization, policy, and regulatory bodies. The research has developed a multi-dimensional resilience measurement tool encompassing five dimensions; technical, organizational, environmental, social, and economic for Tanzania water supply system; the tool is the main result of the research which need a careful application in order to bring the intended outcomes effectively. By applying the tool, water managers would be able to identify resilience weaknesses in their water supply systems and be able to develop appropriate measures for improving the resilience. As such, in addition to the tool, the current research contains evaluation results in the form of resilience problems and their specific improvement measures for enhancing the resilience of the water supply system. The following sections show the guidelines for implementing resilience in Tanzania water supply systems.

12.4.1 Establishing the context

This sub-section concerns translation of stakeholders' needs into specific, actionable, and customized goals cascade from high-level water organization goals to enabler goals. The enabler goals can later be associated with best practice, standards, and compliance requirements from the relevant area of concern. Taking an example of Tanzania water supply systems, the lead stakeholders are water supply and sanitation authorities (WSSAs). The WSSAs are responsible for infrastructures development, operation and maintenance, service delivery, revenue collection, and environmental safeguarding. However, building partnership with other players will help the WSSAs anticipate actions, and clarify roles and responsibilities leading to a successful resilience building in the water supply system, and efficient response and recovery should the system be severely damaged. Such stakeholders are; water basin offices—responsible for water resources monitoring and conservation, EWURA—for evaluating the water supply utilities, LGA—planning department-settlements development and land use planning, and PMO—disaster management department-emergency response. Others are; VPO—environment department-enforcement of environmental protection regulations, Tanzania forest Services (TFS) agency—forests conservation, and the community-paying bills, protecting the water resources and the infrastructure, the Tanzania meteorological agency, nongovernmental organizations, community organizations, and academic institutions (see **Figure 12.2**). Cadete et al. (2018) suggest that a Goal Cascade Methodology (GCM) would be a viable approach in translating stakeholders' needs. In this methodology, stakeholders' drivers such as technical, organizational, social, economic, and environmental issues can be used in defining the needs, and the needs are applicable in defining the WSSAs' goals and cascading them to divisions, departments, and enabler goals.



NOTES: EWURA-Energy and water utilities regulatory authority, MoW-Ministry of water, PMO-Prime minister office, LGA & MC-Local government authorities and Municipal councils, MoNRT-Ministry of natural resources and tourism, TFS-Tanzania forest services agency

Figure 12.1: Key stakeholders in the implementation of the water supply systems resilience in Tanzania

12.4.2 Risk identification and analysis

Identification of the potential for floods and other crises to happen and damage the key assets of the water supply system is the next step. A risk scenario is useful, encompassing the description of a possible event that, when occurring, will affect the achievement of the WSSAs' objectives. In the current study, the possible effects that can influence the achievements of the water organizations' goals range from technical, organizational, social, economic and environmental aspects. A top-down approach could be applied, starting from the overall

WSSAs' objectives, and identify water supply services objectives, and scenarios with the highest impact on the achievement of the water supply services objectives. Also, the frequency and the impacts can be estimated using risk factors, such as those conditions influencing the frequency and impacts on the water supply services. The variables developed in the current tool provide a comprehensive platform for understanding and determining the factors that may exacerbate the risk impacts, also known as vulnerabilities/weaknesses; this may be done based on the experience, known current events and possible future circumstances

12.4.3 Resilience analysis

By applying the currently developed multi-dimensional resilience measurement tool, analysts can relate the risk scenarios with current and predicted technical, organizational, social, economic, and environmental capability levels to determine the existing weaknesses/vulnerabilities. Scores on the measures based on the graduated qualitative measurement scales will initially apply to operationalize the tool. As shown in previous chapters, scales relate to the performance of a measure in five levels from 1-very poor performance to 5-very high performance. The tool will lead to semi-quantitative indices at an indicator level, principle level, dimension level, and the overall water supply system. These indices will entail the possible weaknesses in the water supply systems based on the level of performance of the variables.

12.4.4 Resilience evaluation and treatment

This section compares the outcomes of the resilience analysis with criteria set to determine whether the resilience level is acceptable and identify areas for improvement. The current tool provides a decision means on whether the resilience is acceptable. The final water supply index can be visualized in five different levels of resilience, ranging from 1-very low resilience, 2-low resilience, 3-moderate resilience, 4-high resilience, and 5-very high resilience. Each level indicates the implication to the system performance. For instance, "very low resilience" means very poor performance and extensive improvement measures are required, "low resilience" indicates poor performance and improvements are required, "moderate resilience" shows less than desirable performance and specific improvements should be prioritized, "high resilience" indicate acceptable performance in relation to a measure (s) and some improvements could be made, and "very high resilience" meets all requirements. As indicated, level 1 – 4 show the needs for improvements; these needs can be determined from the variables-dimensions, principles, and indicators low performances. Cadete et al. (2018) suggest that the resilience responses—improvement needs should be integrated into a common decision-making process and contribute to a single security, safety, and resilience strategy. However, the implementation of specific resilience improvements may be realized by specialized projects, within a coherent portfolio that integrates the different dimensions.

12.4.5 Monitoring and review

Monitoring and review is an essential part of the implementation of the resilience measurement tool for water supply systems. Monitoring and review should include the governance bodies, to ensure that improvement measures are effective and efficient in all dimensions of the water supply system, obtaining further information to improve the resilience, analyzing and learning lessons, detecting changes in the external and internal context, and identifying emerging risks. EWURA is responsible for regulating the technical and economic performance of the regional and national project water utilities in Tanzania. In their review report for water utilities performance for the financial year 2017/2018, they used 20 indicators. The indicators are rather situated on the traditional performance of the water utilities than the resilience against disasters. As an already existing regulatory body, suggestions are that their list of indicators be improved to encompass resilience indicators to be able to review the resilience performance of the Tanzania water utilities.

Similarly, the National Environmental Management Council (NEMC)-Tanzania is a designated body to ensure that environmental and social impacts assessments (EIA and ESIA) are conducted before the execution of any project in the country. Besides, NEMC is a designated body responsible for all environmental audit activities in the country. Some resilience aspects could be incorporated in the procedures for conducting EIA and later on be audited to determine the effectiveness of the implementation of the measures to the water supply systems resilience, especially in the environmental and social dimensions. Moreover, a separate government authority can be established to oversee all critical infrastructures resilience issues in the county, including for water supply system.

12.5 RESILIENCE TOOL IMPLEMENTATION PLAN FOR WATER SUPPLY SYSTEMS IN OTHER DEVELOPING COUNTRIES

Tanzania is not the only developing country whose water supply systems are vulnerable to the impact of disasters such as floods. In 2019 Mozambique and Zimbabwe experienced two cyclones leading to severe floods in the countries. Mauritius is always under the threat of cyclonic events, and heavy rainfalls and their water supply systems are affected. Many developing countries in Asia and Pacific are also vulnerable, and their water supply systems are not secure. These countries experience similar problems that affect the water supply systems ranging from technical, organizational, environmental, social, and economical. For instance; Mauritius, water supply systems, experience problems such as the age of infrastructure and political influences (Proag, 2016) which have been identified in the current research as affecting the resilience of water supply systems. Zimbabwe's annual per capita internal renewable water resource is less than 1000m^3/yr.c far less than that of Tanzania suggesting that the communities experience similar problems as for Tanzania when floods impact the water supply systems. As indicated earlier, the country is also flood-prone caused by cyclones developing in the Indian Ocean, leading to water borne diseases and damage to critical infrastructures, among others (Mavhura 2019).

Other developing countries also encompass informal settlements with poor populations which are highly vulnerable as the water supply systems are affected by floods; for instance, Kenya's Mombasa coastal city has a history of significant severe incidences of flooding with the health of the population living in the informal settlement being under great danger. Studies have shown that the majority experience problems getting drinking water during floods whereas some get water from wells, but the wells get contaminated with flooding water, and they still have to use the water because they have no other alternatives (Okaka & Odhiambo, 2019). Majority of the developing countries also have not fully implemented resilience strategies to prepare their water supply systems to the impacts of disaster. Such similarities show that majority experience similar resilience problems as in the Tanzania water supply systems. As such, since the tool that has been developed in the current research contains variables which were initially derived through integrating a wide-range of literature-based variables from various resilience measurement tools, there is high confidence that they have a generality nature and could be used in other developing countries. Little may need to be done to make the variables more appealing to other developing countries as the current forms were based on the expert's judgement elicitation focusing on Tanzania water supply system. Implementation of the resilience tool will thus follow the same guidelines as in the previous sections. Minor adjustments may exist in the setting of the context as stakeholders may differ from one country to another.

12.6 CONCLUSION

This chapter discussed the measures that can be used to address the resilience problems that emerged when the tool was evaluated in the selected Tanzania water supply systems. The tool has portrayed the capability to guide the users to decide on the measures that are appropriate for the enhancement of the water supply resilience. Measures suggested in this chapter aligns with the broadness of water supply systems in terms of the aspects that have an influence on their resilience, such as technical, organizational, environmental, social, and economical. The interactive nature of these aspects suggests that the measures are also interactive such that, measures from one dimension can influence improvements in other dimensions too. Overall measures have been set such that they can enhance the absorptive, adaptive, coping, and learning capacities in the water supply systems. In all cases, learning measures are required across all dimensions to ensure that water organizations continually refresh their management approaches on water supply systems to adapt to resilience-based approaches that will always enhance the capacity of their water supply systems to deliver the water supply service continuously—particularly in the context of a changing environment brought about by climate change. Besides, implementation guidelines developed in this chapter aligns with the need to carry out the resilience assessment in a consistent manner such that outcomes from different tool users may be easily comparable enhancing the effectiveness of the water organization, policy, and regulatory bodies.

Chapter 13
Conclusion and Recommendations

13.1 RESEARCH OVERVIEW

The research has indicated that water supply systems are always affected by the impacts of weather-related disasters such as floods. Developing countries such as Tanzania are already water-stressed and experience regular flood risks that have shown grave impacts on peoples' lives, infrastructure, and the economy. As flood risks to water supply systems are expected to rise due to climate change, un-functioning drainage systems, and poor planning, improving their resilience to prepare for future impacts is inevitable. The research attempted to propose an appropriate means to improve their resilience by developing a multi-dimensional measurement tool. In that quest, firstly, the study evaluated the concepts related to resilience and determining factors affecting resilience in the context of water supply systems. The factors were consequently pretested in Dar es Salaam to evaluate the on-ground resilience problems and the needs for developing a measurement tool. Secondly, the research developed a multi-dimensional qualitative tool for measuring water supply systems resilience encompassing five dimensions; technical, organizational, social, economic, and environmental and further tested in selected examples to show how it works. Thirdly, the research examined the content validity of the tool, followed by assessing the tool's applicability and generality, together with identifying resilience problems through evaluating in selected Tanzania water supply systems. Fourthly, the research discussed the improvement measures to the resilience problems, and the tool implementation plan to enable implementation of improvement measures in Tanzania and other developing countries, leading to sustainably enhanced water supply systems resilience. Each previous chapter provided specific conclusions, whereas the current chapter draws the general conclusion and recommendations from this research.

13.2 OBJECTIVE DEVELOPMENT

The research attained the *main objective* "to improve the Tanzania water supply systems resilience to flood hazards through developing a resilience measurement tool," by determining the concepts relating to resilience, factors and the problems affecting the resilience of water supply systems to create awareness to decision-makers on the problems that affect the water supply systems resilience in the country. Also, developing a validated multi-dimensional tool for measuring the resilience to floods of Tanzania water supply systems. The tool encompasses technical, organizational, social, environmental, and economic dimensions, which are appropriate in addressing the multi-dimensional problems of water supply systems. Such a tool contains measures and measurement scales applicable in assessing the resilience level of the water supply systems, identifying vulnerabilities, and prioritizing appropriate measures for enhancing the resilience. Moreover, the tool can assist in resources allocation for planning and budgeting to enhance the resilience of the water supply systems against the impacts of floods.

In achieving the *first objective*; the research in chapter two identified several concepts relating to resilience in the Tanzania water sector, including IWRM, vulnerability, risk management, and sustainability. Such concepts interact with one another, posing the need to identify their relationship in relation to resilience. The first principle of IWRM indicates that freshwater is a finite and vulnerable resource essential to sustain life, development and the environment. It aligns with the vulnerability of the water resources due to exposure to different risks. Such risks require risk management activities to avoid or limit the adverse effects of floods on the water supply systems. IWRM principles also lead to a sustainable water supply, thereby imposing protection measures such that the resource can suffice the current and future generation. Resilience and vulnerability are also interactive concepts; the current research suggests that resilience should be considered as a component of sustainability, thereby operating with the fact that increasing resilience makes the system sustainable. The emphasis is that evaluating and building resilience will enhance sustainability in the systems. As such, resilience improvement will reduce vulnerability – supporting the first principle of the IWRM, reduce risks, and enhance sustainability in the water supply system.

Chapter two and four suggest that factors ranging from technical, organizational, social, economic, and environmental have effects on the water supply systems such that water managers will need to put them into consideration when wanting to improve the resilience of their water supply systems. The factors are dependent on each other, requiring a carefully integrated treatment such as developed in the current research leading to a comprehensive list of issues that affect the systems. This group of factors that influence global water supply systems are also apparent in Tanzania water supply systems leading to systems vulnerability to weather-related risks such as floods. Such factors are useful in understanding the resilience of water supply systems. For instance, technical factors such as ageing infrastructure, insufficient rehabilitation, are influential on the ability of the physical infrastructure to withstand the impact of flooding. Poor management – organizational factor – influences the ability of the water organizations to respond and recover the water services from a potential flooding event. Rapid population growth – social factor – puts more pressure on the system due to rapid water demand increase that is not consistent with the infrastructure development, thus magnifying the consequences of flooding. Unbalanced systems investment is an economic factor where production systems are more invested than distribution systems, and rapid urbanization leading to environmental degradation affecting the water sources in terms of water availability and quality. Such an argument is evident as when pretested to Dar es Salaam water supply system; they show that the water supply system resilience needs improvements. The system experiences issues such as lacking alternative facilities for critical assets, significant water losses, rapid urbanization causing encroachment of human activities in the water catchments and recharge areas and lacking adequate preparedness from both the water organizations and the community for future impacts of flooding.

The *second objective* was covered in chapter five through ten where the research developed a multi-dimensional resilience measurement tool. The technical, organizational, social, economic, and environmental factors determined in the first objective entailed five dimensions that help to measure the resilience of water supply systems comprehensively. Each dimension contains variables that can be applied to measure and demonstrate how they can be applied to enhance the water supply system's resilience.

Variables in the technical dimension assess the ability of the physical components of water supply systems to continuously deliver water at the acceptable standards in terms of quantity and quality when hit by floods. The variables include "robustness," "system redundancy," "flexibility," and "safe-to-fail" principles and ten indicators spread throughout the principles. The most significant indicators are "system maintenance," "system future expansion capability," "system renewal," "critical spare parts and equipment availability," and "system connectedness." The indicators contain qualitative measures, and scales graduated based on the system performance. The scales enable the applicability of the variables by only scoring each measure based on the level of performance of the system pertinent to that particular measure.

Building on the ResOrg model, the research came out with a new model of the essential variables of organizational resilience and comprehensive assessment tools "measures and scales" to help guide the water suppliers in providing uninterrupted service, regardless of environmental conditions. Awareness of environmental issues, having an emergency response plan in place, providing staff and the public with opportunities to learn more about building resilience, clear and ongoing communications, and strong leadership emerged as the most important indicators for measuring the organizational resilience of water supply systems. Encompassing change readiness, leadership and culture, legal frameworks and institutional set-up, and networks and relationships, the new organizational model can guide water authorities' managers in developing processes to ensure uninterrupted services to their communities.

The water supply system is also constrained by environmental factors that play a significant role in the availability and quality of the water resources during flooding. Such factors are essential to address in order to enhance the resilience of the water supply systems. To that understanding, environmental variables encompassing factors such as environmental resources sensitivity, environmental capacity, natural floods attenuation, and natural assets are essential in assessing the environmental resilience for water supply systems. These factors contain a total of nine indicators, their measures and assessment scales that can reveal the level of environmental resilience and the weaknesses that may exacerbate the impact of flooding on the water supply system.

The communities served by the water supply systems are usually left stranded when the systems experience floods/disasters and are unable to deliver services at a required standard. In developing countries, for instance, the deprived population living in vulnerable areas are the most affected. The current developed social variables evaluate the way water users such as households, communities, institutions, and industries relate, network, and bond together to promote cooperation and linkup to exchange ideas and resources to facilitate rapid recovery aftermath. The variables contain nine indicators organized in five mechanisms for measuring social resilience. The most significant indicators include community awareness, preventive health measures, mitigation plan, location of houses, and community participation. Such variables include measures and measurement scales that can reveal the community's resilience position and the need for improvement to enhance their ability to cope with and recover from flooding impacts to water supply systems.

Moreover, the systems face economic factors such as those contributing to the ability of economic entities like individuals, households, societies, water supply authorities, and firms to use their economic resources to quickly recover or adjust to the loss of water supply services due to flooding. Economic dynamism referred to as the efficient use of resources over time for investment in repair and reconstruction, focusing on the speed of recovery of water supply systems from flooding impacts is a significant economic factor. This factor encompassing system investment proportionality, public-private-partnership, and cost recovery as the leading indicators and their measures and scales is useful to particularly portray the water organizations' readiness in terms of own financial resources, and the partnership with other stakeholders establish to improve resilience in the form of enhanced response and recovery of the water supply services.

All five dimensions integrate into a multi-dimensional tool for measuring water supply systems resilience that can enable the resilience assessors to examine the overall resilience of their water supply systems in a single assessment. In this case, engineering integrates with organizational, social, economic, and environmental aspects to provide operational decision making in managing water supply systems during floods. The tool is qualitative consisting of a conceptual framework and assessment tools relying on operators and managers, is flexible, easy to implement, and requires minimum computational requirements making it advantageous for the assessment of overall water supply systems resilience in developing countries such as Tanzania. The tool leads to an overall water supply system resilience semi-quantitative index (*OSR*) that indicates the resilience level of the water supply system, such that water managers can be able to understand the current capacity of their systems against flooding impacts.

For the *third objective*; the research in chapter 11 tested the tool's content validity, applicability and generality showing that the tool's validity is adequate, and the variables are useful in assessing the resilience of water supply systems in Tanzania – because there was significant group opinions and convergence of the opinions for the inclusion of the variables. There was at least .700 Cronbach's alpha for the final variables in all dimensions with an overall value of .975, indicating that the tool is a reliable measure. Most indicators showed a positive correlation meaning that they are consistent with each other with adequate relationship pattern in the dimensions. The level of agreement between the second and the third Delphi survey was significant showing that the experts reached a consensus regarding the tool's variables. The tool is applicable for Tanzania water supply systems as evaluation results assisted in examining the improvement needs and measures for enhancing resilience. The tool's generality is adequate as it was able to reveal the resilience position of all case studies of WSSAs showing similarities of resilience issues for most of the dimensions.

In the *fourth objective*; the research in chapter 12 suggested measures to address the resilience problems in line with the research's primary objective of improving the water supply systems resilience to floods. The tool has portrayed the capability to guide the users to decide on the measures that are appropriate for the enhancement of the water supply resilience. The measures align with the broadness of water supply systems in terms of the aspects that have an influence on their resilience, such as technical, organizational, environmental, social, and economical. The interactive nature of these aspects suggests that the measures are also interactive such that, measures from one dimension can influence improvements in other dimensions. The setting of the overall measures is such a way that they can enhance the absorptive, adaptive, coping, and learning (AACL) capacities in all dimensions of the water supply systems. In all cases, learning measures are crucial across all dimensions to ensure that water organizations continually refresh their management approaches on water supply systems to adapt to resilience-based approaches that will always enhance the capacity of their water supply systems to deliver the water supply service continuously. The identification of the measures is in such a flexible manner that allows the possibility of proposing new measures every time the assessors apply the tool to monitor the resilience identifying new emerging vulnerabilities in the context of climate change. Besides, the proposed implementation guidelines align with the need to carry out the resilience assessment in a consistent manner such that outcomes from different tool users may be easily comparable enhancing the effectiveness of the water organization, policy, and regulatory bodies.

13.3 PRACTICALITY, GENERALITY AND APPLICABILITY

The tool is qualitative, developed to meet the circumstances of developing countries like Tanzania, where data availability is a problem. The variables of the tool were subjected to experts' judgement elicitation through experienced Tanzania water and environmental experts to make them more appropriate to the environment of the country's water supply systems. Such experts have a better knowledge of needs, vulnerabilities, and coping capacities of their community, and the water supply systems. Such advantages are consistent with water supply systems containing several aspects of physical, organizational, social, economic, and, environmental nature. In the country, resilience is still a theoretical concept, as very few studies exist for measuring resilience, thus needing such a method as qualitative with minimum computational requirements, and easy to implement. Also, some indicators, measures and measurement scales align with local Tanzania National Water Policy and contributes to the implementation of the Tanzania Water Resources Management Act 2009 and are consistent with meeting the needs of the Paris Agreement and achieving the Sustainable Development Goals. Most information required during the assessment is from the WSSAs' internal data. Although in some instances, the assessor will need to liaise with other agencies to smoothen the assessment process. For instance, cooperation with the respective basin water offices will be needed to obtain current information regarding the environmental dimension resilience assessment. The WSSAs' could use their billing or communication systems to collect consumers' information to assess social resilience. The tool effectively portrayed the resilience indices of water supply systems in Tanzania, showing the weaknesses that need improvement in the selected systems. The systems are three water supply systems managed by Tanzanian WSSAs, as presented in chapter three. The cases differ from their technical capacities, water production capacities, population served, nature of the water sources and financial capabilities, representing about 26 other WSSAs across the country. Since the tool that has been developed in the current research contains variables which were initially derived through integrating a wide range of literature-based variables from various resilience measurement tools, there is high confidence that they have a generality nature and could be used in other developing countries. Little may need to be done to make the variables more appealing to other developing countries as the current forms were based on the expert's judgement elicitation focusing on the Tanzania water supply system. Implementation of the resilience tool will thus follow the same guidelines as presented in chapter 12. Minor adjustments may exist in the setting of the context as stakeholders may differ from one country to another.

13.4 RESEARCH CONTRIBUTIONS

The research makes several contributions;

- ❖ It entails the essential starting point for a comprehensive agreement regarding significant factors affecting the resilience of water supply systems in Tanzania through integrating several resilience characteristics into a comprehensive tool with five dimensions, 18 principles and 47 indicators with their measures and assessment scales.
- ❖ The methodology used in developing the tool involves a precise stage of processes that can easily be replicated and used to develop resilience tools for other systems with similar risks and geographical locations.
- ❖ The research provides five complete sets of assessment variables pertinent to the five dimensions of resilience, thereby giving flexibility for the water managers to choose to

either assess the resilience of individual dimensions or all dimensions assessed in a multi-dimensional resilience integrated assessment.

- ❖ Resilience assessment will utilize data that are mostly available at the water supply organizations for the technical, organizational, social, and economic dimensions. Besides, water supply organizations can use their billing and communication systems to obtain the information from the water users, for a more reliable social dimension assessment process. This is because most of the tool's variables passed the data availability attribute during the experts' assessment.
- ❖ The measures and assessment scales align with policies, regulations, and guidelines aligned to achieving national and international goals of improving the water supply services. Thus, by using the tool water managers will be preparing their water supply systems to comply with the Paris agreement, and achieve the Sustainable Development Goals related to water development (targets 6.1, 6.3, 6.4, and 6.6) and infrastructure resilience (targets 9.1 and 9 (a)).
- ❖ The tool assists in the implementation of the Tanzania Climate Change Strategy with strategic infrastructure objective for key sectors such as the ministry of water requires promoting deployment and use of appropriate technologies in infrastructure designing and development.
- ❖ The tool also aligns with the Sendai Framework for Disaster Risk Reduction, seven global targets 18(d): to substantially reduce disaster damage to critical infrastructure and disruption of essential services, including through developing their resilience by 2030.
- ❖ Along with the ability to examine the weaknesses of the water supply systems resilience, the tool provides means to propose and priorities the appropriate measures useful in planning and budgeting for improving the resilience of the water supply systems.
- ❖ Since the tool originated from a broad consultation of general concepts presented in the literature, it informs assessment variables that can apply in other developing and developed countries.

13.3 RESEARCH RECOMMENDATIONS

The research makes the following recommendations;

- The tool's variables were scrutinized by experts using six criteria – relevance, availability, affordability, reliability, simplicity, and transparency. Results show that data availability and affordability may pose a certain level of limitation to the assessment process, as WSSAs may not have all data readily available for conducting the assessment. The study recommends that WSSAs collaborate closely with other stakeholders such as the basin water offices, the Ministry of Water, and Tanzania Forest Services Agency (TFS).
- Since the data come from public sectors/institutions, there might be a certain degree of bias as the information may be exaggerated or downplayed. Besides, like other qualitative tools, there is a certain level of subjectivity in both scoring and weighting the variables. Thus, the research recommends to carry-out the initial scoring process in a group setting of well-skilled and knowledgeable staff.
- The water organizations may establish their weightings with the help of the equations developed in chapter 10 that align with their objectives and priorities, budget, and the risks to which their water supply system is exposed.
- Due to changing environmental risks in terms of magnitude and frequency, and evolution of new risks, the research recommends continuous testing and improving/refining of the tool after major events to keep it updated.
- Also, the research recommends improving the Water Policy (2002), Water Resources Management Act (2009/2019), Water Supply and Sanitation Act (2009/2019), to address resilience issues related to the water supply. Besides, the current Tanzania water supply and wastewater disposal design manual needs improvements to adapt resilience approaches, leading to the enhancement of the water supply systems' ability to survive the impacts of floods and other disasters.
- The Disaster Management Act 2015 establishes a disaster management agency as a focal point for coordinating disaster risk reduction and management activities, acting as a central coordinating and monitoring body for the prevention, mitigation, preparedness, response, and recovery to all disaster risks. Also, the agency is responsible for coordinating and monitoring inter-ministerial, multi-sectoral entities, and technical committees responsible for disaster management at all levels. As resilience is becoming an unavoidable undertaking to prepare for disaster impacts, the research recommends that according to the powers conferred in section 11 (1) the agency establish a directorate or section responsible for building resilience including in critical infrastructure such as water supply system. Such directorate may act as a

monitoring and evaluation body for the resilience implementations in various sectors, including water.

- ❖ Applying the implementation plan will promote consistent application of the tool such that results from different assessors can be easily compared, thereby reducing discrepancies.

13.4 RESEARCH LIMITATIONS

Despite the evident significance of using the tool to measure the water supply systems' resilience, possible limitations can be drawn. The tool's variables were scrutinized by experts using six criteria-relevance, availability, affordability, reliability, simplicity, and transparency. Results show that data availability and affordability may limit the assessment process, as WSSAs may not have readily available data for conducting the assessment. This problem can be resolved when the WSSAs collaborate closely with the basin water offices, the Ministry of water, and Tanzania Forest Services Agency (TFS). The data are obtained from public sectors/institutions so is the assessment. That may increase the degree of bias as information may be exaggerated or downplayed. Moreover, there is an expected level of subjectivity when assigning scores and weightings, to mitigate this, weightings and scores should be developed in a group setting of knowledgeable and skillful staff.

References

Acreman, M., & Holden, J. (2013). How wetlands affect floods. *Wetlands*, *33*(5), 773-786.

Adger, W. N. (2000). Social and ecological resilience: are they related?. *Progress in human geography*, *24*(3), 347-364.

Agarwal, J. (2015). Improving resilience through vulnerability assessment and management. *Civil Engineering and Environmental Systems*, *32*(1-2), 5-17.

Ahern, J. (2013). Urban landscape sustainability and resilience: the promise and challenges of integrating ecology with urban planning and design. *Landscape ecology*, *28*(6), 1203-1212.

Alexander, D. (2002). From civil defense to civil protection–and back again. *Disaster Prevention and Management: An International Journal*, *11*(3), 209-213.

Alshehri, S. A., Rezgui, Y., & Li, H. (2015). Disaster community resilience assessment method: a consensus-based Delphi and AHP approach. *Natural Hazards*, *78*(1), 395-416.

Amarasinghe, P. (2014). *Resilience of water supply systems in meeting the challenges posed by climate change and population growth.* Doctoral dissertation, Queensland University of Technology.

AQUASTAT. (2015). *Food and agricultural organization.* AQUASTAT Database. Accessed Online at, University of Auckland, New Zealand

Arrighi, C., Tarani, F., Vicario, E., & Castelli, F. (2017). Flood impacts on a water distribution network. *Natural Hazards and Earth System Sciences*, *17*(12), 2109-2123.

ARUP, SIWI. (2019). *The City Water Resilience Approach*. Rockefeller Foundation. https://www.arup.com/perspectives/city-water-resilience-approach

Assad, A., Moselhi, O., & Zayed, T. (2019). A New Metric for Assessing Resilience of Water Distribution Networks. *Water*, *11*(8), 1701

Bakkensen, L. A., Fox-Lent, C., Read, L. K., & Linkov, I. (2017). Validating resilience and vulnerability indices in the context of natural disasters. *Risk analysis*, *37*(5), 982-1004.

Balaei, B., Wilkinson, S., Potangaroa, R., Hassani, N., & Alavi-Shoshtari, M. (2018). Developing a Framework for Measuring Water Supply Resilience. *Natural Hazards Review*, *19*(4), 04018013.

Balaei, B., Wilkinson, S., Potangaroa, R., Adamson, C., & Alavi-Shoshtari, M. (2019). Social factors affecting water supply resilience to disasters. *International Journal of Disaster Risk Reduction*, *37*, 101187.

Barnes, P., Egodawatta, P., & Goonetilleke, A. (2012). *Modelling resilience in a water supply system: Contrasting conditions of drought and flood.* Kumamoto, Japan: Kumamoto University.

Bastaminia, A., Rezaei, M. R., & Dastoorpoor, M. (2017). Identification and evaluation of the components and factors affecting social and economic resilience in city of Rudbar, Iran. *International journal of disaster risk reduction*, *22*, 269-280.

Basupi, I., & Kapelan, Z. (2015). Flexible water distribution system design under future demand uncertainty. *Journal of Water Resources Planning and Management*, *141*(4), 04014067.

Bayliss, K., & Tukai, R. (2011). *Services and supply chains: The role of the domestic private sector in water service delivery in Tanzania.* United Nations Development Programme.

Bhattacharya, A., Meltzer, J. P., Oppenheim, J., Qureshi, Z., & Stern, N. (2016*). Delivering on Sustainable Infrastructure for Better Development and Better Climate.* Washington, DC: Brookings Institution.

Birkmann, J. (2006). Indicators and criteria for measuring vulnerability: Theoretical bases and requirements. In Birkmann, J. (Ed), *Measuring vulnerability to natural hazards: Towards disaster resilient societies*, 55-77. Tokyo, Japan: United Nations Press.

Boin, A., & McConnell, A. (2007). Preparing for critical infrastructure breakdowns: the limits of crisis management and the need for resilience. *Journal of Contingencies and Crisis Management*, *15*(1), 50-59.

Braasch, G. (2013). Climate change: Is seeing believing?. *Bulletin of the Atomic Scientists*, *69*(6), 33-41.

Brenkert, A. L., & Malone, E. L. (2005). Modeling vulnerability and resilience to climate change: a case study of India and Indian states. *Climatic Change*, *72*(1-2), 57-102.

Brody, S. D., Peacock, W. G., & Gunn, J. (2012). Ecological indicators of flood risk along the Gulf of Mexico. *Ecological Indicators*, *18*, 493-500.

Brown, C., Milke, M., & Seville, E. (2010). Waste management as a "Lifeline"? A New Zealand case study analysis. *International Journal of Disaster Resilience in the Built Environment*, *1*(2), 192-206.

Brown, B. (2012). *Planning for resilience in Oregon's coastal drinking water systems Oregon Sea Grant.* Oregon State, United states: Oregon State University.

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., et al. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra, 19*(4), 733-752.

Butler, D., Ward, S., Sweetapple, C., Astaraie-Imani, M., Diao, K., Farmani, R., et al. (2017). Reliable, resilient and sustainable water management: The safe & SuRe approach. *Global Challenges*, *1*(1), 63-77.

Cabell, J., & Oelofse, M. (2012). An indicator framework for assessing agroecosystem resilience. *Ecology and Society*, *17*(1).

Cadete, G., Rød, B., & da Silva, M. M. (2018). Implementation guidance for resilience management of critical infrastructure. In Haugen et al. (Eds) *Safety and Reliability–Safe Societies in a Changing World* (pp. 1923-1931). London, UK. Taylor & Francis Group.

Carvalho, H., Barroso, A. P., Machado, V. H., Azevedo, S., & Cruz-Machado, V. (2012). Supply chain redesign for resilience using simulation. *Computers & Industrial Engineering*, *62*(1), 329-341.

Casmiri, D. (2009). *Vulnerability of Dar es Salaam city to impacts of climate change.* Undated, unpublished paper. EPSM, Dar es Salaam, Tanzania

Chaudhry, P., & Ruysschaert, G. (2007). *Climate Change and Human Development in Viet Nam: A case study*. (Human Development Report 2007/2008). Hanoi, Vietnam: UNDP.

Chang, S. E., & Shinozuka, M. (2004). Measuring improvements in the disaster resilience of communities. *Earthquake spectra*, *20*(3), 739-755.

Choi, J., Naderpajouh, N., Yu, D. J., & Hastak, M. (2019). Capacity Building for an Infrastructure System in Case of Disaster Using the System's Associated Social and Technical Components. *Journal of Management in Engineering*, *35*(4), 04019013.

Christopherson, S., Michie, J., & Tyler, P. (2010). Regional resilience: theoretical and empirical perspectives. *Cambridge Journal of regions, economy, and society*, *3*(1), 3-10.

Cicchetti, D. V. (1984). On a model for assessing the security of infantile attachment: Issues of observer reliability and validity. *Behavioral and Brain Sciences*, *7*(1), 149-150.

Cimellaro, G. P., Renschler, C., Reinhorn, A. M., & Arendt, L. (2016). PEOPLES: a framework for evaluating resilience. *Journal of Structural Engineering*, *142*(10), 04016063.

Clarke J, Coaffee J, Rowlands R, Finger J, Hasenstein S, Siebold U (2016) Realising European ReSILiencE for Critical INfraStructure. Retrieved 21st May 2020 https://resilens.eu/wp-content/uploads/2016/01/D1.1-Resilience-Evaluation-and-SOTA-Summary-Report.pdf.

Collier, M. J., Nedović-Budić, Z., Aerts, J., Connop, S., Foley, D., Foley, K., ... & Verburg, P. (2013). Transitioning to resilience and sustainability in urban communities. *Cities*, *32*, S21-S28.

Comfort, L. K., Boin, A., & Demchak, C. C. (Eds.). (2010). *Designing Resilience: Preparing for extreme events*. Pennsylvania, USA: The University of Pittsburgh Pre.

Coppola, D. P. (2006). *Introduction to international disaster management*. Oxford, UK: Elsevier Inc.

Cox, R. S., & Hamlen, M. (2015). Community disaster resilience and the rural resilience index. *American Behavioral Scientist*, *59*(2), 220-237.

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. *Journal of homeland security and emergency management*, *7*(1).

Cutter, S. L. (2016). The landscape of disaster resilience indicators in the USA. *Natural hazards*, *80*(2), 741-758.

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. *Global environmental change*, *18*(4), 598-606.

Cutter, S. L. (2014, September). The Landscape of Resilience Measures. In *Presentation at the Resilient America 562 Roundtable Workshop on Measures of Community Resilience*.

Cutter, S. L., & Finch, C. (2008). Temporal and spatial changes in social vulnerability to natural hazards. *Proceedings of the National Academy of Sciences*, *105*(7), 2301-2306.

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social science quarterly, 84*(2), 242-261.

Davis, C. A., Mostafavi, A., & Wang, H. (2018). Establishing Characteristics to Operationalize Resilience for Lifeline Systems. *Natural Hazards Review*, *19*(4), 04018014.

de Bruijn, K., Buurman, J., Mens, M., Dahm, R., & Klijn, F. (2017). Resilience in practice: Five principles to enable societies to cope with extreme weather events. *Environmental Science & Policy*, *70*, 21-30.

de Guzman, E. M. (2003). *Towards total disaster risk management approach.* United National Office for the Coordination of Humanitarian Affairs: Asian Disaster Response Unit.

DeVon, H. A., Block, M. E., Moyle-Wright, P., Ernst, D. M., Hayden, S. J., Lazzara, D. J., ... & Kostas-Polston, E. (2007). A psychometric toolbox for testing validity and reliability. *Journal of Nursing scholarship*, *39*(2), 155-164.

Disaster Management Act, United Republic of Tanzania. (2015).

D'Lima, M., & Medda, F. (2015). A new measure of resilience: An application to the London Underground. *Transportation Research Part A: Policy and Practice*, *81*, 35-46.

Douglas, I., Alam, K., Maghenda, M., Mcdonnell, Y., McLean, L., & Campbell, J. (2008). Unjust waters: climate change, flooding and the urban poor in Africa. *Environment and urbanization*, *20*(1), 187-205.

Dungumaro, E. W., & Madulu, N. F. (2003). Public participation in integrated water resources management: the case of Tanzania. *Physics and Chemistry of the Earth, Parts A/B/C, 28*(20-27), 1009-1014.

Ehrhart, C. and Twena, M. (2006): *Climate Change and Poverty in Tanzania.* (Background report). Dar es Salaam, Tanzania: CARE International Poverty-Climate Change Initiative.

Eid, M. S., & El-Adaway, I. H. (2016). Sustainable disaster recovery decision-making support tool: Integrating economic vulnerability into the objective functions of the associated stakeholders. *Journal of Management in Engineering*, *33*(2), 04016041.

EM-DAT: The Emergency Events Database - Universite catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium https://www.emdat.be/emdat_db/

Energy and Water Utilities Regulatory Authorities Act, United republic of Tanzania. (2001)

Environmental Management Act, United Republic of Tanzania. (2004).

Ferguson, B., Brown, R., & Deletic, A. (2013). A diagnostic procedure for transformative change based on transitions, resilience, and institutional thinking. *Ecology and Society, 18*(4)

Fernández-Llamazares, C. M., Hernández-Gago, Y., Pozas, M., Cabañas, M. J., Feal, B., Villaronga, M., ... & Valverde, E. (2013). Two-round Delphi technique for the consensual design of a paediatric pharmaceutical care model. *Pharmacological Research*, *68*(1), 31-37.

Fiksel, J., I. Goodman, and A. Hecht. 2014. Resilience: Navigating toward a Sustainable Future. *Solutions*:1–13.

Fisher, R. E., Bassett, G. W., Buehring, W. A., Collins, M. J., Dickinson, D. C., Eaton, L. K., ... & Millier, D. J. (2010). *Constructing a resilience index for the enhanced critical infrastructure protection program* (No. ANL/DIS-10-9). Argonne, IL, United States: Argonne National Lab. (ANL).

Fisher, R., & Norman, M. (2010). Developing measurement indices to enhance protection and resilience of critical infrastructure and key resources. *Journal of business continuity & emergency planning*, *4*(3), 191-206.

Fleiss, J. L. (1971). Measuring nominal scale agreement among many raters. *Psychological bulletin*, *76*(5), 378

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., & Walker, B. (2002). Resilience and sustainable development: building adaptive capacity in a world of transformations. *AMBIO: A journal of the human environment, 31*(5), 437-440.

Gardner-Outlaw, T., & Engelman, R. (1997). *Sustaining water, easing scarcity: a second update*. (Revised data for the Population Action International Report. Sustaining Water: Population and the Future of Renewable Water Supplies). Washington DC: Population Action International.

García-Valiñas, M. Á., & Miquel-Florensa, J. (2013). Water service quality in Tanzania: access and management. *International journal of water resources development*, *29*(3), 451-471.

Gargon, E., Crew, R., Burnside, G., & Williamson, P. R. (2019). Higher number of items associated with significantly lower response rates in COS Delphi surveys. *Journal of clinical epidemiology*, *108*, 110-120.

GLOWS – FIU. 2014. *Climate, Forest Cover and Water Resources Vulnerability, Wami/Ruvu Basin, Tanzania*. 87 p. Florida, USA: Florida International University.

Gondwe, E. (1990). Water management in urban areas of a developing country. *Proceedings of the Hydrological Processes and Water Management in Urban Areas,* 337-340

Greatorex, J., & Dexter, T. (2000). An accessible analytical approach for investigating what happens between the rounds of a Delphi study. *Journal of advanced nursing*, *32*(4), 1016-1024

Guha-Sapir, D., Below, R., & Hoyois, P. (2016). *EM-DAT.2016. The OFDA/CRED International Disaster Database.* Belgium: Université Catholique De Louvain.

Habiba, U., Abedin, M. A., & Shaw, R. (2013). Defining water insecurity. In *Water Insecurity: A Social Dilemma* (pp. 3-20). UK: Emerald Group Publishing Ltd.

Hák, T., Janoušková, S., & Moldan, B. (2016). Sustainable Development Goals: A need for relevant indicators. *Ecological Indicators*, *60*, 565-573.

Hansen, J. (2012) James Hansen: Why I must speak out about climate change. TED Talk, February. Retrieved on 21st May 2020 www.ted.com/talks/james_hansen_why_i_must_speak_ out_about_climate_change.ht

Hasson, F., Keeney, S., & McKenna, H. (2000). Research guidelines for the Delphi survey technique. *Journal of Advanced Nursing,* 32 (4), 1008-1015.

Hirji, R., Davis, R., & Brown, F. A. (2009). *Improving Water Security for Sustaining Livelihoods and Growth in Tanzania.* (Water P-Notes; No. 23). World Bank, Washington, DC: World Bank.

Higgins, L., Koutsouris, A. J., Westerberg, L., & Risberg, J. (2016). Surface area variability of a north-central Tanzanian crater lake. *Geosciences*, *6*(2), 27.

Holey, E. A., Feeley, J. L., Dixon, J., & Whittaker, V. J. (2007). An exploration of the use of simple statistics to measure consensus and stability in Delphi studies. *BMC medical research methodology*, *7*(1), 52.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, *4*(1), 1-23.

Hosseini, S., Barker, K., & Ramirez-Marquez, J. E. (2015). A review of definitions and measures of system resilience. *Reliability Engineering & System Safety*, *145*, 47-61.

Howard, G., & Bartram, J. (2010). *The resilience of water supply and sanitation in the face of climate change.* (Technical Report). Geneva, Switzerland: World Health Organization.

Hsu, C. C., & Sandford, B. A. (2007). The Delphi technique: making sense of consensus. *Practical assessment, research & evaluation*, *12*(10), 1-8. https:// scholarworks.umass.edu/pare/vol12/iss1/10

Hwang, H., Forrester, A., & Lansey, K. (2013). Resilience of regional water supply systems. *World Environmental and Water Resources Congress 2013: Showcasing the Future,* pp. 946-954.

Hughes, J. F., & Healy, K. (2014). *Measuring the resilience of transport infrastructure.* (NZ Transport Agency research report 546). Wellington, New Zealand: NZ Transport Agency

Irajifar, L., Alizadeh, T., & Sipe, N. (2013, May). Disaster resiliency measurement frameworks: State of the art. In *S. Kajewski, K. Manley, & K. Hampson. Presented at the World Building Congress.* Brisbane, Australia.

Independent Evaluation Group (2006), *Hazards of Nature: Risks to Development. An IEG Evaluation of World Bank Assistance for Natural Disasters.* page 48. Washington DC, USA: World Bank.

Intergovernmental Panel on Climate Change. (2014). *Climate Change 2014–Impacts, Adaptation and Vulnerability: Regional Aspects*. Cambridge, UK: Cambridge University Press.

IPCC. (2018). Summary for Policymakers. In Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.). *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. In Press.

Ispas, D. & Borman, W. C. (2015) Personnel Selection, Psychology of. *International Encyclopedia of the Social & Behavioral Sciences* (2nd Ed. pp 936-940). Elsevier Ltd

Jayaraman, V., Chandrasekhar, M.G. and Rao, U.R. (1997), "Managing the natural disasters from space technology inputs." *Acta Astronautica*, Vol. 40 Nos 2/8, pp. 291-325.

JICA (February 2013). *The Study on Water Resources Management and Development in Wami/Ruvu Basin in the United Republic of Tanzania* (Main Report-Interim Word Version). Dar es Salaam, Tanzania: Japan International Cooperation Agency (JICA) on behalf of Tanzanian Ministry of Water.

JICA (Japan International Cooperation Agency), 2012. *The Study on Water Resources Management and Development in Wami/Ruvu Basin in the United Republic of Tanzania*. (Progress Report 2). Dar es Salaam, Tanzania: Japan International Cooperation Agency (JICA) on behalf of Tanzanian Ministry of Water

Jiménez, A., & Pérez-Foguet, A. (2010). Challenges for water governance in rural water supply: lessons learned from Tanzania. *International Journal of Water Resources Development*, *26*(2), 235-248.

Johannessen, Å., & Wamsler, C. (2017). What does resilience mean for urban water services?. *Ecology and Society*, *22*(1).

Jones, A. E., Wort, U. U., Morse, A. P., Hastings, I. M., & Gagnon, A. S. (2007). Climate prediction of El Niño malaria epidemics in north-west Tanzania. *Malaria journal*, *6*(1), 162.

Jovanovic, A., Klimek, P., Choudhary, A., Schmid, N., Linkov, I., Øien, K., & Lieberz, D. (2016). *Analysis of existing assessment resilience approaches, indicators and data sources: Usability and limitations of existing indicators for assessing, predicting and monitoring critical infrastructure resilience.* (IVL Report No. E 002). Stuttgart, Germany: EU-VRi – European Virtual Institute for Integrated Risk Management.

Juan-García, P., Butler, D., Comas, J., Darch, G., Sweetapple, C., Thornton, A., & Corominas, L. (2017). Resilience theory incorporated into urban wastewater systems management. State of the art. *Water research*, *115*, 149-161.

Jung, D., Kang, D., Kim, J. H., & Lansey, K. (2014). Robustness-based design of water distribution systems. *Journal of Water Resources Planning and Management*, *140*(11), 04014033.

Kajitani, Y., & Tatano, H. (2009). Estimation of lifeline resilience factors based on surveys of Japanese industries. *Earthquake Spectra*, *25*(4), 755-776.

Kanza, G.G. and Ndesamburo, J. (1996). An Approach Towards Solving Water Related Environmental Problems in Dar Es Salaam City.- In: Niemczynowicz J (ed.) *Environmental Research Forum Vol. 3-4, Searches for New, Realistic Approaches with Respect to the Developing World.* Proceedings of the International Symposium held in Lund, Sweden, 26.-30. September 1995 within UNESCO International Hydrological Programme (UNESCO-IHP) (pp 379-394). Switzerland: Transtec Publications.

Karamouz, M., Saadati, S., & Ahmadi, A. (2010). Vulnerability assessment and risk reduction of water supply systems. *World Environmental and Water Resources Congress 2010: Challenges of Change*, pp. 4414-4426.

Karamouz, M., Taheri, M., Khalili, P., & Chen, X. (2019). Building infrastructure resilience in coastal flood risk management. *Journal of Water Resources Planning and Management*, *145*(4), 04019004.

Khatavkar, P., & Mays, L. W. (2019). Resilience of Water Distribution Systems during Real-Time Operations under Limited Water and/or Energy Availability Conditions. *Journal of Water Resources Planning and Management, 145*(10), 04019045.

Kassenga, G. R. and Mbuligwe, S.E. (2009). “Comparative assessment of physico-chemical quality of bottled and tap water in Dar Es Salaam, Tanzania”. *International Journal of Biological and Chemical Sciences*. Vol. 3; No. 2; pp. 209-217.

Kebede, A. S., & Nicholls, R. J. (2012). Exposure and vulnerability to climate extremes: population and asset exposure to coastal flooding in Dar es Salaam, Tanzania. *Regional Environmental Change*, *12*(1), 81-94.

Khaled, A. A., Jin, M., Clarke, D. B., & Hoque, M. A. (2015). Train design and routing optimization for evaluating criticality of freight railroad infrastructures. *Transportation Research Part B: Methodological*, *71*, 71-84.

Khalili, S., Harre, M., & Morley, P. (2015). A temporal framework of social resilience indicators of communities to flood, case studies: Wagga Wagga and Kempsey, NSW, Australia. *International Journal of Disaster Risk Reduction*, *13*, 248-254.

Kijazi, A. L., & Reason, C. J. C. (2009). Analysis of the 2006 floods over northern Tanzania. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *29*(7), 955-970.

Kjellén, M. (2008). Structural leakage in Dar es Salaam: The investment deficit in water distribution. *Meeting Global Challenges in Research Cooperation,* pp. 304.

Kjellén, M. (2000). Complementary water systems in Dar es Salaam, Tanzania: The case of water vending. *International Journal of Water Resources Development*, *16*(1), 143-154.

Klein, R. J., Nicholls, R. J., & Thomalla, F. (2003). Resilience to natural hazards: How useful is this concept? *Global Environmental Change Part B: Environmental Hazards, 5*(1), 35-45.

Klise, K. A., Murray, R., & Walker, L. T. N. (2015). *Systems measures of water distribution system resilience* (Technical Report No. SAND2015-20746R). Albuquerque, NM United States. Sandia National Lab. (SNL-NM).

Kotzee, I., & Reyers, B. (2016). Piloting a social-ecological index for measuring flood resilience: A composite index approach. *Ecological Indicators, 60*, 45-53.

Kusumastuti, R. D., Husodo, Z. A., Suardi, L., & Danarsari, D. N. (2014). Developing a resilience index toward natural disasters in Indonesia. *International journal of disaster risk reduction*, *10*, 327-340.

Kwok, A. H., Doyle, E. E., Becker, J., Johnston, D., & Paton, D. (2016). What is 'social resilience'? Perspectives of disaster researchers, emergency management practitioners, and policymakers in New Zealand. *International Journal of Disaster Risk Reduction*, *19*, 197-211.

Kyessi, A. G. (2001). Community-based urban water management under scarcity in Dar es Salaam, Tanzania. *The Journal of Building and Land Development*, *8*(1-3), 28-41.

Labaka, L., Comes, T., Hernantes, J., Sarriegi, J. M., & Gonzalez, J. J. (2014, January). Implementation methodology of the resilience framework. In *2014 47th Hawaii International Conference on System Sciences* (pp. 139-148). IEEE.

Labaka, L., Hernantes, J., & Sarriegi, J. M. (2015). Resilience framework for critical infrastructures: An empirical study in a nuclear plant. *Reliability Engineering & System Safety*, *141*, 92-105.

Lakoff, G. (2012). Global warming systemically caused hurricane sandy.

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *biometrics*, 159-174. DOI: 10.2307/2529310

Lee, A. V., Vargo, J., & Seville, E. (2013). Developing a tool to measure and compare organizations' resilience. *Natural Hazards Review*, *14*(1), 29-41.

Limbumba, T. M., & Ngware, N. (2016). Informal Housing Options and Locations for Poor Urban Dwellers in Dar es Salaam City. *The Journal of Social Sciences Research*, *2*(5), 93-99.

Lin Moe, T., & Pathranarakul, P. (2006). An integrated approach to natural disaster management: public project management and its critical success factors. *Disaster Prevention and Management: An International Journal*, *15*(3), 396-413.

Liu, W. T. (2014). The application of resilience assessment—resilience of what, to what, with what? A case study based on Caledon, Ontario, Canada. *Ecology and Society*, *19*(4).

Luborsky, M. R. (1994). The identification and analysis of themes and patterns. In J. F. Gubrium & A. Sankar (Eds.), *Sage focus edition, Vol. 168. Qualitative methods in aging research* (p. 189–210). Sage Publications, Inc.

Maganga, F. P., Butterworth, J. A., & Moriarty, P. (2002). Domestic water supply, competition for water resources and IWRM in Tanzania: a review and discussion paper. *Physics and Chemistry of the Earth, Parts A/B/C*, *27*(11-22), 919-926.

Maguire, B., & Hagan, P. (2007). Disasters and communities: understanding social resilience. *Australian Journal of Emergency Management, The*, *22*(2), 16.

Manyena, S. B. (2006). The concept of resilience revisited. *Disasters, 30*(4), 434-450.

Mao, F., Clark, J., Karpouzoglou, T., Dewulf, A., Buytaert, W., & Hannah, D. (2017). HESS Opinions: A conceptual framework for assessing socio-hydrological resilience under change. *Hydrology & Earth System Sciences*, *21*(7).

Marchese, D., Reynolds, E., Bates, M. E., Morgan, H., Clark, S. S., & Linkov, I. (2018). Resilience and sustainability: Similarities and differences in environmental management applications. *Science of the total environment*, *613*, 1275-1283.

Marchese, D., Jin, A., Fox-Lent, C., & Linkov, I. (2020). Resilience for Smart Water Systems. *Journal of Water Resources Planning and Management*, *146*(1), 02519002.

Martin, R. (2011). Regional economic resilience, hysteresis, and recessionary shocks. *Journal of economic geography*, *12*(1), 1-32.

Martinelli, D., Cimellaro, G. P., Terzic, V., & Mahin, S. (2014). Analysis of economic resiliency of communities affected by natural disasters: the bay area case study. *Procedia Economics and Finance*, *18*, 959-968.

Marzi, S., Mysiak, J., Essenfelder, A. H., Amadio, M., Giove, S., & Fekete, A. (2019). Constructing a comprehensive disaster resilience index: The case of Italy. *PloS one*, *14*(9), e0221585.

Mato, R. R. (2002). *Groundwater pollution in urban Dar es Salaam, Tanzania: Assessing vulnerability and protection priorities*. Doctoral Thesis, Technische Universiteit Eindhoven, The Netherlands

Mattsson, L. G., & Jenelius, E. (2015). Vulnerability and resilience of transport systems–A discussion of recent research. *Transportation Research Part A: Policy and Practice, 81*, 16-34.

Maurya, S. P., Singh, P. K., Ohri, A., & Singh, R. (2019). Identification of indicators for sustainable urban water development planning. *Ecological Indicators*, *108*, 105691.

Mavhura, E. (2019). Systems Analysis of Vulnerability to Hydrometeorological Threats: An Exploratory Study of Vulnerability Drivers in Northern Zimbabwe. *International Journal of Disaster Risk Science, 10*(2), 204-219.

Mayunga, J. S. (2007). Understanding and applying the concept of community disaster resilience: a capital-based approach. *Summer academy for social vulnerability and resilience building*, *1*(1), 1-16.

Mayer, D.G. and Butler, D.G. (1993) Statistical Validation. *Ecological Modelling*, 68, 21-32.

Masys, A. (Ed.). (2015). *Disaster management: enabling resilience*. Springer.

Mayunga, J. S. (2009). *Measuring the measure: A multi-dimensional scale model to measure community disaster resilience in the US Gulf Coast region*. Doctoral Thesis, Texas A&M University, Texas.

Meijering, J. V., Tobi, H., & Kern, K. (2018). Defining and measuring urban sustainability in Europe: A Delphi study on identifying its most relevant components. *Ecological Indicators*, *90*, 38-46.

Messick, S. (1987). Validity. *ETS Research Report Series*, *1987*(2), i-208.

McCrickard, L. S., Massay, A. E., Narra, R., Mghamba, J., Mohamed, A. A., Kishimba, R. S., ... & Gibson, J. J. (2017). Cholera Mortality during Urban Epidemic, Dar es Salaam, Tanzania, August 16, 2015–January 16, 2016. *Emerging infectious diseases*, *23*(Suppl 1), S154.

McManus, S. T. (2008). *Organizational resilience in New Zealand.* Doctoral thesis, University of Canterbury, Christchurch, New Zealand.

Mitchell, T., Haris, K. (2012). *Resilience: A Risk Management approach.* (ODI Background Note 1-7). London, UK: Overseas Development Institute.

Monica Schoch-Spana et al. "Top-Down and Bottom-Up Measurement to Enhance Community Resilience to Disasters", *American Journal of Public Health* 109, no. S4 (September 1, 2019): pp. S265-S267.

Morley, K. M. (2012). *Evaluating Resilience in the Water Sector: Application of the Utility Resilience Index (URI).* Doctoral dissertation, George Mason University, Virginia.

Moteff, J. D. (2012). *Critical infrastructure resilience: the evolution of policy and programs and issues for congress*. Washington DC, USA: Congressional Research Service.

Mugume, S. N., Gomez, D. E., Fu, G., Farmani, R., & Butler, D. (2015). A global analysis approach for investigating structural resilience in urban drainage systems. *Water research*, *81*, 15-26.

Muller, G. (2012). Fuzzy architecture assessment for critical infrastructure resilience. *Procedia Computer Science*, *12*, 367-372.

National Bureau of Statistics (2017) *National Environmental Statistics Report.* (NESR report 2017). Dar es Salaam, Tanzania Mainland: National Bureau of Statistics.

National Bureau of Statistics-NBS (2015) *National Environmental Statistics Report.* (NESR report 2014). Dar es Salaam, Tanzania Mainland: National Bureau of Statistics-NBS

National Bureau of Statistics (NBS) and ICF Macro. (2011). *Tanzania demographic and health survey 2010.* Dar es Salaam, Tanzania: NBS and ICF Macro.

Newman, R., Ashley, R., Molyneux-Hodgson, S., & Cashman, A. (2011). Managing water as a socio-technical system: The shift from 'experts' to 'alliances.' *Proceedings of the Institution of Civil Engineers-Engineering Sustainability, 164.* (1) pp. 95-102.

Ngana, J. (2010). *Ruvu Basin: A Situation Analysis: Report for the Wami/Ruvu Basin Water Office*. Nairobi, Kenya: International Union for Conservation of Nature and Natural Resources (IUCN).

Nobert, J and Skinner, J (2016) *Meeting future demand for drinking water supply in Dar es Salaam: hydrological modelling of the Ruvu River and assessment of flows*. (IIED

Working Paper). London, UK: International Institute for Environment and Development (IIED).

Odada, E. O., Olago, D. O., Kulindwa, K., Ntiba, M., & Wandiga, S. (2004). Mitigation of environmental problems in Lake Victoria, East Africa: causal chain and policy options analyses. *Ambio: A journal of the human environment*, *33*(1), 13-23.

Okaka, F. O., & Odhiambo, B. D. (2019). Health vulnerability to flood-induced risks of households in flood-prone informal settlements in the Coastal City of Mombasa, Kenya. *Natural Hazards*, *99*(2), 1007-1029.

Oktari, R. S., Comfort, L. K., & Dwitama, P. (2020). Measuring coastal cities' resilience toward coastal hazards: Instrument development and validation. *Progress in Disaster Science*, *5*, 100057.

Oţoiu, A., & Grădinaru, G. (2018). Proposing a composite environmental index to account for the actual state and changes in environmental dimensions, as a critique to EPI. *Ecological indicators*, *93*, 1209-1221.

Paavola, J. (2008). Livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania. *Environmental Science & Policy, 11*(7), 642-654.

Pagano, A., Pluchinotta, I., Giordano, R., & Vurro, M. (2017). Drinking water supply in resilient cities: notes from L'Aquila earthquake case study. *Sustainable cities and society*, *28*, 435-449.

Pallela, E. (2000). *The impact of anthropogenic factors on urban wetlands: The case of Msimbazi valley, Dar es Salaam.* (Doctoral dissertation). Dar es salaam, Tanzania: University of Dar es Salaam.

Pan American Health Organization (1998) *Natural Disaster Mitigation in Drinking Water and Sewerage Systems: Guidelines for Vulnerability Analysis*. Washington D.C: Pan American Health Organization.

Parsons, M., Glavac, S., Hastings, P., Marshall, G., McGregor, J., McNeill, J., ... & Stayner, R. (2016). Top-down assessment of disaster resilience: A conceptual framework using coping and adaptive capacities. *International Journal of Disaster Risk Reduction*, *19*, 1-11.

Pavlova, V. (2016). *Strategies for city resilience to riverine floods. Case of Mzimbazi River, Dar es Salaam*. Master's thesis, Politecnico Di Milano, School of Architecture Urban Planning Construction Engineering.

Pearce, L. (2003). Disaster management and community planning, and public participation: how to achieve sustainable hazard mitigation. *Natural hazards*, *28*(2), 211-228.

Perry, H. (2013). *An Approach to Assessing the Resilience of the Water Service in England and Wales–Can we Answer the Question: Is the Service Resilient Or Brittle?*. Master's thesis, Birmingham, UK: University of Birmingham.

Petit, F., Buehring, W., Whitfield, R., Fisher, R., & Collins, M. (2011). Protective measures and vulnerability indices for the Enhanced Critical Infrastructure Protection Programme. *International Journal of Critical Infrastructures*, *7*(3), 200-219.

Prior, T. (2015). *Measuring critical infrastructure resilience: Possible indicators.* (Risk and Resilience Report, 9, 1-10). ETH Zürich: Center for Security Studies.

Prior, T., & Hagmann, J. (2014). Measuring resilience: methodological and political challenges of a trend security concept. *Journal of risk research*, *17*(3), 281-298.

Proag, V. (2016). Building resilience in the water supply network of Mauritius. *Water Utility Journal, 12: 39-48.*

Qasim, S., Qasim, M., Shrestha, R. P., Khan, A. N., Tun, K., & Ashraf, M. (2016). Community resilience to flood hazards in Khyber Pukhthunkhwa province of Pakistan. *International Journal of Disaster Risk Reduction*, *18*, 100-106.

Quandt, A. (2018). Measuring livelihood resilience: The household livelihood resilience approach (HLRA). *World Development*, *107*, 253-263.

Rashid, S. F. (2000). The urban poor in Dhaka City: their struggles and coping strategies during the floods of 1998. *Disasters*, *24*(3), 240-253.

Renschler, C., Frazier, A., Arendt, L., Cimellaro, G.P., Reinhorn, A.M., Bruneau, M. (2010). *"Framework for Defining and Measuring Resilience at the Community Scale: The PEOPLES Resilience Framework."* (MCEER Technical Report MCEER-10-006). New York, US: University of Buffalo.

Resilient Organizations. (2012). What is organizational resilience?. Retrieved from https://www.resorgs.org.nz/about-resorgs/what-is-organisational-resilience/

Rose, A. (2004). Defining and measuring economic resilience to disasters. *Disaster Prevention and Management: An International Journal*, *13*(4), 307-314.

Rose, A., and Liao, S. Y. (2005). "Modelling regional economic resilience to disasters: A computable general equilibrium analysis of water service disruptions." J. Reg. Sci., 45(1), 75–112.

Rose, A. (2007). Economic resilience to natural and man-made disasters: Multidisciplinary origins and contextual dimensions. *Environmental Hazards*, *7*(4), 383-398.

Rose, A. (2017). *Defining and measuring economic resilience from a societal, environmental and security perspective*. Singapore: Springer Nature Singapore Pte Ltd.

Rose, A., & Krausmann, E. (2013). An economic framework for the development of a resilience index for business recovery. *International Journal of Disaster Risk Reduction*, *5*, 73-83.

Rubin, C. B. (1991). Recovery from disaster. *Emergency Management: Principles and Practice for Local Government* 224-259. Washington DC: International City Management Association.

Rugemalila, R., & Gibbs, L. (2015). Urban water governance failure and local strategies for overcoming water shortages in Dar es Salaam, Tanzania. *Environment and Planning C: Government and Policy, 33*(2), 412-427.

Saja, A. A., Goonetilleke, A., Teo, M., & Ziyath, A. M. (2019). A critical review of social resilience assessment frameworks in disaster management. *International Journal of Disaster Risk Reduction*, 101096.

Sakijege, T., Lupala, J., & Sheuya, S. (2012). Flooding, flood risks and coping strategies in urban informal residential areas: The case of Keko Machungwa, Dar es Salaam, Tanzania. *Jàmbá: Journal of Disaster Risk Studies*, *4*(1), 1-10.

Sappa, G., Ergul, S., Ferranti, F., Sweya, L. N., & Luciani, G. (2015). Effects of seasonal change and seawater intrusion on water quality for drinking and irrigation purposes, in coastal aquifers of Dar es Salaam, Tanzania. *Journal of African Earth Sciences, 105*, 64-84.

Schaefer, M. P., & Dietrich, O. (2015). *Water resources situation in CSS.* (Deliverable 4.4.2). Müncheberg, Germany: Institute of Landscape Hydrology Leibniz Centre for Agricultural Landscape Research (ZALF).

Sharifi, A. (2016). A critical review of selected tools for assessing community resilience. *Ecological Indicators*, *69*, 629-647.

Shemsanga, C., Omambia, A., & Gu, Y. (2010). The cost of climate change in Tanzania: Impacts and adaptations. *J.Am.Sci*, *6*

Shemsanga, C., Muzuka, A. N. N., Martz, L., Komakech, H., & Mcharo, E. (2018). Indigenous knowledge on development and management of shallow dug wells of Dodoma Municipality in Tanzania. *Applied Water Science*, *8*(2), 59.

Shirali, G. A., Mohammadfam, I., & Ebrahimipour, V. (2013). A new method for quantitative assessment of resilience engineering by PCA and NT approach: A case study in a process industry. *Reliability Engineering & System Safety*, *119*, 88-94.

Silva, J. D., & Morera, B. E. (2014). *City Resilience Framework: City Resilience Index.* London, UK: Rockefeller Foundation and Arup International Development.

Sinisi, L., & Aertgeerts, R. (Ed). (2011). *Guidance on water supply and sanitation in extreme weather events.* Copenhagen, Denmark: World Health Organization, & United Nations-Economic Commission for Europe.

Smiley, S. L. (2016). Water availability and reliability in Dar es Salaam, Tanzania. *The Journal of Development Studies*, *52*(9), 1320-1334.

Smith, H. M. (2014). 33. Understanding resilience: Implications for the water sector. *Global Water: Issues and Insights*, *193*.

Sokile, C. S., Mwaruvanda, W., & Van Koppen, B. (2005). Integrated water resource management in Tanzania: Interface between formal and informal institutions. *Conference African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa,* pp. 26-28.

Soldi, D., Candelieri, A., & Archetti, F. (2015). Resilience and vulnerability in urban water distribution networks through network theory and hydraulic simulation. *Procedia Engineering*, *119*, 1259-1268.

Specht, A. (2006). Natural disaster management. *Tourism in Turbulent Times: Towards Safe Experiences for Visitors*, 123-42.

Speranza, C. I., Wiesmann, U., & Rist, S. (2014). An indicator framework for assessing livelihood resilience in the context of social–ecological dynamics. *Global Environmental Change*, *28*, 109-119.

Steele, R., Bosma, H., Johnston, M. F., Cadell, S., Davies, B., Siden, H., & Straatman, L. (2008). Research priorities in pediatric palliative care: a Delphi study. *Journal of palliative care*, *24*(4), 229-239.

Stevenson, S. R., Vargo, J., Ivory, V., Bowie, C., & Wilkinson, S. (2015). *Resilience Benchmarking and Monitoring Review*. (Working paper, deliverable 1). New Zealand. National Science Challenges. Retrieved on 21st May 2020 https://www.resorgs.org.nz/wp-content/uploads/2017/07/nsc_rnc_full_report_july_2015_c.pdf

Suwaratchai, P., Sithisarankul, P., Sriratanban, J., Chenvidhya, D., & Phonburee, W. (2011). Utilize the modified Delphi technique to develop trauma care indicators. *Journal of The Medical Association of Thailand*, *91*(1), 99.

Sweya, L.N.; Wilkinson, S. and Kassenga, G. (2019) *Resilience improvement needs for public water supply systems in Dar Es Salaam.* (Contributing Paper to GAR 2019). Geneva, Switzerland: United Nations Office for Disaster Risk Reduction (UNDRR)

Sweya, L. N., Wilkinson, S., & Chang-Richard, A. (2018). Understanding Water Systems Resilience Problems in Tanzania. *Procedia Engineering*, *212*, 488-495.

Sweya, L. N., Wilkinson, S., Mayunga, J., Joseph, A., Lugomela, G., & Victor, J. (2020a). Development of a Tool to Measure Resilience against Floods for Water Supply Systems in Tanzania. *Journal of Management in Engineering*, *36*(4), 05020007.

Sweya, L. N., Wilkinson, S., Kassenga, G., & Mayunga, J. (2020b). Developing a tool to measure the organizational resilience of Tanzania's water supply systems. *Global Business and Organizational Excellence*.

Sweya, L. N., & Wilkinson, S. (2020). A tool for measuring environmental resilience to floods in Tanzania water supply systems. *Ecological Indicators*, *112*, 106165.

Tate, E. C. (2011). *Indices of social vulnerability to hazards: model uncertainty and sensitivity.* (Doctoral dissertation). South Carolina, Columbia: University of South Carolina.

Teglasi, H. (1998). Assessment of schema and problem-solving strategies with projective techniques. *Comprehensive Clinical Psychology* Volume 4, Pages 459-499.

Tierney, K., & Bruneau, M. (2007). Conceptualizing and measuring resilience: A key to disaster loss reduction. *TR News*, (250).

Tierney, K. J. (1997). Business impacts of the Northridge earthquake. *Journal of Contingencies and crisis management*, *5*(2), 87-97.

Tkemaladze, G. S., & Makhashvili, K. A. (2016). Climate changes and photosynthesis. *Annals of Agrarian Science*, *14*(2), 119-126.

UN-Water. (2013). *Country Briefs United republic of Tanzania*. New York, USA: United Nations.

UNCC (2019). *Climate Actions and Support Trends*. Bonn, Germany: United Nations Climate Change Secretariat. Retrieved from https://unfccc.int/sites/default/files/resource/

UNDP (2019) *Nasolo Village, Fiji Country Case Study on Enhanced Income Security through a Risk Informed Farm Road, for GAR19.* Geneva, Switzerland: United Nations Office for Disaster Risk Reduction (UNDRR)

UNDRR (2019). *Global Assessment Report on Disaster Risk Reduction.* Geneva, Switzerland: United Nations Office for Disaster Risk Reduction (UNDRR).

Ungar, M. (2003). Qualitative contributions to resilience research. *Qualitative social work*, *2*(1), 85-102.

UNISDR. (2005). Hyogo framework for action 2005–2015: Building the resilience of nations and communities to disasters. In *Extract from the final report of the World Conference on Disaster Reduction (A/CONF. 206/6)* (Vol. 380). Geneva: The United Nations International Strategy for Disaster Reduction.

UNISDR (2009). *Terminology on Disaster Risk Reduction*. Geneva, Switzerland: United Nations.

UNISDR (2015, March). Sendai framework for disaster risk reduction 2015–2030. In *Proceedings of the 3rd United Nations World Conference on DRR, Sendai, Japan* (pp. 14-18).

United Nations. (n.d.) Sustainable development goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation. Retrieved on 21st May 2020 https://www.un.org/sustainabledevelopment/infrastructure-industrialization/

United Nations (2018) *Sustainable Development Goals Report*. New York, USA: United Nations.

United Nations (2015). Paris Agreement. Retrieved on 21st May 2020 https://unfccc.int/files/ essential_background/ convention/ application/pdf/

United Republic of Tanzania. (2002). *National water policy*. Dar Es Salaam, Tanzania: Ministry of Water and Livestock Development

United Republic of Tanzania (2006a). *Water Sector Development Programme (2005-2025)*. Dar Es Salaam, Tanzania: Ministry of Water

United Republic of Tanzania (2006b) *State of the Environment Report 2006*. Dar es Salaam, Tanzania: Vice President's Office, Division of Environment,

United Republic of Tanzania (2007) *National Adaptation Programme of Action*. Dar es Salaam, Tanzania: Vice President's Office, Division of Environment,

United Republic of Tanzania (2014) *State of the Environment Report 2014;* Dar es Salaam, Tanzania: Vice President's Office-Division of Environment.

United Republic of Tanzania. (2003). Initial National Communication under the United Nations Framework Convention on Climate Change, (UNFCCC). Dar es Salaam, Tanzania: Vice-President's Office (VPO)-Government printers.

United Republic of Tanzania (2012a). *Performance Audit Report on the Management of Water Distribution in Urban Areas*. Dar es Salaam, Tanzania: National Audit Office.

United Republic of Tanzania (2012b). *Population and housing census: Population distribution by administrative areas*. Dar Es Salaam, Tanzania: Ministry of Finance.

United Republic of Tanzania (2012c). *National Climate Change Strategy*. Dar Es Salaam, Tanzania, Vice President's Office, Division of Environment.

United Republic of Tanzania (2015). *Guidelines for The Preparation of Water Safety Plans - Resilient to Climate Change for Urban Water Supply Utilities*. Dar Es Salaam, Tanzania: Ministry of Water.

United Republic of Tanzania. (2017a). *Water Utilities Performance Review Report for the FY 2016/2017: Regional and National Project Water Utilities*. Dar Es Salaam, Tanzania: Energy and Water Utilities Regulatory Authority.

United Republic of Tanzania (2017b). *Securing Watershed Services through Sustainable Land Management in the Ruvu and Zigi Catchments (Eastern Arc Region).* Morogoro, Tanzania: Wami/Ruvu Basin Office.

United Republic of Tanzania (2008a). *National Water sector Development Strategy.* Dar Es Salaam, Tanzania: Ministry of Water and Irrigation.

United Republic of Tanzania. (2008b). *Water Sector Performance report.* Dar es Salaam, Tanzania: Ministry of Water and Irrigation.

United Republic of Tanzania (2016). *Tanzania Demographic and Health Survey and Malaria Indicator Survey 2015-2016 Final Report.* Dar es Salaam, Tanzania and Rockville, Maryland, USA: Ministry of Health, Community Development, Gender, Elderly and Children (MoHCDGEC)[Tanzania Mainland], Ministry of Health (MoH)[Zanzibar], National Bureau of Statistics (NBS), Office of the Chief Government Statistician (OCGS), and ICF.

United Republic of Tanzania (2018). *Water utilities performance review report for the financial year 2017/2018.* Dar es Salaam, Tanzania: Energy and Water Utilities Regulatory Authority (EWURA).

United Republic of Tanzania (2009). *Design Manual for Water Supply and Wastewater Disposal.* Dar es Salaam, Tanzania: Ministry of water.

Van Leuven, L. J. (2011). Water/wastewater infrastructure security: Threats and vulnerabilities. *Handbook of water and wastewater systems protection* (pp. 27-46) Springer.

Villagrán_De_León, J. C. (2006). Vulnerability assessment in the context of disaster-risk, a conceptual and methodological review. *SOURCE No. 4, 2006*. Bonn, Germany: United Nations University-Institute of Environment and Human Security.

Vugrin, E. D., Warren, D. E., Ehlen, M. A., & Camphouse, R. C. (2010). A framework for assessing the resilience of infrastructure and economic systems. *Sustainable and resilient critical infrastructure systems* (pp. 77-116) Springer.

Vugrin, E. D., Warren, D. E., & Ehlen, M. A. (2011). A resilience assessment framework for infrastructure and economic systems: Quantitative and qualitative resilience analysis of petrochemical supply chains to a hurricane. *Process Safety Progress*, *30*(3), 280-290.

Vugrin, E. D., Turnquist, M. A., & Brown, N. J. (2014). Optimal recovery sequencing for enhanced resilience and service restoration in transportation networks. *IJCIS*, *10*(3/4), 218-246.

Wakai, A., O'Sullivan, R., Staunton, P., Walsh, C., Hickey, F., & Plunkett, P. K. (2013). Development of key performance indicators for emergency departments in Ireland using an electronic modified-Delphi consensus approach. *European Journal of Emergency Medicine*, *20*(2), 109-114.

Walker LO, Avant KC. (2004) *Strategies for Theory Construction in Nursing* (4th ed.). Upper Saddle River, NJ, USA: Pearson Education.

Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S., & Schultz, L. (2006). A handful of heuristics and some propositions for understanding resilience in social-ecological systems. *Ecology and society*, *11*(1).

Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and society*, *9*(2).

Wang, C. H., & Blackmore, J. M. (2009). Resilience concepts for water resource systems. *Journal of Water Resources Planning and Management*, *135*(6), 528-536.

Ward, S., & Butler, D. (2016). Rainwater harvesting and social networks: Visualising interactions for niche governance, resilience, and sustainability. *Water*, *8*(11), 526.

Ward, S., Borden, D. S., Kabo-Bah, A., Fatawu, A. N., & Mwinkom, X. F. (2019). Water resources data, models and decisions: International expert opinion on knowledge management for an uncertain but resilient future. *Journal of Hydroinformatics,* 21(1), 32-44.

Water resources management Act, United republic of Tanzania. (2009).

Water Supply and Sanitation Act, United Republic of Tanzania (2009).

WaterAid. (2008). Why did City Water fail? The rise and fall of private sector participation in Dar es Salaam's water supply. *WaterAid Tanzania, Dar es Salaam*.

Watts, L. (2012). Capturing Indigenous Knowledge in water management processes. *New Left Review*, *212*, 68-93.

Way, C. (2015). *The millennium development goals report 2015*. New York: United Nations.

White, C. (2014). *Integrated Water Resources Management: What is it and why is it used.* GWF Discussion Paper 1324. Canberra, Australia: Global Water Forum.

Willis, H. H., & Loa, K. (2015). *Measuring the resilience of energy distribution systems.* Santa Monica, Calif: RAND Corporation.

Windle, G. (2011). What is resilience? A review and concept analysis. *Reviews in Clinical Gerontology*, *21*(2), 152-169.

World Bank. (2018). Reaching for the SDGs: *The Untapped Potential of Tanzania's Water Supply, Sanitation, and Hygiene Sector. WASH Poverty Diagnostic*. Washington, DC: World Bank.

World Bank (2019) *Tanzania: Country Environmental Analysis-Environmental Trends and Threats, and Pathways to Improve Sustainability*. Washington DC: World Bank.

World Economic Forum (2020) *The Global Risk Report, 15th edition Insight Report*, Geneva, Switzerland: World Economic Forum.

World Economic Forum (2019). *Global Risks Report; 14th edition*. World Economic Forum, Geneva : World Economic Forum.

World Economic Forum (2017) *The Global Risk Report, 12th Edition Insight Report*, Geneva, Switzerland: World Economic Forum.

World Health Organization, & UNICEF. (2015). *Progress on sanitation and drinking water–2015 update and MDG assessment.* Geneva, Switzerland: World Health Organization Press.

Wynd, C. A., Schmidt, B., & Schaefer, M. A. (2003). Two quantitative approaches for estimating content validity. *Western journal of nursing research*, *25*(5), 508-518.

Yanda, P. Z., & Munishi, P. K. T. (2007). *Hydrologic and land use/cover change analysis for the Ruvu River (Uluguru) and Sigi River (East Usambara) watersheds.* Dar es Salaam, Tanzania: WWF/CARE.

Yang, Y., Ng, S. T., Xu, F. J., Skitmore, M., & Zhou, S. (2019). Towards resilient civil infrastructure asset management: An information elicitation and analytical framework. *Sustainability*, *11*(16), 4439.

Zhang, Y. J., & Hao, J. F. (2016). The evaluation of environmental capacity: evidence in Hunan province of China. *Ecological indicators*, *60*, 514-523.

Zhong, S., Clark, M., Hou, X. Y., Zang, Y., & FitzGerald, G. (2015). Development of key indicators of hospital resilience: a modified Delphi study. *Journal of health services research & policy*, *20*(2), 74-82.

http://www.tanzaniatoday.co.tz/news/dawasco-yatangaza-kukosekana-huduma-ya-maji-kwa-siku-mbili-jijini-dar (18th March 2018)

http://www.dawasco.go.tz/waterservices.html (18th March 2018)

https://issamichuzi.blogspot.co.nz/2018/03/waziri-wa-maji-azungumzia-umuhimu-wa.html (21st March 2018)

http://dawasa.go.tz/facilities (August 2018)

https://www.who.int/globalchange/resources/wash-toolkit/tanzania-climate-change-health-wash.pdf (last access 28th May 2019)

https://www.undp.org/content/dam/undp/library/corporate/brochure/SDGs_Booklet_Web_En.pdf (last access 4th September 2019)

https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf (last access 4th September 2019)

https://www.weforum.org/events/world-economic-forum-annual-meeting-2019 (last access 17th January 2020)

http://www.tawasanet.or.tz/files/Tanzania%20water%20policy%20-%202002.pdf (last access 4th September 2019)

https://unstats.un.org/unsd/environment/envpdf/UNSD_UNEP_ECOWAS%20Workshop/Session%2004-4-1%20Introduction%20to%20water%20statistics%20 (UNSD).pdf (Last access 6th January 2020)

https://www.preventionweb.net/english/policies/v.php?id=68441&cid=184

https://www.undrr.org/terminology/disaster (Last access 27th September 2020)

https://www.macrotrends.net/cities/22894/dar-es-salaam/population (Last access 10th September 2020)

https://www.macrotrends.net/cities/22898/morogoro/population (Last access 10th September 2020)

http://extwprlegs1.fao.org/docs/pdf/tan171056.pdf (Last access 28th September 2020)

www.thecitizen.co.tz/News/Five-NEMC-officials-charged/1840340-4831472-14b4pt3z/index.html (Last access 28th September 2020)

www.dailynews.co.tz/news/two-nemc-officials-in-court-over-bribery-charges.aspx (Last access 28th September 2020)

https://www.dailynews.co.tz/news/floods-cost-tanzania-us-2billion-annually.aspx (Last access 28th September 2020)

https://www.maji.go.tz (Last access 28th September 2020)

Appendix 1: Ethics

Research Office
Post-Award Support Services

The University of Auckland
Private Bag 92019
Auckland, New Zealand

Level 10, 49 Symonds Street
Telephone: 64 9 373 7599
Extension: 83711
Facsimile: 64 9 373 7432
ro-ethics@auckland.ac.nz

UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE (UAHPEC)

18-Aug-2017

MEMORANDUM TO:

Prof Suzanne Wilkinson
Civil and Environmental Eng

Re: Application for Ethics Approval (Our Ref. 019619): Approved with comment

The Committee considered your application for ethics approval for your study entitled **Improving Water Supply System Resilience to Flood: Developing a Measurement Tool for Tanzania.**

Ethics approval was given for a period of three years with the following comment(s):

1. Please proof-read item 2 in the CF: organisation.

The expiry date for this approval is 18-Aug-2020.

If the project changes significantly you are required to resubmit a new application to UAHPEC for further consideration.

If you have obtained funding other than from UniServices, send a copy of this approval letter to the Activations team in the Research Office, at ro-awards@auckland.ac.nz. For UniServices contracts, send a copy of the approval letter to the Contract Manager, UniServices.

The Chair and the members of UAHPEC would be happy to discuss general matters relating to ethics approvals if you wish to do so. Contact should be made through the UAHPEC Ethics Administrators at ro-ethics@auckland.ac.nz in the first instance.

Please quote Protocol number **019619** on all communication with the UAHPEC regarding this application.

(This is a computer generated letter. No signature required.)

UAHPEC Administrators

University of Auckland Human Participants Ethics Committee

c.c. Head of Department / School, Civil and Environmental Eng
Mr Lukuba Sweya

Additional information:

1. Do not forget to fill in the 'approval wording' on the Participant Information Sheets, Consent Forms and/or advertisements, giving the dates of approval and the reference number. This needs to be completed, before you use them or send them out to your participants.

2. At the end of three years, or if the study is completed before the expiry, you are requested to advise the Committee of its completion.

3. Should you require an extension or need to make any changes to the project, please complete the online Amendment Request form associated with this approval number giving full details along with revised documentation. If requested before the current approval expires, an extension may be granted for a further three years, after which time you must submit a new application.

Department of Civil and Environmental Engineering,
Faculty of Engineering,
Engineering Building,
20 Symonds Street.
Telephone 64 9 3737599 ext 88166
www.cee.auckland.ac.nz

The University of Auckland,
Private Bag 92019,
Auckland 1142,
New Zealand.

PARTICIPANT INFORMATION SHEET

Permanent Secretary,
Ministry of Water and Irrigation,
Telephone: 022 2450838/40-41
NBC Mazengo Branch
Fax: 022 2450533
Kuu Street
E-mail: psmw@maji.go.tz
P.O. Box 456,
Dodoma, Tanzania.

Research Project Title: Improving Water Supply System Resilience to Flood: Developing a Measurement Tool for Tanzania

Name of Researcher: Lukuba Ngalya Sweya
Degree: PhD in Civil Engineering (Disaster Management)
Department: Civil & Environmental Engineering
Research Supervisors: Professor Suzanne Wilkinson and Doctor Alice Chang-Richard
My name is Lukuba N. Sweya; I am a doctoral student in the Department of Civil and Environmental Engineering at the University of Auckland. My supervisors for this research are Professor Suzanne Wilkinson, and Doctor Alice Chang-Richard both of the Department of Civil and Environmental Engineering.
Your ministry is invited to participate in the research project titled "**Improving water Supply Systems Resilience to Flood: Developing a Measurement tool for Tanzania**" undertaken at the University of Auckland. This project aims at developing a tool for measuring the resilience of water supply systems in Tanzania.

Invitation to participate
The purpose of this Participant Information Sheet is to invite you to participate in the research through granting us permission to conduct our study in the urban water supply and sanitation, water quality, and Water Resources divisions of your ministry, which will mainly involve DAWASA, DAWASCO, and the Wami/Ruvu basin water office. In the first place, water experts will be requested to review the proposed resilience indicators from which the outcome will be used to improve the proposed resilience measurement tool. The water expert will be interviewed in later stages during the implementation of the tool for measuring the resilience of water supply systems. Besides, in assessing the organisational dimension, some questions will focus on the employing organisation.
The estimated time for the review of indicators, and interviews is two hours, and one hour respectively. Participants will have right to withdraw from the interview during the study without needing to provide a reason.

Research Background
The concept of resilience has come into prominence to prepare for the increasing threats of terrorism, natural disasters, and other crisis. In recent years, the impact of climate change has been reported to intensify the frequency and magnitude of natural disasters. Flood hazards, for example, are reported all over the world, Africa without exclusion where systems such as roads, telecommunications, and water to mention a few are vulnerable, thus call for resilience.

Water systems, in particular, are lifeline infrastructures and have a downstream and upstream interdependency with other sectors. They are social-ecological-technical systems due to their direct relation to the community and the managing organisations, the composition that gives a serious opportunity for threats. Tanzania, for the period from 1900 to 2016 has experienced 266 different disasters which caused 13,288 causalities, 57,556 injuries, and damages valued at 465.79 million USD. Of concerns are the nationwide El Nino episodes of 1992-1993 and 1997-1998 that contributed to economic losses, nationwide power blackout and rationing, food shortage and increased prices, severe losses of livestock and crops, widespread water-related diseases, infrastructural, settlements, livelihoods and other property destructions.

Studies on climate change in Tanzania indicate that there will be an increase in extreme weather in the form of floods, droughts, cyclones, and tropical storms. Although more effort is made in examining water-related issues, little is known about the resilience metrics of the water supply systems in the face of disasters. It is the purpose of this study to develop a tool that can be used to measure the water supply systems resilience to flood in Tanzania. The findings from this study could be useful in informing the water supply systems managers, of the current water supply systems resilience and its improvement needs, while the tool can be used as a foundation to assess water supply systems resilience to flood disasters elsewhere.

Audio recording during the interview
There will not be any audio recordings during the interview. All records of the interview will be written by researchers and will be completely anonymous.

Possible benefits from this study
The potential benefits to the participants of taking part in the research include:

(1) *The tool developed from this study will help the ministry and its organs including the water authorities to measure the current water supply system resilience to flood, monitor the system resilience, and be able to improve the resilience so that the system and its dimensions have less vulnerability to flooding hazards.*
(2) Participants will have the opportunity to contribute to the study by challenging the proposed indicators and suggest more suitable indicators for measuring the resilience of water supply system in Tanzania.
(3) The participants can get copies of interview data analysis in the first instance, further updates during the report writing process, and a copy of the final report on request.

Anonymity and confidentiality
Before any potential participation of your staff, this document together with Consent Form will be provided to your Ministry asking for permission to have access. I seek your assurance that participation or non-participation will have no effect on their employment status or relationship with the Ministry.

The review of indicators and interview with the participants will be only conducted on receipt of the consent from your Office. The results of the project will be published in reports and academic journals, but the anonymity of the participants will be preserved at all times. The name and personal details of the participant will never be divulged to anyone, nor used in any written or published material from the project. All collected data including indicators review documents, interview notes and consent forms will be separately and securely kept in the locked cabinet within the University of Auckland premises for six years and safely destroyed by appropriate means of incineration or refuse disposal after that.

Contact details and approval

Student Researcher name and contact details	**Supervisor name and contact details**	**Supervisor name and contact details**
Lukuba Ngalya Sweya Department of Civil and Environmental Engineering lswe528@aucklanduni.ac.nz Phone: 093737599 ext. 88674	Professor Suzanne Wilkinson Department of Civil and Environmental Engineering s.wilkinson@auckland.ac.nz Phone: +64 9 9238184	Doctor Alice Chang-Richard Department of Civil and Environmental Engineering Email: yan.chang@auckland.ac.nz Phone: 64-9-3737599 ext. 88558

For any queries regarding ethical concerns, you may contact the Chair, The University of Auckland Human Participants Ethics Committee, The University of Auckland, Research Office, Private Bag 92019, Auckland 1142. Telephone: 09 373-7599 ext. 83711. Email: ro-ethics@auckland.ac.nz".

Approved by the University of Auckland Human Participants Ethics Committee on **18th August 2017** for three years, Reference Number **019619**

Department of Civil and Environmental Engineering,
Faculty of Engineering,
Engineering Building,
20 Symonds Street.
Telephone 64 9 3737599 ext 88166
www.cee.auckland.ac.nz

The University of Auckland,
Private Bag 92019,
Auckland 1142,
New Zealand.

PARTICIPANT INFORMATION SHEET
(MUNICIPALITIES)

CONTACT DETAILS
FOR A MUNICIPAL COUNCIL
Dar es Salaam, Tanzania.

Research Project Title: Improving Water Supply System Resilience to Flood: Developing a Measurement Tool for Tanzania

Name of Researcher: Lukuba Ngalya Sweya
Degree: PhD in Civil Engineering (Disaster Management)
Department: Civil & Environmental Engineering
Research Supervisors: Professor Suzanne Wilkinson and Doctor Alice Chang-Richard
My name is Lukuba N. Sweya; I am a doctoral student in the Department of Civil and Environmental Engineering at the University of Auckland. My supervisors for this research are Professor Suzanne Wilkinson, and Doctor Alice Chang-Richard both of the Department of Civil and Environmental Engineering.
Your Municipality is invited to participate in the research project titled "**Improving water Supply Systems Resilience to Flood: Developing a Measurement tool for Tanzania"** undertaken at the University of Auckland. This project aims at developing a tool for measuring the resilience of water supply systems in Tanzania.

Invitation to participate
The purpose of this Participant Information Sheet is to invite you to participate in the research through granting us permission to administer questionnaires within the community of your administrative area and meet the Municipal water expert who will help in the review of the resilience indicators. The water expert will be interviewed in later stages during the implementation of the tool for measuring the resilience of water supply systems. Besides, in assessing the organisational dimension, some questions will focus on the employing organisation.
The estimated time for the review of indicators, questionnaires administration and interviews are two hours, thirty minutes, and one hour respectively. Participants will have right to choose not to answer any question during the study without needing to provide a reason.

Research Background
The concept of resilience has come into prominence to prepare for the increasing threats of terrorism, natural disasters, and other crisis. In recent years, the impact of climate change has been reported to intensify the frequency and magnitude of natural disasters. Flood hazards, for example, are reported all over the world, Africa without exclusion where systems such as roads, telecommunications, and water to mention a few are vulnerable, thus call for resilience.

Water systems, in particular, are lifeline infrastructures and have a downstream and upstream interdependency with other sectors. They are social-ecological-technical systems due to their direct relation to the community and the managing organizations, the composition that gives a serious opportunity for threats. Tanzania, for the period from 1900 to 2016 has experienced 266 different disasters which caused 13,288 causalities, 57,556 injuries, and damages valued at 465.79 million USD. Of concerns are the nationwide El Nino episodes of 1992-1993 and 1997-1998 that contributed to economic losses, nationwide power blackout and rationing, food shortage and increased prices, severe losses of livestock and crops, widespread water-related diseases, infrastructural, settlements, livelihoods and other property destructions.

Studies on climate change in Tanzania indicate that there will be an increase in extreme weather in the form of floods, droughts, cyclones, and tropical storms. Although more effort is made in examining water-related issues, little is known about the resilience metrics of the water supply systems in the face of disasters. It is the purpose of this study to develop a tool that can be used to measure the water supply systems resilience to flood in Tanzania. The findings from this study could be useful in informing the water supply systems managers, of the current water supply systems resilience and its improvement needs, while the tool can be used as a foundation to assess water supply systems resilience to flood disasters elsewhere.

Audio recording during the interview
There will not be any audio recordings during the interview. All records of the interview will be written by researchers and completely anonymous.

Possible benefits from this study

The potential benefits to the participants of taking part in the research include:

(1) Participation in the project can provide community participants with an opportunity to reflect their status against water supply systems, which may help them build resilience and for the Municipal Council to understand the current resilience issues and the improvement needs.

(2) The Municipal Council will have the opportunity to contribute to the study by challenging the proposed indicators and suggest more suitable indicators for measuring the resilience of water supply system in Tanzania.

(3) The participants can get copies of interview data analysis in the first instance, further updates during the report writing process, and a copy of the final report on request.

Anonymity and confidentiality
Before any potential participation of your staff and community, this document together with Consent Form will be provided to your Municipality asking for permission to have access. I seek your assurance that participation or non-participation of staff in particular will have no effect on their employment status or relationship with the Municipality.

The review of indicators, interview, and questionnaire administration with the participants will be only conducted on receipt of the consent from your Office. The results of the project will be published in reports and academic journals, but the anonymity of the participants will be preserved at all times. The name and personal details of the participant will never be divulged to anyone, nor used in any written or published material from the project. All collected data including indicators review documents, interview notes, questionnaires and consent forms will be separately and securely kept in the locked cabinet within the University of Auckland premises for six years and safely destroyed by appropriate means of incineration or refuse disposal after that.

Contact details and approval

Student Researcher name and contact details	**Supervisor name and contact details**	**Supervisor name and contact details**
Lukuba Ngalya Sweya Department of Civil and Environmental Engineering lswe528@aucklanduni.ac.nz Phone: 093737599 ext. 88674	Professor Suzanne Wilkinson Department of Civil and Environmental Engineering s.wilkinson@auckland.ac.nz Phone: +64 9 9238184	Doctor Alice Chang-Richard Department of Civil and Environmental Engineering Email: yan.chang@auckland.ac.nz Phone: 64-9-3737599 ext. 88558

For any queries regarding ethical concerns, you may contact the Chair, The University of Auckland Human Participants Ethics Committee, The University of Auckland, Research Office, Private Bag 92019, Auckland 1142. Telephone: 09 373-7599 ext. 83711. Email: ro-ethics@auckland.ac.nz".

Approved by the University of Auckland Human Participants Ethics Committee on **18th August 2017** for three years, Reference Number **019619**

Department of Civil and Environmental Engineering,
Faculty of Engineering,
Engineering Building,
20 Symonds Street.
Telephone 64 9 3737599 ext 88166
www.cee.auckland.ac.nz

The University of Auckland,
Private Bag 92019,
Auckland 1142,
New Zealand.

PARTICIPANT INFORMATION SHEET
(ORGANISATIONS)

CONTACT DETAILS
FOR AN ORGANISATION
Dar es Salaam, Tanzania.

Research Project Title: Improving Water Supply System Resilience to Flood: Developing a Measurement Tool for Tanzania

Name of Researcher: Lukuba Ngalya Sweya
Degree: PhD in Civil Engineering (Disaster Management)
Department: Civil & Environmental Engineering
Research Supervisors: Professor Suzanne Wilkinson and Doctor Alice Chang-Richard
My name is Lukuba N. Sweya; I am a doctoral student in the Department of Civil and Environmental Engineering at the University of Auckland. My supervisors for this research are Professor Suzanne Wilkinson, and Doctor Alice Chang-Richard both of the Department of Civil and Environmental Engineering.
Your organisation is invited to participate in the research project titled "**Improving water Supply Systems Resilience to Flood: Developing a Measurement tool for Tanzania**" undertaken at the University of Auckland. This project aims at developing a tool for measuring the resilience of water supply systems in Tanzania.

Invitation to participate
The purpose of this Participant Information Sheet is to invite you as a water expert company to participate in the research through reviewing the proposed resilience indicators for measuring the resilience of water supply systems in Tanzania.
The estimated time for the review of indicators is two hours. You or your delegates will have right to choose not to participate in the study without needing to provide a reason.

Research Background
The concept of resilience has come into prominence to prepare for the increasing threats of terrorism, natural disasters, and other crisis. In recent years, the impact of climate change has been reported to intensify the frequency and magnitude of natural disasters. Flood hazards, for example, are reported all over the world, Africa without exclusion where systems such as roads, telecommunications, and water to mention a few are vulnerable, thus call for resilience.

Water systems, in particular, are lifeline infrastructures and have a downstream and upstream interdependency with other sectors. They are social-ecological-technical systems due to their direct relation to the community and the managing organizations, the composition that gives a serious opportunity for threats. Tanzania, for the period from 1900 to 2016 has experienced 266 different disasters which caused 13,288 causalities, 57,556 injuries, and damages valued at 465.79 million USD. Of concerns are the nationwide El Nino episodes of 1992-1993 and

1997-1998 that contributed to economic losses, nationwide power blackout and rationing, food shortage and increased prices, severe losses of livestock and crops, widespread water-related diseases, infrastructural, settlements, livelihoods and other property destructions.

Studies on climate change in Tanzania indicate that there will be an increase in extreme weather in the form of floods, droughts, cyclones, and tropical storms. Although more effort is made in examining water-related issues, little is known about the resilience metrics of the water supply systems in the face of disasters. It is the purpose of this study to develop a tool that can be used to measure the water supply systems resilience to flood in Tanzania. The findings from this study could be useful in informing the water supply systems managers, of the current water supply systems resilience and its improvement needs, while the tool can be used as a foundation to assess water supply systems resilience to flood disasters elsewhere.

Possible benefits from this study

The potential benefits to the participants of taking part in the research include:

(1) Participation in the project can provide participants with an opportunity to reflect their status regarding water supply systems, understand the current resilience issues, and the improvement needs.
(2) The organisation will have the opportunity to contribute to the study by challenging the proposed indicators and suggest more suitable indicators for measuring the resilience of water supply system in Tanzania.
(3) The participants can get copies of interview data analysis in the first instance, further updates during the report writing process, and a copy of the final report on request.

Anonymity and confidentiality

Before any potential participation of your staff, this document together with Consent Form will be provided to your Organisation asking for permission to have access. I seek your assurance that participation or non-participation will have no effect on their employment status or relationship with the organisation.

The review of indicators by the participants will be only conducted on receipt of the consent from your Office. The results of the project will be published in reports and academic journals, but the anonymity of the participants will be preserved at all times. The name and personal details of the participant will never be divulged to anyone, nor used in any written or published material from the project. All collected data including indicators review documents and consent forms will be separately and securely kept in the locked cabinet within the University of Auckland premises for six years and safely destroyed by appropriate means of incineration or refuse disposal after that.

Contact details and approval

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Lukuba Ngalya Sweya Department of Civil and Environmental Engineering lswe528@aucklanduni.ac.nz Phone: 093737599 ext. 88674	Professor Suzanne Wilkinson Department of Civil and Environmental Engineering s.wilkinson@auckland.ac.nz Phone: +64 9 9238184	Doctor Alice Chang-Richard Department of Civil and Environmental Engineering Email: yan.chang@auckland.ac.nz Phone: 64-9-3737599 ext. 88558

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Auckland 1142,
New Zealand.

PARTICIPANT INFORMATION SHEET
(EXPERTS)

....
Dar es Salaam, Tanzania.

Research Project Title: Improving Water Supply System Resilience to Flood: Developing a Measurement Tool for Tanzania

Name of Researcher: Lukuba Ngalya Sweya
Degree: PhD in Civil Engineering (Disaster Management)
Department: Civil & Environmental Engineering
Research Supervisors: Professor Suzanne Wilkinson and Doctor Alice Chang-Richard
My name is Lukuba N. Sweya; I am a doctoral student in the Department of Civil and Environmental Engineering at the University of Auckland. My supervisors for this research are Professor Suzanne Wilkinson, and Doctor Alice Chang-Richard both of the Department of Civil and Environmental Engineering.
You are invited to participate in the research project titled "**Improving water Supply Systems Resilience to Flood: Developing a Measurement tool for Tanzania**" undertaken at the University of Auckland. This project aims at developing a tool for measuring the resilience of water supply systems in Tanzania.

Invitation to participate
The purpose of this Participant Information Sheet is to invite you as an expert in the water sector to participate in the research through reviewing the proposed resilience indicators for developing a tool for measuring the resilience of water supply systems in Tanzania.
The estimated time for the review of indicators is two hours. Besides, you will have right to withdraw data within one month after the interview without needing to provide a reason.

Research Background
The concept of resilience has come into prominence to prepare for the increasing threats of terrorism, natural disasters, and other crisis. In recent years, the impact of climate change has been reported to intensify the frequency and magnitude of natural disasters. Flood hazards, for example, are reported all over the world, Africa without exclusion where systems such as roads, telecommunications, and water to mention a few are vulnerable, thus call for resilience.
Water systems, in particular, are lifeline infrastructures and have a downstream and upstream interdependency with other sectors. They are social-ecological-technical systems due to their direct relation to the community and the

managing organizations, the composition that gives a serious opportunity for threats. Tanzania, for the period from 1900 to 2016 has experienced 266 different disasters which caused 13,288 causalities, 57,556 injuries, and damages valued at 465.79 million USD. Of concerns are the nationwide El Nino episodes of 1992-1993 and 1997-1998 that contributed to economic losses, nationwide power blackout and rationing, food shortage and increased prices, severe losses of livestock and crops, widespread water-related diseases, infrastructural, settlements, livelihoods and other property destructions.

Studies on climate change in Tanzania indicate that there will be an increase in extreme weather in the form of floods, droughts, cyclones, and tropical storms. Although more effort is made in examining water-related issues, little is known about the resilience metrics of the water supply systems in the face of disasters. It is the purpose of this study to develop a tool that can be used to measure the water supply systems resilience to flood in Tanzania. The findings from this study could be useful in informing the water supply systems managers, of the current water supply systems resilience and its improvement needs, while the tool can be used as a foundation to assess water supply systems resilience to flood disasters elsewhere.

Audio recording during the interview

There will not be any audio recordings during the interview. All records of the interview will be written by researchers and will be completely anonymous.

Possible benefits from this study

The potential benefits to the participants of taking part in the research include:

(1) Participation in the project can provide participants with an opportunity to reflect their status regarding water supply systems, understand the current resilience issues, and the improvement needs.

(2) The participant will have the opportunity to contribute to the study by challenging the proposed indicators and suggest more suitable indicators for measuring the resilience of water supply system in Tanzania.

(3) The participants can get copies of interview data analysis in the first instance, further updates during the report writing process, and a copy of the final report on request.

Anonymity and confidentiality

The results of the project will be published in reports and academic journals, but the anonymity of the participants will be preserved at all times. Your name and personal details will never be divulged to anyone, nor used in any written or published material from the project. All collected data including indicators review documents, interview notes and consent forms will be separately and securely kept in the locked cabinet within the University of Auckland premises for six years and safely destroyed by appropriate means of incineration or refuse disposal after that. However, confidentiality cannot be guaranteed given that the CEO is likely to know who has participated

Contact details and approval

Student Researcher name and contact details	**Supervisor name and contact details**	**Supervisor name and contact details**
Lukuba Ngalya Sweya Department of Civil and Environmental Engineering lswe528@aucklanduni.ac.nz Phone: 093737599 ext. 88674	Professor Suzanne Wilkinson Department of Civil and Environmental Engineering s.wilkinson@auckland.ac.nz Phone: +64 9 9238184	Doctor Alice Chang-Richard Department of Civil and Environmental Engineering Email: yan.chang@auckland.ac.nz Phone: 64-9-3737599 ext. 88558

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The University of Auckland,
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Auckland 1142,
New Zealand.

KARATASI YA TAARIFA KWA MSHIRIKI
(PIS - COMMUNITY)

....
....
Dar es Salaam, Tanzania.

Kichwa cha Mradi wa Utafiti: **Kuboresha Ustahimilivu wa Mifumo ya Ugavi wa Maji wakati wa Mafuriko: Kuandaa chombo cha Upimaji Tanzania**

Jina la Mtafiti: Lukuba Ngalya Sweya

Shahada: Shahada ya Uzamivu ya Civil Engineering (Usimamizi wa Maafa)

Idara: Civil & Environmental Engineering

Wasimamizi: Professor Suzanne Wilkinson and Doctor Alice Chang-Richard

Jina langu ni Lukuba N. Sweya; Mimi ni mwanafunzi wa Shahada ya Uzamivu katika Idara ya Civil and Environmental Engineering katika Chuo Kikuu cha Auckland. Wasimamizi wangu kwa ajili ya utafiti huu ni Profesa Suzanne Wilkinson, na Daktari Alice Chang-Richard wote wawili wa Idara ya Civil and Environmental Engineering.
Unaalikwa kushiriki katika mradi wa utafiti unaoitwa **"Kuboresha Ustahimilivu wa Mifumo ya Ugavi wa Maji wakati wa Mafuriko: Kuandaa chombo cha Upimaji Tanzania"** unaofanyika Chuo Kikuu cha Auckland. Mradi huu unalenga katika kuandaa chombo cha kupima ustahimilivu wa mifumo ya maji nchini Tanzania

Mwaliko wa Kushiriki

Madhumuni ya Karatasi ya Taarifa ya Mshiriki ni kukualika kama mjumbe wa jumuiya ya Dar es Salaam kushiriki katika utafiti kupitia kujibu maswali ambayo hutumiwa kuchunguza hali ya kijamii kwa kupima ustahimilivu wa mfumo wa maji katika jiji hili
Wakati uliokadiriwa wa mjadala ni nusu saa. Utakuwa na haki ya kuchagua kutoshiriki katika utafiti bila kuhitaji kutoa sababu.

Historia ya Utafiti

Dhana ya ustahimilivu imejitokeza kujiandaa kwa vitisho vya kuongezeka kwa ugaidi, majanga ya asili, na mgogoro mingine. Katika miaka ya hivi karibuni, athari za mabadiliko ya hali ya hewa zimeripotiwa kuimarisha mzunguko na ukubwa wa majanga ya asili. Hatari za mafuriko, kwa mfano, zinaripotiwa ulimwenguni pote, Afrika bila kusahaulika ambapo mifumo kama vile barabara, mawasiliano ya simu, na maji kwa kutaja michache iko katika hatari, hivyo kusababisha uhitaji wa ustahimilivu.
Mifumo ya maji, hasa, ni miundombinu ya uhai na huwa na uingiliano na sekta zingine. Hii ni mifumo ya kijamii-kiikolojia-kiufundi kutokana na uhusiano wa moja kwa moja na jumuiya na mashirika ya kusimamia, muundo ambao unatoa fursa kubwa kwa vitisho. Tanzania, kwa kipindi cha 1900 hadi 2016 imepata maafa

tofauti 266 ambayo yalisababisha maafa 13,288, majeraha 57,556, na uharibifu wa thamani ya dola milioni 465.79. Ya wasiwasi ni matukio ya kitaifa ya El Nino ya 1992-1993 na 1997-1998 ambayo yalichangia hasara za kiuchumi, upungufu wa umeme wa nchi nzima na mgawo, upungufu wa chakula na kuongezeka kwa bei, hasara kubwa ya kupoteza mifugo na mazao, magonjwa yanayohusiana na maji, miundombinu, makazi , maisha na uharibifu mwingine wa mali.
Tafiti juu ya mabadiliko ya tabia ya nchi nchini Tanzania zinaonyesha kwamba kutakuwa na ongezeko la hali ya hewa kali sana kama vile mafuriko, ukame, vimbunga, na dhoruba za kitropiki. Ijapokuwa jitihada nyingi zinafanywa katika kuchunguza masuala yanayohusiana na maji, inajulikani kidogo kuhusu vipimo vya ustahimilivu wa mifumo ya maji wakati wa majanga. Ni kusudi la utafiti huu kuandaa chombo ambacho kinaweza kutumika kupima ustahimilivu wa mifumo ya maji wakati wa mafuriko nchini Tanzania. Matokeo ya utafiti huu yanaweza kuwa na manufaa katika kuwajulisha mameneja wa mifumo ya maji, ustahimilivu wa sasa wa mifumo usambazaji wa maji na mahitaji yake ya kuboresha, wakati huohuo chombo hicho kinaweza kutumika kama msingi wa kupima ustahimilivu wa mifumo ya maji kwa majanga ya mafuriko mahali pengine.

Faida zinazopatikana kutokana na utafiti huu
Faida za washiriki wa kushiriki katika utafiti ni pamoja na:

(1) Kushiriki katika mradi unaweza kuwapa washiriki fursa ya kutafakari hali yao kuhusu mifumo ya maji, kuelewa masuala ya sasa ya ustahimilivu, na mahitaji ya kuboresha hiyo mifumo
(2) Washiriki wanaweza kupata nakala ya uchambuzi wa data ya maswali kwa mara ya kwanza, taarifa zaidi wakati wa kuandika ripoti, na nakala ya ripoti ya mwisho wakihitaji

Kutambulika na siri
Matokeo ya mradi yatachapishwa katika ripoti na majarida ya kitaaluma, lakini kutokujulikana kwa washiriki kutahifadhiwa wakati wote. Jina lako na maelezo yako ya kibinafsi hayatatambulishwa kwa mtu yeyote, wala hutumiwa katika nyenzo yoyote iliyoandikwa au iliyochapishwa kutoka kwenye mradi huu. Data zote zilizokusanywa ikiwa ni pamoja na nyaraka za ukaguzi wa viashiria vya ustahimilivu, maelezo ya mahojiano na fomu za ruhusa vyote vitakuwa salama na kutunzwa katika kabati lililofungwa ndani ya jengo la Chuo Kikuu cha Auckland kwa miaka sita na kuharibiwa kwa usalama kwa njia sahihi za kuwaka au kutupwa kama taka.

Maelezo ya mawasiliano na idhini

Jina la Mtafiti Wanafunzi na maelezo ya mawasiliano	Jina la Msimamizi na maelezo ya mawasiliano	Jina la Msimamizi na maelezo ya mawasiliano
Lukuba Ngalya Sweya Department of Civil and Environmental Engineering lswe528@aucklanduni.ac.nz Phone: 093737599 ext. 88674	Professor Suzanne Wilkinson Department of Civil and Environmental Engineering s.wilkinson@auckland.ac.nz Phone: +64 9 9238184	Doctor Alice Chang-Richard Department of Civil and Environmental Engineering Email: yan.chang@auckland.ac.nz Phone: 64-9-3737599 ext. 88558

Kwa maswali yoyote kuhusu wasiwasi wa kimaadili, unaweza kuwasiliana na Mwenyekiti, The University of Auckland Human Participants Ethics Committee, The University of Auckland, Research Office, Private Bag 92019, Auckland 1142. Telephone: 09 373-7599 ext. 83711. Email: ro-ethics@auckland.ac.nz".

IMEIDHINISHWA NA THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE TAREHE **18 AGOSTI 2017** KWA MIAKA MITATU, REFERENCE NUMBER **019619**

Department of Civil and Environmental Engineering,
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20 Symonds Street.
Telephone 64 9 3737599 ext 88166
www.cee.auckland.ac.nz

The University of Auckland,
Private Bag 92019,
Auckland 1142,
New Zealand.

CONSENT FORM (ORGANISATION)

THIS FORM WILL BE HELD FOR 6 YEARS

Research Project Title: Improving Water Supply System Resilience to Flood: Developing a Measurement Tool for Tanzania

Supervisors: Professor Suzanne Wilkinson and Doctor Alice Chang-Richard

Researcher: Lukuba Ngalya Sweya

I have read the Participant Information Sheet (PIS), and I have understood the nature of the research and why I have been invited. I have had the opportunity to ask questions and have them answered to my satisfaction.

1. I agree that my organisation will participate in this research.
2. I give permission for the researcher to invite employees to participate in this project. organisation
3. I give my assurance that the decision of employees to participate or not will have no impact on their employment or relationship with the organisation.

I understand that,

4. My organisation has the right to withdraw the data within one month after the interview.
5. All raw data gathered will be stored securely within The University of Auckland premises for six years and will subsequently be destroyed afterward, by appropriate means of incineration or shredding.
6. The researchers themselves will do data analysis without the involvement of any third party.
7. The results of the project will be published in reports and academic journals, but the anonymity of the participant and my organisation will be preserved at all times. The name and personal details of the participant will never be divulged to anyone, nor used in any written or published material from the project;
8. I wish to receive a summary of findings, which can be emailed to me at this email address: ____

Name____________________ Signature____________________ Date____________________

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON **18th August 2017** FOR 3 YEARS, REFERENCE NUMBER **019619**

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The University of Auckland,
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Auckland 1142,
New Zealand.

CONSENT FORM (EMPLOYEE/EXPERTS)

THIS FORM WILL BE HELD FOR 6 YEARS

Research Project Title: Improving Water Supply System Resilience to Flood: Developing a Measurement Tool for Tanzania

Supervisors: Professor Suzanne Wilkinson and Doctor Alice Chang-Richard

Researcher: Lukuba Ngalya Sweya

I have read the Participant Information Sheet (PIS), and I have understood the nature of the research and why I have been invited. I have had the opportunity to ask questions and have them answered to my satisfaction.

1. I voluntarily agree to participate in the review of the indicators ☐
2. I voluntarily agree to participate in the Interviews ☐

I understand that,

3. An assurance has been given by my employer, that my decision to participate in this study will have no impact on my employment or relationship with the organization
4. The confidentiality is not guaranteed since the CEO is likely to know my participation
5. I have the right to withdraw the data within one month after the interview.
6. All raw data gathered will be stored securely within The University of Auckland premises for six years and will subsequently be destroyed afterward, by appropriate means of incineration or shredding.
7. The researchers themselves will do data analysis without the involvement of any third party.
8. The results of the project will be published in reports and academic journals, but my anonymity will be preserved at all times. The name and personal details of the participant will never be divulged to anyone, nor used in any written or published material from the project;
9. I wish to receive a summary of findings, which can be emailed to me at this email address: ____

Name____________________ Signature____________________ Date____________________

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON **18th August 2017** FOR 3 YEARS, REFERENCE NUMBER **019619**

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FOMU YA KURIDHIA

FOMU HII ITATUNZWA KWA MUDA WA MIAKA 6

Kichwa cha Mradi wa Utafiti: **Kuboresha Ustahimilivu wa Mifumo ya Ugavi wa Maji wakati wa Mafuriko: Kuandaa chombo cha Upimaji Tanzania**

Jina la Mtafiti: Lukuba Ngalya Sweya

Wasimamizi: Professor Suzanne Wilkinson and Doctor Alice Chang-Richard

Nimesoma Karatasi ya Taarifa ya Mshiriki (PIS), na nimelewa hali ya utafiti na kwa nini nimealikwa. Nimekuwa na fursa ya kuuliza maswali na kupata majibu ya kuridhisha.

Najua kwamba;

1. Kushiriki kwangu katika mradi ni kwa hiari kabisa.
2. Mimi niko huru kujiondoa kwenye ushiriki wakati wowote bila hasara yoyote
3. Taarifa ya kibinafsi ya kutambua itahifadhiwa peke yake tofauti na data na itahifadhiwa kwa namna isiyojulikana. Takwimu zitahifadhiwa kwa usalama kwa miaka sita na hatimaye zitaharibiwa baadaye, kwa njia sahihi za kuchomwa au kusagwasagwa.
4. Dodoso litachukua muda wa dakika 30, na uchambuzi utafanywa na watafiti bila ushiriki wa mtu mwingine yeyote.
5. Matokeo ya mradi yatachapishwa katika ripoti na majarida ya kitaaluma, lakini kutokujulikana kwangu kutahifadhiwa wakati wote. Jina langu na maelezo ya kibinafsi hayatatambulishwa kwa mtu yeyote, wala kutumika katika nyenzo yoyote iliyoandikwa au kuchapishwa kutoka kwa mradi huu.
6. Napenda kupokea muhtasari wa matokeo, ambayo yanaweza kutumwa barua pepe kwangu kwenye anwani hii ya barua pepe:

   ____

Jina ____________________ Sahihi ____________________ Tarehe ____________________

IMEIDHINISHWA NA THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE TAREHE **18 AGOSTI 2017** KWA MIAKA MITATU, REFERENCE NUMBER **019619**

Appendix 2: Pre-assessment and Pretesting tools

Pre-assessment of Key Indicators for Measuring the Water Supply System Resilience to Flood in Tanzania

Research topic: Improving Water Supply System Resilience to Flood: Developing a Measurement Tool for Tanzania.

Name of Researcher: Lukuba Ngalya Sweya
Degree: PhD in Civil Engineering
Department: Civil & Environmental Engineering, University of Auckland, New Zealand
Research Supervisors: Professor Suzanne Wilkinson and Doctor Alice Chang-Richard

Introduction
Delphi study is a method that allows researchers to involve experts systematically in consensus development and prioritisation involving multiple rounds. This method is developed to involve diverse experiences and areas of expertise, indicate the convergence and divergence points of expert opinion, narrow the scope of agreed information, and refine or modify information to achieve consensus. The indicators first presented in this study were derived from literature review and are grouped into five domains. Forty experts are invited to review the indicators and develop a set of potential measures of the resilience of water supply. The importance of the proposed indicators is scored on a five-point Likert scale, and the agreement on indicators and measures will be defined as at least 70% of the responders agreeing or strongly agreeing on the inclusion of the indicator.

PART I: PROPOSED DOMAINS

Based on literature review, five domains are proposed namely Technical, Organisational, Social, Economic, and Environmental.

The ***technical*** dimension of resilience refers to the ability of physical systems (including components, their interconnections and interactions, and entire systems) to perform to acceptable/desired levels when subject to disaster forces.

The ***organizational*** dimension of resilience refers to the capacity of organizations that manage critical facilities and have the responsibility for carrying out critical disaster-related functions to make decisions and take actions that contribute to achieving the properties of resilience that help to achieve greater robustness, redundancy, resourcefulness, and rapidity.

The ***social*** dimension of resilience consists of measures specifically designed to lessen the extent to which disaster-stricken communities and governmental jurisdictions suffer negative consequences due to the loss of critical services as a result of flood.

The ***economic*** dimension of resilience refers to the capacity to reduce both direct and indirect economic losses resulting from flood.

The ***environmental*** dimension consists of measures designed to lessen the impacts of flood to the environment

Please,

1. give comments or modifications on these preliminary domains
The environmental domain is important because is acts as enabler factor to building reliance to flooding. For example, technical dimension comes from the building on the environmental conditions to allow placement of various infrastructures ranging from small to large. Additionally, social dimension will carry the same weight as environmental dimension this because directly deals with mind-set and behaviour change. For example, any decision of any matter you can call comes from how we perceive things.

2. rate the importance of each domain on a five-point Likert scale as shown in the table below.

Likert scale / Domains	Strongly disagree (1)	Disagree (2)	Neither agree nor disagree (3)	Agree (4)	Strongly agree (5)
Technical					
Organisational					
Social					
Economic					
Environmental					

PART II: PROPOSED INDICATORS

Proposed indicators for measuring the resilience of water supply systems were derived from literature review. These indicators had been used in various frameworks for measuring the resilience of infrastructures. Regarding developing a realistic tool for measuring the resilience of water supply systems in Tanzania, the indicators are subjected into a review from different experts in this Delphi study. Inclusion of these indicators is based on meeting one of the criteria of robustness, redundancy, resourcefulness, and rapidity.

Therefore, please,

1. modify these proposed potential indicators, or add additional ones that you feel essential for measuring the resilience of water supply system in Tanzania

2. rate the importance of each indicator on a five-point Likert scale ranging from strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4), strongly agree (5) as shown in the Table below.

TECHNICAL DOMAIN

Indicators	Definition	Five-points Likert scale				
		(1)	(2)	(3)	(4)	(5)
Structural	Physical measures relating to asset/network design, maintenance and renewal, alternate routes and modes, backup supplies/resources, and the extent to which innovative design approaches are implemented, allowing controlled failure during unpredicted conditions					
Procedural	Non-physical measures relating to existence, suitability and application of design codes, guidelines, existence of diversion and communication plans, and the extent to which safe-to-fail designs are specified in design guidelines					
Interdependencies	This relates to upstream dependencies and their relative robustness and redundancy in both a structural and procedural sense,					

(1)= Strongly Disagree, (2) = Disagree, (3) = Neither Agree nor Disagree, (4) = Agree, (5) = Strongly Agree

Comments

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ORGANISATIONAL DOMAIN

Indicators	Definition	Five-points Likert scale				
		(1)	(2)	(3)	(4)	(5)
Leadership	Strong crisis leadership to provide good management and decision-making during times of crisis, as well as					

	continuous evaluation of strategies and work programs against organisational goals					
Situation awareness	Staff are encouraged to be vigilant about the organisation, its performance and potential problems					
Innovation and creativity	Staff are encouraged and rewarded for using their knowledge in novel ways to solve new and existing problems, and for utilising innovative and creative approaches to developing solutions					
Staff engagement and involvement	The engagement and involvement of staff who understand the link between their own work, the organisation's resilience, and its long-term success.					
Decision making	Staffs have the appropriate authority to make decisions related to their work and authority is clearly delegated to enable a crisis response.					
Proactive posture	A strategic and behavioural readiness to respond to early warning signals of change in the organisation's internal and external environment before they escalate into crisis					
Stress testing/drills and response exercises	The participation of staff in simulations or scenarios designed to practice response arrangements and validate plans.					
Planning strategy	The development and evaluation of plans and strategies to manage vulnerabilities in relation to the business environment and its stakeholders.					
Unity purpose/clear recovery priorities	An organisation wide awareness of what the organisation's priorities would be following a crisis, clearly defined at the organisation level, as well as an understanding of the organisation's minimum operating requirements.					
Communication and warning	This relates to the existence and effectiveness of communication and warning systems					
Learning	Past actions and adaptation strategies are observed and evaluated in terms of their success in mitigating hazards.					
Breaking silos	Minimisation of divisive social, cultural and behavioural barriers, which are most often manifested as communication barriers creating disjointed, disconnected and detrimental ways of working.					
Leveraging knowledge/information and knowledge	Critical information is stored in a number of formats and locations and staffs have access to expert opinions when needed.					
Effective partnerships	An understanding of the relationships and resources the organisation might need to access from other organisations during a crisis, and planning and management to ensure this access					
Engage with regulators	Engagement with regulators so that, any changes in operations and other additional costs are reported. This helps regulators to set realistic prices of the service					
Resources	Resources to ensure the ability to operate during business as usual, as well as being able to provide the extra capacity required during a crisis, and					
Flexible working to cope	A system is more likely to be resilient where the staff are willing to work at inconvenient times or for additional time in order to deal with risks arising					
Honesty	Honesty and transparency is also important so that risks are identified at the earliest possibility					
Good diagnostic procedures	Procedures for identifying problems and snags are important in aiding corporate learning following service failures.					
Logs during incidents	It is good practice when service risks arise to track progress and issues which occur along the way.					

Meaningful lessons learned and procedures changed	A method of improving resilience is to carry out meaningful analysis of service failures and consider improvements and changes to the system which would reduce risks to service.					
Assurance (process audit)	Process and procedures can be subject to external scrutiny and offer recommendations and improvements for how they can be improved.					

(1)= Strongly Disagree, (2) = Disagree, (3) = Neither Agree nor Disagree, (4) = Agree, (5) = Strongly Agree

Comments

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SOCIAL DOMAIN

Indicators	Definition	Five-points Likert scale				
		(1)	(2)	(3)	(4)	(5)
Social structure	The distinctive, stable arrangement of institutions whereby human beings in a society interact and live together					
Equity and diversity	Stands for equal opportunities. It is the obligation to protect against discrimination					
Community bonds, social support and social institution	Related to the degree of connectedness across the community groups, volunteerism, engagement in social works and others					
Safety and wellbeing	Related to safety of the people from crime and their health					
Preparedness	A state of readiness during disasters					
Responsiveness	The quality of responding quickly and positively during disasters					
Self-organisation	The essence of creating oneness within the community through forming of small groups for a certain purpose					
Learning and Innovation	Attitudes towards change					
Inclusion	Related to making a person part or involved in community activities in various forms and different stages					
Aspiration	Related to exposure to media and the number of contacts across ecosystem boundaries					

(1)= Strongly Disagree, (2) = Disagree, (3) = Neither Agree nor Disagree, (4) = Agree, (5) = Strongly Agree

Comments

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ENVIRONMENTAL DOMAIN

Indicators	Definitions	Five-points Likert scale				
		(1)	(2)	(3)	(4)	(5)
Natural assets (Environment and Resources)	These are assets of the natural environment consisting of biological, land and water with their ecosystems, subsoil and air					
Environmental capacity	The environment and its ability to accommodate a particular activity or rate of an activity without unacceptable impact (GESAMP, 1986).					
Ecosystem sensitivity	Includes the degree of human intrusion into the natural landscape and land fragmentation, and pollution loading on ecosystem					
Natural flood buffers	Related to amount of land which is wetland					
Efficient energy use	Rate of energy consumption					
Pervious surfaces	Perviousness of the area					
Efficient water use	Water supply stress index					
Water resources sensitivity	Related to supply of water from internal renewable resources and inflow from rivers, and withdrawals to meet current or projected needs					

(1)= Strongly Disagree, (2) = Disagree, (3) = Neither Agree nor Disagree, (4) = Agree, (5) = Strongly Agree

Comments

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ECONOMIC DOMAIN

Indicators and Definitions	Five-points Likert scale				
	(1)	(2)	(3)	(4)	(5)
Insurances for hazard events					
Availability of funding for all elements of resilience planning including technical and organisational.					
Qualification of the working age population					
Openness to micro enterprises and micro finance services, entrepreneurism					
Individuals with high and multiple skills; literacy (education)					
Stability of prices and incomes, property value					
Connections with regional economy					
Public private partnership					
Locally owned business and employers					

(1)= Strongly Disagree, (2) = Disagree, (3) = Neither Agree nor Disagree, (4) = Agree, (5) = Strongly Agree

Comments

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IMPROVING WATER SUPPLY SYSTEM RESILIENCE TO FLOOD: DEVELOPING A MEASUREMENT TOOL FOR TANZANIA

Pre-testing questionnaire (Social dimension)
(Dodoso iliyopendekezwa ya kutathmini hali ya kijamii ya ustahimilivu wa mfumo wa maji)

WASIFU BINAFSI

1. Jinsia:

Mme ☐

Mke ☐

Nyingine ☐

2. Hali ya ndoa:

Si mwanandoa ☐

Mwanandoa ☐

Mwanandoa na watoto ☐

3. Ni aina gani ya aina hii ya umri inayotumika kwako?

18-25 ☐ 26-45 ☐ 46-65 ☐ 65 na zaidi ☐

4. Una kiwango gani cha juu cha kufuzu kwa elimu?

Elimu ya Msingi ☐

Elimu ya Sekondari ☐

Digrii ya kwanza ya Chuo kikuu ☐

Digrii ya pili na zaidi ya Chuo kikuu ☐

Cheti au diploma ☐

5. Umeishi Dar es Salaam muda gani? Tafadhali taja kwa miaka……

HALI YA KIJAMII NA KIUCHUMI

6. Je, ni aina gani ya kundi kati ya haya unayojiweka mwenyewe?

Mwajiriwa ☐ Si Mwajiriwa ☐ Msitaafu ☐ Mwanafunzi ☐

Mengine, tafadhali taja ……………………………………………………………

7. Je wewe, au mwanafamilia yeyote wa kaya yako amekodisha au anamiliki nyumba mnayoishi?

Miliki nyumba ☐ Nunua nyumba ☐ Panga nyumba ☐ Nyingine ☐

8. Je, wewe na nyumba yako mna bima ya bima kwa ajili ya hatari za mafuriko?

Ndiyo ☐ Hapana ☐ Tuna mpango wa kukata ☐

HATARI ZA MAFURIKO NA MIFUMO YA MAJI

9. Ni ipi kati ya hatari hizi za asili ambayo unafikiri ni au inaweza kutokea Dar es Salaam? Unaweza kujaza zaidi ya sanduku moja

Tetemeko la ardhi ☐ Mafuriko ☐ Tsunami ☐ Milipuko ya volkano ☐

Landslide ☐ Mmomonyoko wa pwani ☐ Kimbunga ☐ Ukame ☐ Hakuna ☐

10. Kwa kiipimo cha 1-5, ni uwezekano gani unaathirika na hatari za mafuriko huko Dar es Salaam?

1. Hakuna uwezekano ☐ 2. Uwezekano kiasi fulani ☐ 3. Uwezekano wa wastani ☐ 4. Uwezekano kabisa ☐ 5. Uwezekano mkubwa ☐

11. Ni kipi kati ya vifuatazo kinazoelezea vizuri uzoefu wako na hatari za mafuriko?

Nimeathirika na hatari za mafuriko ☐
Sijaathirika na hatari za mafuriko ☐
Mpendwa wangu mmoja ameathirika na hatari za mafuriko ☐

12. Kwa kipimo cha 1-5, ni uwezekano gani unaathirika na athari za hatari za mafuriko kwenye mfumo wa maji hapa Dar es Salaam?

Kipengele	**Hakuna uwezekano (1)**	**Uwezekano kiasi fulani (2)**	**Uwezekano wa wastani (3)**	**Uwezekano kabisa (4)**	**Uwezekano mkubwa (5)**
Ubora wa maji					
Kiasi cha maji					
Huduma ya maji					

13. Kwa kipimo cha 1 hadi 5. Moja kuwa chini na tano kuwa ya juu zaidi. Je, ungependa kiwango gani kuhusu maandalizi yako kuhusu maji kwa ajili ya hatari za mafuriko zitarajiwazo Dar es Salaam leo?

1. Chini kabisa ☐ 2. Chini ☐ 3. Juu ☐ 4. Juu kabisa ☐ 5. Juu kuliko ☐

14. Je, unapokea habari kama vile ushauri matumizi ya maji kutoka kwa mamlaka ikiwa mfumo wa maji unashindwa kutokana na hatari za mafuriko?

Ndiyo ☐ Hapana ☐ Sina uhakika ☐

15. Je! Unapataje maji wakati wa dharura (yaani wakati wa mafuriko)?

……

16. Katika kiwango cha kibinafsi, ni hatua gani ulizochukua ili kujiandaa kwa matukio ya mafuriko na matokeo yae juu ya mfumo wa maji katika Dar es Salaam?

………

MTAZAMO/MAJIBU YA KIJAMII

17. Una hamu gani kuwasaidia jirani zako wakati wa mgogoro wa maji kutokana na hatari za mafuriko?

Sina hamu ☐ Nina hamu ☐ Nina hamu sana ☐ Sina uhakika ☐

18. Kuhusu kuhusika katika masuala ya jumuiya yako, tafadhali elezea ni mara ngapi unafanya kila moja ya yafuatayo

	Kila mara	**Mara nyingi**	**Mara nyingine**	**Mara chache**	**Sijawahi**
Nimefanya kazi na wengine kwenye miradi ili kuboresha maisha yangu ya kijamii.					
Mimi ni mwanachama hai wa jumuiya ya watumiaji wa maji, na hushiriki katika shughuli zinazohusiana na ulinzi wa mifumo ya maji (k.m. kuripoti kwa kamati kuhusu uharibifu wa mfumo, uvujaji wa maji, na uunganishaji kinyume cha sheria)					
Mimi kushiriki katika shughuli za kijamii na matukio kama vile sherehe na mikusanyiko ya kijamii.					
Nimechangia pesa, chakula au nguo kwa sababu za ndani, misaada, au kwa wengine katika jamii yangu					
Nimehudhuria mikutano ya umma juu ya masuala yaa kijamii.					
Nimejihusisha na shughuli za kujitolea zinazolenga kufaidisha jumuiya yangu (k.m., kutafuta fedha, siku za kusafisha, na vikundi vya mitaa).					

19. Wewe ni mjumbe wa mashirika mengapi ya kijamii?................

20. Kama mjumbe, unapata msaada gani kutoka shirika lako la jamii wakati kuna kushindwa kwa mfumo wa maji kutokana na matukio ya mafuriko?

………
……………………………………………………………………………..

21. Kuhusu uwezo wa jumuiya yako ya kuhimili hatari za mafuriko ya baadaye hapa Dar es Salaam, ungekuwa tayari

	Ndiyo	**Inawezekana**	**Hapana**
Kushiriki mara kwa mara, kwa msingi unaoendelea (k.m. kuwa mwanakikundi kama vile ushirika wa maji na wengine; kuhudhuria mikutano ya kila mwezi)			
Kushiriki kwa sababu maalum au matukio (k.m. kuhudhuria mkutano wa jumuia moja, kushiriki katika mipango ya dharura na maandaalizi)			
Kutoa habari kwa wanachama wengine wa jumuiya yako juu ya hatari yoyote ya mafuriko ya baadaye?			
Kuhimiza watu wengine katika jamii yako kuwa tayari muda wote kutarajia hatari yoyote ya mafuriko?			
Kushiriki katika kozi za mafunzo kusaidia jumuiya yako kuhimili hatari za mafuriko ya baadaye na matokeo yake juu ya mifumo ya maji hapa Dar es Salaam?			

RASILIMALI

22. Je! Unafahamu shirika la dharura la ndani ambalo hufanya tayari jumuiya yako katika hali ya maafa?

Yes Ndiyo ☐ No Hapana ☐ Not sure Sina uhakika ☐

23. Ni mara ngapi jumuiya yako inakutana na shirika la usimamizi wa dharura la mitaa kujadili masuala yanayohusiana na utayarishaji wa jamii yako kwa hatari za mafuriko?

Kila mara ☐ Mara kwa mara ☐ Mara nyingine ☐ Mara chache ☐ Hakuna ☐

24. Je! Unakubaliana kuwa una habari za kutosha kutoka kwa shirika lako la usimamizi wa dharura la serikali za mitaa ili kukuwezesha kujiandaa kwa athari za mafuriko kwenye mifumo ya maji?

Nakubaliana kabisa ☐ Nakubaliana ☐ Sikubaliani ☐ Sikubaliani kabisa ☐ Sijui ☐

25. Ni nani anayehusika na kujiandaa kwa hatari za mafuriko?

	Nakubaliana kabisa (5)	**Nakubaliana (4)**	**Sikubali wala sikatai (3)**	**Sikubaliani (2)**	**Sikubaliani kabisa (1)**
Nina jukumu la kibinafsi kujiandaa kwa changamoto za maafa					
Ni wajibu wa shirika la serikali kunilinda kutoka kwa maafa					

IMPROVING WATER SUPPLY SYSTEM RESILIENCE TO FLOOD: DEVELOPING A MEASUREMENT TOOL FOR TANZANIA

(Pre-testing interview questions)

TECHNICAL

1. What are the critical assets for the Dar es Salaam water supply system?
2. What is the Non-Revenue Water for Dar es Salaam?
3. How efficient, maintenance is made for the critical asset?
4. Is there established assets renewal and upgrade plans to improve resilience?
5. How suitable are the designs for critical assets?
6. What is the current condition of critical assets?
7. What are critical assets located in the flood hazard area?
8. What is the additional capacity of the critical assets in the events of partial failure or a sudden increase in demand?
9. Are there existing updated design codes for physical assets which incorporate resilience design approaches?
10. What is the awareness of robustness issues in the supplier utilities such as power, and telecommunication?
11. Are there alternative water supply facilities for the critical assets that would probably not be affected by flood hazards?
12. Are there robust, and tested plans to establish diversions to alternate water supply network when the failure of critical network occurs?
13. Is there robust and tested plan to establish diversions to alternate water supply network when the failure of critical network occurs?
14. Have safe-to-fail design approaches been considered in conjunction with robustness and redundancy design approaches (where considered relevant) for existing assets?
15. Are safe-to-fail design approaches specified in design guidelines?
16. How connected is the water supply system? (Intra & Interconnected)
17. Is there existing back up supply during crisis?

ENVIRONMENTAL

18. How are local knowledge and native species used in the ecosystem monitoring and protection?
19. To what extent soil is protected from erosion as a result of flood hazards?
20. To what extent wetlands and watersheds are protected from flood hazards?
21. What is the availability and accessibility of water resource?
22. What are the efforts to reduce environmental impacts as a result of pollution from different sources?
23. How are water resources managed regarding production, consumption, conservation, and recycling?
24. To what extent population increase has stressed the ecosystem?
25. What is the degree of human intrusion into the natural landscapes such as wetlands and watersheds, and land fragmentation?
26. What is the water resources withdrawal to meet current or projected needs?
27. What are the natural flood buffers?

Appendix 3: Delphi questionnaires

First round Delphi Survey for Developing Key Indicators for Measuring the Water Supply System Resilience to Flood in Tanzania

Research topic: Improving Water Supply Systems Resilience to Flood: Developing a Measurement Tool for Tanzania.

Name of Researcher: Lukuba Ngalya Sweya
Degree: PhD in Civil Engineering
Department: Civil & Environmental Engineering, University of Auckland, New Zealand
Research Supervisors: Professor Suzanne Wilkinson and Doctor Alice Chang-Richard

INTRODUCTION

Water supply systems are lifeline infrastructures because they provide essential needs for the communities. They are also called socio-ecological-technical systems due to their interaction with natural, physical, organisational and social systems, a composition that gives serious opportunities for threats. In Tanzania, the resilience of the water supply systems has been tested by 266 different disasters between 1900 and 2016 floods being of major concern. Factors such as aging infrastructures, unbalanced systems development, insufficient rehabilitation, interdependency, urbanisation, pollution, poverty etc. contribute to lack of sufficient resilience in the water supply systems. Thus, during flooding, the systems are affected in different ways resulting to lack of sufficient portable water supply to the community and other users.

> "Resilience is defined as the ability to absorb the effects of a disruptive event, minimize adverse impacts, respond effectively post-event, maintain or recover functionality, and adapt in a way that allows for learning and thriving, while mitigating the adverse impacts of future events"

Measuring resilience of the water supply systems would support the decision on appropriate measures to be taken for improvements and bridge the gap between theory and applications. Thus, this research tries to develop tools that can be used to undertake the measurements of the resilience of the water supply systems in Tanzania.

Development of the tools follows the Delphi techniques, these tools are in the form of indicators and measures, and they are first derived from different frameworks for measuring resilience in water and other infrastructures around the world. The indicators are grouped into five dimensions based on the broadness of the factors that affect the water supply systems: technical, organisational, social, economic, and environmental dimensions.

This is a second part of the tools development involving water experts in a three rounds Delphi study. First round is to comment and modify the proposed dimensions, principles, and indicators, and add more indicators. While in second and third rounds the experts will be asked to rate the relevance, availability, simplicity, affordability, transparency, and reliability of the indicators and measures on a five Likert scale: 1= Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, 5 = Strongly Agree. And lastly the agreement on indicators and measures will be defined as at least 70% of the experts agreeing or strongly agreeing on the six factors for inclusion of the indicator.

Therefore, please,

In this first round of the Delphi study, comment or modify the proposed dimensions, principles, and indicators in part I, II, and II respectively. You can also add more indicators, ones that you feel essential for measuring the resilience of water supply system against floods in Tanzania

PART I: PROPOSED DIMENSIONS

Based on literature review, five dimensions are proposed namely Technical, Organisational, Social, Economic, and Environmental.

Dimensions	Comments
Technical dimension Technical dimension is the ability of the physical components of water supply systems to continuously deliver the acceptable quantity, and quality standards of water during the impacts of flooding. It involves all aspects of the functionality of physical components such as intakes, pumps and pumping stations, treatment units, pipelines and storage facilities, during flood emergencies.	
Organisational dimension The key attributes for this dimension are the capacity, service provision, decision making and taking actions, plan and manage, extending from construction regulations to the quality of emergence response. Therefore, the organisational dimension refers to the capacity of the organisations "urban water supply authorities" to make decision and take actions to plan and manage and respond to the impacts of floods in order to achieve the desired service of water and properties of resilience as a whole.	
Social dimension The way water users such as households, communities, institutions, and industries, relate, network, bond together to promote cooperation, and link up to exchange ideas and resources is important in order to facilitate rapid recovery aftermath. Thus, social dimension is focused on building people's skills and knowledge (response capability and plans) to lessen the suffering of negative consequences due to loss of water supply service during flooding.	
Economic dimension Water supply systems are also composed of economic factors that affect the functionality and recovery processes aftermath. Such economic factors play a great role on the speed of recovery as they determine options households, communities, firms, water supply authorities etc. can have when the water supply system is affected by the impacts of floods. Thus, economic dimension is referred to the ability of an economic body such as individuals, households, societies, water supply authorities, firms, etc. to use their economic resources to quickly recover or adjust to the loss of water supply services due to flooding impacts.	
Environmental dimension Water sources, their catchments, and recharge areas are integral components of the water supply system. The environment within which they are located is vital and determines the quantity and quality of incoming water to the treatment plants. Flooding from degraded environment can pollute the sources, cause post-contamination in distribution networks, and damage the intake structures and pumps. Thus, environmental dimension is related to their ability to withstand environmental changes and maintain the quantity and quality standards to meet the demands of the water users.	

PART II: PROPOSED PRINCIPLES

Principles are defined as specific mechanisms and behaviours that can make a system resilient. Such principles are applicable in the extensive process of measuring resilience and provide insights on how organisations can improve the systems' resilience. The following are proposed principles;

	Principles	Description	Comments
Technical dimension	Robustness	Strength, or the ability of elements, systems and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function	
	Redundancy	The degree to which multiple elements or components provide similar functions, to minimise failure propagation through the system or to enable critical operations to be diverted to alternative parts of the system during flooding.	
	Safe to fail	Innovative design approach that acknowledges that failures are inevitable and seeks systems that can easily survive and afford (cost reduction) failures and provide room for learning rather than rely on preventing their occurrence 'fail safe'.	

	Flexibility	Inbuilt system capability to adjust or reconfigure so as to maintain acceptable levels when subject to the impacts of flooding disasters. It can be increased through intentional one-off or phased interventions that enhance inbuilt system properties of resilience.	
Organisational dimension	Change readiness	The planning undertaken, and direction established to enable the organisation to continuously initiate and respond to changes in ways that create advantage, minimise risks, and sustain performances. This principle includes attributes such as the ability to; sense and anticipate hazards, identify problems and failures, develop a forewarning of disruption threats, understand social vulnerability, adapt and learn from the success or failure of the past adaptive measure, and mobilise resources	
	Networks and relationship	The ability to establish relationships, mutual aid arrangements and regulatory partnerships, understand connectedness and vulnerability across all aspects of supply chains and distribution networks, and; promote open communication and mitigation of internal/external silos (isolation from others). This principle also emphasizes the need for broad consultation and many views to create a sense of shared ownership or a joint vision to build the system resilience.	
	Leadership and culture	The ability to develop an organisational mind-set/culture of enthusiasm for the challenges, agility (ability to move quickly and easily or ability to think and understand quickly), flexibility, adaptive capacity, innovation and taking opportunities	
Social dimension	Social structure	The system of societal stratification (e.g. the class structure), or, other patterned interactions between large social groups. It entails the ability of individuals or different social groups to respond and recover from the impacts of floods to water supply systems.	
	Togetherness	The sense of unit within the society that fosters the eagerness of solving common problems during crisis, such as water issues as the result of flooding impacts.	
	Safety and wellbeing	Access to immediate security and health services regarding epidemic water-borne and water related diseases such as cholera, diarrhoea and skin diseases respectively during flooding	
	Education	Knowledge, and innovative skills passed down the generation through cultural processes or learned from government agencies and others to enhance the resilience of the society regarding water issues during flooding.	
	Equity and diversity	The desire to generate equitable and inclusive environment (e.g. equal opportunities) for all people in the society regardless of their ethnicity, gender, disability, education, age etc.	
	Preparedness	Measures taken by the society to prepare and reduce the water crisis during flooding.	
Economic dimension	Structure	The composition and patterns of various components of the economy such as trade, income, employment etc. ranging from water users to the organisations that run the water supply systems.	
	Security/Static	The ability of an entity or system (household, society or organisation) to maintain function by making the best use of available resources. It is essentially concerned with	

		efficient allocation of resources and it principally involves users (customers).	
	Dynamism	The efficient use of resources over time for investment in repair and reconstruction focusing on the speed of recovery of water supply from the impacts of flooding	
Environmental dimension	Natural assets	Assets of the natural environment consisting of biological, land and water areas with their ecosystems, subsoil assets and air.	
	Environmental capacity	The ability of environmental properties to accommodate particular activities or rate of activities without unacceptable impacts.	
	Environmental resources sensitivity	The degree at which the environment (i.e. ecosystem and water resources) can be upset due to exposure to low level perturbations. It includes the extent of human intrusion into natural landscapes, land fragmentation, and pollution loading on the ecosystems. It is also related to the extent of the supply of water from internal renewable resources, and withdrawals to meet current or projected needs.	
	Natural flood attenuation	Floods control through natural processes where flood buffers such as wetlands naturally reduce the impacts of floods to water supply systems.	

PART III: PROPOSED INDICATORS

Indicators are typically used to assess the relative levels of resilience. Proposed indicators were first derived from literature. Inclusion of these indicators is based on meeting one of the principles of the respective dimension. For a more realistic tool for measuring the resilience of water supply systems in Tanzania, the indicators are subjected into a review from different experts in Delphi study.

TECHNICAL DIMENSION

Principle	**Indicator**	**Definition**	**Comments**
Robustness	System maintenance	Effectiveness of providing periodic maintenance and post floods rehabilitation of critical assets of the water supply system	
	System renewal	Established assets renewal and upgrade plans to improve the resilience of the system against floods	
	System design	Suitability of critical assets designs across the whole water supply system, their condition, and locations in areas known to be vulnerable to floods	
	Standards/codes	Design codes and other codes of practices incorporating resilience principles for physical assets regarding the impacts of flooding.	
	Upstream interdependencies	The impacts of robustness and redundancy issues in supplier utilities such as power, telecommunication, and roads to the water supply system	
	Non-Revenue-Water (Water loss)	Quantity of water lost after production before reaching the consumers (unbilled water) due to some reasons such as leakages and vandalism	
	Unbalanced system development	System development such that water production capacity is higher than the distribution capacity and vice versa.	

Redundancy	System redundancy	Availability of alternate facilities and routes for critical assets such as intakes, treatment units, pumps, transmission mains etc. that would probably not be affected during flooding.	
	Back-up capacities	Availability of back-up facilities or equipment such as standby pumps, power generators and emergence supplies to respond to flooding events	
Safe to fail	Design approaches in existing assets	Consideration of safe-to-fail design approaches for critical assets in conjunction with robustness and redundancy design approaches (where considered relevant)	
	Design approaches in guidelines	Stipulation of safe-to-fail design approaches into design guidelines	
Flexibility	System decentralization	The use of decentralised water distribution schemes such that failure may not affect the whole system	
	Connectedness of the system	Extent at which different water schemes are interconnected such that one can dampen failure in another, and the degree of connectedness of the service points in individual distribution schemes.	
	Buffering capacity/factor of safety	Additional capacity of the system's critical components to cater in the events of partial failure or surge in demand	
	Systems future expansion capability	System designed and developed such that has option for future expansion	
	Spare parts availability	Ensuring that spare parts are readily available at any given time to facilitate rapid response to flooding impacts	

ORGANISATIONAL DIMENSION

Principles	**Indicator**	**Definition**	**Comments**
Change readiness	Emergency Response Plan (ERP)	Set of intended actions developed to mitigate the impacts of flooding events that could affect the water supply infrastructure and the ability of the water authority to deliver the service to the community	
	Communication and warning	Means of warning the staff and community regarding the water issues, inform about the water service options, and devise communication options ahead of time to enhance information flow.	
	Proactive posture	A strategic and behavioural readiness to respond to early warning signals of change in the water authority's internal and external environment before they become crisis	
	Planning strategies	Development and evaluation of plans to manage water supply system vulnerabilities in relation to the system environment and stakeholders	
	Awareness	Staff and public awareness of the flood disasters and their impacts on the water supply system	
Networks and	Effective partnership	An understanding of the relationships and resources the water authority might need to access from other organisations during flooding and planning to ensure this access	
	Leveraging knowledge	Critical information is stored in a number of formats and locations and staff have access to expert opinions when needed. Roles are shared, and staff are trained so that someone will always be able to fill key roles	
	Learning	Exposure of staff and the public to education and awareness material/messaging.	

	Internal resources	The management and mobilization of the water authority's resources to ensure its ability to operate during business as usual, as well as being able to provide the exact capacity required during flooding events.	
Leadership and culture	Leadership	Strong leadership to provide good management and decision-making during flooding, as well as continuous evaluation of strategies and work programs against the goals of the water authority	
	Engagement and involvement	Staff awareness and involvement in regular resilience discussions. Also, full consultation of stakeholders/public during water projects development to create a sense of ownership	
	Decision making	Clear delegation that enable highly skilled staff to make appropriate decision in response to flooding	
	Innovation and creativity	Staff are encouraged and rewarded for using their knowledge, and innovative and creative approaches to address flooding challenges	
	Political will	The influence of politics in decision making regarding water supply issues	
	Restructuring	Changes in the water sector that have impacts in implementing the water supply plans.	

SOCIAL DIMENSION

Leadership	**Indicator**	**Definition**	**Comments**
Social structure	Population composition	Distribution of the population according to characteristics such as age, and cultural diversity, that help to understand how the community is stratified.	
	House ownership and connectivity to water supply system	Population owning houses with or without house connection to water supply system	
	Media of communication	Means of communication from which the community receive warnings during flooding	
	Level of education and skills diversity	Maximum level of education achieved and the diversity of skills within the community to pull together in response to flooding events and fasten the rate of recovery	
	Location	The status of the area where people reside, whether is planned or unplanned settlement, and its vulnerability to floods	
Togetherness	Degree of connectedness across community groups	The existing unit the community has that entails capacity of the community to jointly respond to water problems during flooding	
	Volunteering rate	Rate of people within the community to actively take on responsibilities, or participate in community projects without financial gain	
	Shared water facilities	Water facilities such as boreholes, water trucks, water storage tanks etc. that are jointly owned within the community	
Safety and wellbeing	Preventive health measures	Measures for preventing eruption of water borne and water related diseases due to using contaminated water during flooding	
	Water and sanitation disaster response kit	Collection of basic supplies that are designed for giving emergency water supply and sanitation to overcome effects of water borne and water related diseases during flooding	
Ed uc	Past experience with disasters	Experience the community has regarding previous flooding disasters and their impacts on water supply systems	

	Cultural and historical prevention: indigenous knowledge and traditions	Use of indigenous knowledge, traditional ideas, customs, and social behaviour of the society in preventing or addressing water supply issues during flooding emergencies	
	Adoption of new technologies	Use of new water services technologies that enable the community to survive the crisis of water supply during flooding	
Preparedness	Mitigation plan	Plans prepared and adopted by the community with the primary purpose of identifying, assessing, and reducing water supply problems from flooding hazards	
	Disaster preparedness exercises/drills	Exercises undertaken by the community to prepare for emergency response regarding water supply issues during flooding	

ECONOMIC DIMENSION

Principles	**Indicator**	**Definition**	**Comments**
Structure	Employment rate and opportunities	Employments and other income generating opportunities within the community	
	Income	Amount of monetary or other returns earned, accumulating over a given period of time that is used for household consumptions.	
	Expenditure on water services	Funds spent by households to pay for water services during flooding	
Security	Individual and community savings	Capacity for individual households or community groups to have savings that help meet individual and collective needs of the poorest groups.	
	Insurance	Arrangements taken by members of the community and the water supply authority to be guaranteed of compensation of specified physical damage or loss of the system during flood emergences	
	Stability of prices and incomes	Situation where goods have constant prices and community and the water supply authority have steady incomes including during flood disasters	
Dynamism	Inward investment	Investment in the water supply authority by other companies or investors. It may also involve other companies or investors purchasing products or services from the water supply authority	
	Business cooperation (intra and inter)	Mutual beneficial arrangements to harmonise business activities, units, and departments within the water authority into a single whole, and cooperate with others outside the water authority	
	Public-private partnership	Partnership between the water supply authority and private sector including private water services companies in the delivery of water service during flooding	
	Funding	Availability of funds for all elements of resilience planning at community and organisational levels	
	Cost recovery	Recovering the costs of any given expense regarding operation and maintenance of the water supply system through billing	
	System investment proportionality	Equality of investment for the system from production and transmission system to distribution network such as to ensure uniformity in services and reduce losses	

ENVIRONMENTAL DIMENSION

Principles	Indicator	Definition	Comments
Natural assets	Using local knowledge and native species	Use of indigenous knowledge and native species in water catchments, recharge areas and sources management	
	Soil erosion protection	Protection of river banks to avoid soil erosion during flooding, which result into change of river morphology, affect the depth at intakes, and increase turbidity in the water	
	Accessibility of freshwater resource	Convenience of accessing water from various sources such as surface water, groundwater and rainwater during flooding	
	Quality of water sources	Information about the suitability of water from the main source and alternative sources during flooding, and the possible regular monitoring during flooding	
	Reduction of environmental impacts	Efforts for addressing sources of pollution that have impact to the water systems during flooding	
Environmental capacity	Population density	Population pressure and stresses on the environment/water resource	
Environmental resources	Human encroachment	Degree of human intrusion into the natural landscape/catchment and recharge areas	
	Renewable supply and inflow	Supply of water from internal renewable resources and inflow from rivers	
	Water use	Withdraw to meet current and projected needs	
Natural floods attenuation	Protection of wetlands	Identification and protection of various wetlands, and riparian areas in the basin to enhance natural floods attenuation during flooding	
	Control of urbanisation	Control of human development towards the protected zones such as catchment areas, recharge areas, wetlands and water sources according to the WRMA 2009 Part VI section 34 &37 etc.	

Second round Delphi Study for Developing Key Indicators for Measuring the Water Supply System Resilience to Flood in Tanzania

Research topic: Improving Water Supply System Resilience to Flood: Developing a Measurement Tool for Tanzania.

Name of Researcher: Lukuba Ngalya Sweya
Degree: PhD in Civil Engineering
Department: Civil & Environmental Engineering, University of Auckland, New Zealand
Research Supervisors: Professor Suzanne Wilkinson and Doctor Alice Chang-Richard

In parts I & II of this second round of the Delphi study, rank the importance of the dimensions from 1 for the most important dimension to 5 the least important dimension, and use the same approach to rank the importance of the principles depending on their number in each dimension.

In part III use a Likert scale of 1 to 5 (1= Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, 5 = Strongly Agree), to rate the indicators on the following attributes;

Code	Attribute	Description
A1	Relevance	degree to which indicators are appropriate or relate to this study
A2	Affordability	data accessible/generated for reasonable cost/level of effort
A3	Availability	easy to collect and measure
A4	Reliability	consistent over time
A5	Simplicity	ease of understanding by decision makers
A6	Transparency	can the data be reproduced and verified

PART I: DIMENSIONS

Please, rank the importance of the dimensions from 1 for the most important dimension to 5 the least important dimension

Dimensions	Rank on Importance
Technical dimension	1
Organisational dimension	3
Social dimension	5
Economic dimension	2
Environmental dimension	4

PART II: PROPOSED PRINCIPLES

Please, rank the importance of the principles depending on their number in each dimension, from 1 the most important principle towards the least important principle.

Dimension	Principles	Rank on importance
Technical dimension	Robustness	2
	Redundancy	3
	Safe to fail	1
	Flexibility	4
Organisational dimension	Change readiness	3
	Networks and relationship	4
	Leadership and culture	1
	Legal framework and Institution set-up	2
Social dimension	Social structure	3
	Togetherness	4
	Safety and wellbeing	5

Dimension	Principles	Rank on importance
	Education	2
	Equity and diversity	6
	Preparedness	1
Economic dimension	Structure	3
	Security/Static	1
	Dynamism	2
Environmental dimension	Natural assets	4
	Environmental capacity	1
	Environmental resources sensitivity	2
	Natural flood attenuation	3

PART III: PROPOSED INDICATORS

Please, use a Likert scale of 1 to 5 (1= Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, 5 = Strongly Agree), to rate the indicators on the following attributes;

TECHNICAL DIMENSION

Principle	Indicator	A1	A2	A3	A4	A5	A6
Robustness	System maintenance	5	4	4	4	5	4
	System renewal	5	4	3	4	3	3
	System design	5	5	4	4	4	4
	Standards/codes	5	5	3	3	4	4
	Upstream interdependencies	4	4	3	4	4	4
	Non-Revenue-Water (Water loss)	4	4	4	4	4	4
	Unbalanced system development	5	4	3	4	4	4
Redundancy	System redundancy	4	3	3	4	3	3
	Back-up capacities	5	3	3	3	3	3
Safe to fail	Design approaches in existing assets	5	4	3	4	3	4
	Design approaches in guidelines	5	4	4	4	4	4
Flexibility	System decentralization	5	5	4	4	4	4
	Connectedness of the system	5	4	4	4	4	4
	Buffering capacity/factor of safety	4	4	4	4	3	4
	Systems future expansion capability	5	5	4	4	4	4
	Spare parts availability	5	4	4	4	4	4

ORGANISATIONAL DIMENSION

Principles	Indicator	A1	A2	A3	A4	A5	A6
Change readiness	Emergency Response Plan (ERP)	5	5	5	4	4	4
	Communication and warning	5	5	4	4	4	4
	Proactive posture	5	4	3	4	4	4
	Planning strategies	5	5	5	4	4	4
	Awareness	5	4	4	4	4	4
Networks and relationships	Effective partnership	4	5	4	4	4	4
	Leveraging knowledge	5	5	4	4	4	4
	Learning	5	5	4	4	4	4
	Internal resources	5	5	3	4	3	4
Leadership and culture	Leadership	5	5	4	4	4	4
	Engagement and involvement	5	5	4	3	4	4
	Decision making	5	5	3	4	4	4
	Innovation and creativity	5	5	3	4	4	4
	Political will	5	5	3	4	5	4
	Laws and policies	5	5	4	4	5	4

Principles	Indicator	A1	A2	A3	A4	A5	A6
Legal framework and Institution set-up	Organisational structure:	5	5	4	4	4	4
	Restructuring	4	5	4	4	4	4

SOCIAL DIMENSION

Principles	Indicator	A1	A2	A3	A4	A5	A6
Social structure	Population composition	4	5	5	5	4	4
	House ownership and connectivity to water supply system	4	4	4	4	4	4
	Media of communication	5	5	3	4	4	4
	Level of education and skills diversity	5	5	4	4	4	4
	Location	5	4	4	4	4	4
Togetherness	Degree of connectedness across community groups	5	5	4	4	4	4
	Volunteering rate	5	5	4	4	4	4
	Shared water facilities	4	5	4	4	5	4
Safety and wellbeing	Preventive health measures	4	4	3	4	4	4
	Water and sanitation disaster response kit	4	4	4	4	4	4
Education	Past experience with disasters	5	5	4	4	5	4
	Cultural and historical prevention: indigenous knowledge and traditions	5	5	4	4	4	4
	Adoption of new technologies	5	5	4	4	4	4
Preparedness	Mitigation plan	5	5	4	4	4	4
	Disaster preparedness exercises/drills	5	5	4	4	4	4

ECONOMIC DIMENSION

Principles	Indicator	A1	A2	A3	A4	A5	A6
Structure	Employment and opportunities	5	5	4	4	3	4
	Income	5	5	4	4	3	4
	Expenditure on water services	4	3	3	3	3	3
Security	Individual and community savings	4	5	4	4	4	4
	Insurance	5	5	4	4	4	4
	Stability of prices and incomes	4	5	4	4	4	4
Dynamism	Inward investment	5	4	4	4	4	4
	Business cooperation (intra and inter)	4	5	4	4	4	4
	Public-private partnership	5	5	4	4	5	5
	Funding	5	5	4	4	4	4
	Cost recovery	5	5	4	4	4	4
	System investment proportionality	5	5	4	4	4	4

ENVIRONMENTAL DIMENSION

Principles	Indicator	A1	A2	A3	A4	A5	A6
Natural assets	Local knowledge and native species	4	5	3	4	4	4
	Soil erosion protection	5	5	4	4	4	4
	Accessibility of freshwater resource	5	4	3	4	4	4
	Quality of water sources	5	5	4	4	4	4
	Reduction of environmental impacts	4	5	4	4	4	4
Environmental capacity	Population density	4	5	4	4	4	4
Environmental resources sensitivity	Human encroachment	5	5	4	4	4	4
	Renewable supply and inflow	5	5	4	4	4	4
	Water use	4	5	4	4	4	4
Natural floods attenuation	Protection of wetlands	4	4	3	4	4	4
	Control of urbanisation	5	5	4	4	4	4

Third round Delphi Survey for Developing Key Indicators for Measuring the Water Supply System Resilience to Flood in Tanzania

Research topic: Improving Water Supply System Resilience to Flood: Developing a Measurement Tool for Tanzania.

Name of Researcher: Lukuba Ngalya Sweya
Degree: PhD in Civil Engineering
Department: Civil & Environmental Engineering, University of Auckland, New Zealand
Research Supervisors: Professor Suzanne Wilkinson and Doctor Alice Chang-Richard

In parts I & II of this third round of the Delphi study, you are invited to reconsider your voting and re-rank the importance of the dimensions from 1 for the most important dimension to 5 the least important dimension and use the same approach to re-rank the importance of the principles depending on their number in each dimension.

In part III reconsider your voting and use a Likert scale of 1 to 5 (1= Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, 5 = Strongly Agree), to re-rate the indicators on the following attributes;

Code	Attribute	Description
A1	Relevance	degree to which indicators are appropriate or relate to this study
A2	Affordability	data accessible/generated for reasonable cost/level of effort
A3	Availability	easy to collect and measure
A4	Reliability	consistent over time
A5	Simplicity	ease of understanding by decision makers
A6	Transparency	can the data be reproduced and verified

PART I: DIMENSIONS

Please, rank the importance of the dimensions from 1 for the most important dimension to 5 the least important dimension

Dimensions	Rank on Importance
Technical dimension	3
Organisational dimension	1
Social dimension	4
Economic dimension	5
Environmental dimension	2

PART II: PROPOSED PRINCIPLES

Please, rank the importance of the principles depending on their number in each dimension, from 1 the most important principle towards the least important principle.

Dimension	Principles	Rank on importance
Technical dimension	Robustness	3
	Redundancy	2
	Safe to fail	1
	Flexibility	4
Organisational dimension	Change readiness	1
	Networks and relationship	4
	Leadership and culture	2
	Legal framework and Institution set-up	3
Social dimension	Social structure	5

Dimension	Principles	Rank on importance
	Togetherness	2
	Safety and wellbeing	1
	Education	3
	Equity and diversity	3
	Preparedness	4
Economic dimension	Structure	3
	Security/Static	1
	Dynamism	2
Environmental dimension	Natural assets	4
	Environmental capacity	3
	Environmental resources sensitivity	1
	Natural flood attenuation	2

PART III: PROPOSED INDICATORS

Please, use a Likert scale of 1 to 5 (1= Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, 5 = Strongly Agree), to rate the indicators on the following attributes;

Code	Attribute	Description
A1	Relevance	degree to which indicators are appropriate or relate to this study
A2	Affordability	data accessible/generated for reasonable cost/level of effort
A3	Availability	easy to collect and measure
A4	Reliability	consistent over time
A5	Simplicity	ease of understanding by decision makers
A6	Transparency	can the data be reproduced and verified

TECHNICAL DIMENSION

Principle	Indicator	A1	A2	A3	A4	A5	A6
Robustness	System maintenance	5	5	5	4	4	5
	System renewal	5	5	5	4	5	4
	System design	5	4	4	4	4	4
	Standards/codes	5	5	5	5	5	5
Redundancy	System redundancy	5	4	4	4	5	4
	System decentralization	5	5	5	4	5	4
Safe to fail	Design approaches in guidelines	5	5	4	4	4	4
Flexibility	Connectedness of the system	5	4	4	4	4	4
	Systems future expansion capability	5	5	5	4	5	5
	Spare parts availability	5	5	5	5	5	5

ORGANISATIONAL DIMENSION

Principles	Indicator	A1	A2	A3	A4	A5	A6
Change readiness	Emergency Response Plan (ERP)	5	5	5	4	4	4
	Communication and warning	5	5	5	4	5	5
	Proactive posture	5	4	3	3	4	5
	Planning strategies	5	5	5	4	5	5
	Awareness	5	5	5	4	5	5
Networks and relationships	Effective partnership	5	5	5	4	4	4
	Leveraging knowledge	5	5	5	5	5	5
	Learning	5	5	5	5	5	5
	Internal resources	5	5	5	5	5	5
Leadership and culture	Leadership	5	4	3	3	5	5
	Engagement and involvement	5	5	5	4	5	5
	Decision making	5	5	5	4	5	5

Principles	Indicator	A1	A2	A3	A4	A5	A6
	Innovation and creativity	5	5	4	4	5	5
	Political will	5	5	5	4	5	5
Legal framework and Institution set-up	Laws and policies	5	5	5	5	5	5
	Organisational structure:	5	5	5	5	5	5

SOCIAL DIMENSION

Principles	Indicator	A1	A2	A3	A4	A5	A6
Social structure	Population composition	5	5	5	5	5	5
	Level of education and skills diversity	4	5	5	5	5	5
	Location of houses	5	5	5	5	5	5
Togetherness	Shared water facilities	5	5	5	5	5	5
Safety and wellbeing	Preventive health measures	5	5	5	5	5	5
Education	Adoption of new technologies	5	4	5	4	4	4
	Community awareness	5	5	5	4	5	5
Preparedness	Mitigation plan	5	5	5	5	5	5
	Community participation	5	5	5	4	5	5

ECONOMIC DIMENSION

Principles	Indicator	A1	A2	A3	A4	A5	A6
Dynamism	Public-private partnership	4	4	4	4	4	4
	Cost recovery	4	5	5	5	5	5
	System investment proportionality	5	5	5	5	5	5

ENVIRONMENTAL DIMENSION

Principles	Indicator	A1	A2	A3	A4	A5	A6
Natural assets	Soil erosion protection	5	5	5	5	5	5
	Accessibility of freshwater resource	5	5	5	5	5	5
	Quality of water sources	5	5	5	5	5	5
	Reduction of environmental impacts	5	5	5	4	5	5
Environmental capacity	Population density	5	5	5	5	5	5
Environmental resources sensitivity	Human encroachment	5	5	5	5	5	5
	Water use	5	5	5	5	5	5
Natural floods attenuation	Protection of wetlands	5	5	5	5	5	5
	Control of urbanisation	5	5	5	5	5	5

Appendix 4: Measures, Measurement Scales, and Tool testing

Testing Key Indicators for Measuring the Water Supply System Resilience to Flood in Tanzania

Research topic: Improving Water Supply System Resilience to Flood: Developing a Measurement Tool for Tanzania.

Name of Researcher: Lukuba Ngalya Sweya

Degree: PhD in Civil Engineering

Department: Civil & Environmental Engineering, University of Auckland, New Zealand

Measurement and Measurement scales

Dimension	Principle	Indicators	Measures	Measurement scales	Score
Technical	Robustness	System maintenance	Existing effective processes for maintaining critical assets and ensure integrity and operability as per documented standards, policies, and assets management plans	1. No inspections or corrective maintenance not completed. 2. Ad hoc inspections or corrective maintenance completed, but with delays/backlog. 3. Ad hoc inspection process for critical assets but corrective maintenance completed when required. 4. Non-audited annual inspection process for critical assets and corrective maintenance completed when required. 5. Audited annual inspection process for critical assets and corrective maintenance completed when required.	
		System renewal	Evidence for existing and implemented assets renewal and upgrade plans for improving resilience	1. No plan exists and no controlled renewal or upgrades of assets. 2. Plan is not linked to resilience and an ad hoc approach is undertaken. 3. Renewal and upgrade plans exist for critical assets and are linked to resilience, however no evidence that they are followed. 4. Renewal and upgrade plans exist for critical assets, linked to resilience, and an ad hoc approach is undertaken 5. Renewal and upgrade plans exist for critical assets, are linked to resilience, and are reviewed, updated and implemented.	
		System design	Percentage of the assets that are at or below the current design codes/standards	1. 0-20% are at or above current codes 2. 20-40% are at or above current codes	

Dimension	Principle	Indicators	Measures	Measurement scales	Score
				3. 40-60% are at or above current codes 4. 40-60% are at or above current codes 5. 80-100% are at or above current codes	
			The general condition of the critical assets of the water supply system	1. 0-20% are considered good condition 2. 20-40% are considered good condition 3. 40-60% are considered good condition 4. 60-80% are considered good condition 4. 80-100% are considered good condition	
			Percentage of critical assets located in flood hazard areas, or exposed to flood hazards	1. 80-100% are highly exposed to a hazard 2. 60-80% are highly exposed 3. 40-60% are highly exposed 4. 20-50% are highly exposed 5. <20% are highly exposed	
		Standards/codes	Existence of updated design codes which incorporates resilience design approaches	1. No codes 2. Codes are underdevelopment 3. Codes are in existence but not updated 4. Codes have been developed and updated, however, not implemented 5. Codes exist, have been implemented, are up-to-date and are applicable to all asset types	
	Redundancy	System redundancy	Percentage of the critical assets with alternate facilities.	1 - <20% critical assets have alternate facilities or routes 2. 20-40% critical assets have alternate facilities or routes 3. 40-60% critical assets have alternate facilities or routes 4. 60-80% critical assets have alternate facilities or routes 5. >80% critical assets have alternate facilities or routes	
		System decentralization	Evidence that the water supply system has more than one subsystems (schemes)	1. No information 2. Centralised system comprising single production system 3. Different production systems, with centralised distribution scheme 4. Different production systems, with clear decentralised distribution schemes, and very few interconnections 5. Different production systems with clear decentralised distribution schemes, well planned interconnections within the whole system	
	Safe-to fail	Design approaches in guidelines	Evidence that safe-to-fail approaches are included within asset design codes and guidelines	1. Safe-to-fail not considered at any stage 2. Safe-to-fail approach not included, but plans are to incorporate in near future 3. Safe-to-fail approach not included, but review is underway to incorporate in the design 4. Design codes and guidelines consider safe-to-fail approaches implicitly 5. Design codes and guidelines consider safe-to-fail approaches explicitly for all assets	
	Flexibility	Connectedness of the system	Percentage of service area that is likely to receive service from more than one scheme.	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%	
			Proportion of looped distribution network versus dead end distribution network in the service areas (LS/DeS)	1. No information 2. <40% large part of the service areas have dead end distribution network 3. 40 – 60% the two networks co-exist in nearly the same proportion 4. 60 -80% Improved efforts for implementing looped system	

Dimension	Principle	Indicators	Measures	Measurement scales	Score
				5. 80 – 100% The looped distribution network is dominant	
		Systems future expansion capability	Percentage of components with option for future expansion	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%	
		Spare parts availability	Evidence that spare parts are readily available and accessible during emergencies	1. No clear information 2. Most are ordered from abroad and takes few weeks 3. Most are ordered from abroad and takes few days 4. Most are locally available, but impended by the purchasing procedures 5. Most are locally available, and simple purchasing procedures are followed during emergencies	
Organisational	Change readiness	Emergency Response Plan (ERP)	Evidence that the ERP exists and is functional (Morley, 2012)	1. No Emergency Response Plan. 2. ERP developed and/or updated in compliance with The Tanzania Emergency Prepared and Response Plan (TEPRP). 3. Staff trained on ERP (i.e., Table Top). 4. Resource typed assets/teams defined and inventoried. 5. Functional exercises on the ERP conducted	
		Awareness	Staff are aware of the of the possible disruptions caused by the impacts of floods ; moreover, processes exist to reward staff for identifying new hazards, weak links and warning signs	1. No awareness 2. Some awareness 3. Some awareness and education programs being developed to rise staff awareness 4. Education programs executed and staff are aware of some impacts 5. Staff educated and fully aware of all impacts	
				5. Processes in place and well enacted and embedded in culture 4. Processes new and non-enacted 3. Processes underdevelopment 2. Ad-hoc 1. No process	
		Communication and warning	Existence and effectiveness of early warning systems. Means to warn water users of the problems and advise them the options	1. No warnings 2. Ad hoc warning systems 3. Ad hoc warning, warning systems are underdevelopment 4. Warning systems exist but warning time may not be adequate. 5. Warning systems exist and will allow time for reaction	
			Existence and reliability of communication system that ensures communication flow among staff and water users under extreme conditions	1. No system 2. Large gaps in system, untested 3. Systems exist but have gaps and funding is not adequate 4. Systems exist but funding is not adequate 5. Systems exist and have back up and have been tested	
		Proactive posture	Assess post flooding needs and put in place pre-event agreements for property access, supply of materials and specialist services (e.g. private property or property owned by other public entities, consultancy etc.)	1. Needs unknown, no agreements 2. Some needs known, no agreements 3. Some needs known and some agreements in place 4. Needs known, and some agreements in place 5. Comprehensive assessment of post event needs and agreements in place	
			Disaster risk awareness training implemented during community events in order to maintain an altitude of awareness and preparedness	1 – No training 2 Considering development of awareness trainings 3. Development of awareness training and scenarios – not implemented	

Dimension	Principle	Indicators	Measures	Measurement scales	Score
			regarding the impacts of flooding to the water supply system	4. Ad hoc awareness training, not keyed to scenarios 5. Regular awareness training taking place keyed to scenarios	
		Planning strategies	Existence of robust risk identification and assessment practices including planning for unforeseen risks (including cascading failure, concurrent failure etc)	5. Practices exist and are regularly followed, reviewed and updated 4. Practices exist, however inconsistent 3. Ad hoc approach is undertaken 2. Plans underdevelopment 1. No plans	
			Existence of joint planning such that emergency plans for other agencies and sectors are reviewed, identify required actions and incorporate into plans of the Water authorities as required. Cost sharing agreements in place for significant requirements by others	5. Cross-sector and agency plans linked, and water supply authority requirements documented, cost-sharing agreements 4. Emergency plans linked, gaps in water supply authority requirements, no cost-sharing agreements 3. Cross-sector and authority emergency plan selected for review 2. Discussions for establishing cross-sector and authority emergency plans in place 1. Emergency plans not linked, water supply authority requirements unknown	
			Contingency plan in place to identify ahead of time alternative water pipelines and other facilities required for response, rehabilitation and protection from further disaster	5. Complete plan exists, keyed to scenario 4. Plan exists with very minor gaps 3. Plan exist but with significant gaps 2. Ad hoc plan being drafted 1. No plan	
	Network and relationships	Effective partnership	Presence of cost-sharing arrangements and mechanisms for quick release of emergency funds for failures affecting more than one system	5. Agreement finalised for all sectors 4. Agreement finalised for some sectors only 3. Agreement under development 2. Discussions are in progress to establish an agreement 1. No agreement	
			Presence of effective coordination with other tiers of the government, councils and other water authorities, and private sector. The organisation structure and role definitions to achieve required coordination, signed off by all participants and operating effectively on ground	5. Implemented and operating 4. Participants reviewing structure and definitions for sign off 3. Structures and role definitions being drafted for participants review 2. Early discussions for establishing structures and roles definitions 1. No structure or role definition available, no participants identified	
			Understanding the connectedness with community and community facilities where community leaders and facility identified and consultation underway to represent connectedness with community and community facilities in planning and management processes	5. Community and facility interconnectedness represented in planning 4. Partial representation and tentative connections identified. Not tested 3. Community leaders and facility operators identified not yet consulted 2. Unknown connections or relationship management process 1. No connections or relationship management process	
		Leveraging knowledge	Information sharing that take place across sectors or utilities. Cross-sector critical infrastructure register containing structural information important in a crisis/event is up to date	5. Up to date register exist and information being shared 4. Information sharing taking place, register not up to date 3. Some information sharing taking place, register not updated 2. Some information sharing taking place, no register 1. No information sharing	
			Existence of inter-agency compatibility such that no unresolved incompatibility on major shared physical communications or IT	5. Explicit efforts to ensure compatibility and no known incompatibilities 4. At least one major incompatibility 3. Multiple incompatibilities, no attempt to rectify	

Dimension	Principle	Indicators	Measures	Measurement scales	Score
				2. Attempt make known the incompatibilities 1.No attempt to harmonise with one of more key agencies or adjacent governments	
		Learning	Existence of coordinated education campaign to public and staff and effective validation through market research follow-up.	1. No campaign 2. Infrequent ad hoc campaign 3. Ad hoc, structuring underdevelopment 4. Some structure, not systematic 5. Systematic, structured campaign exists	
				1. No validation 2. Unstructured ad hoc validation 3. Ad hoc validation, existing planning for structuring the validation process 4. Occasional structured validation not campaign specific 5. Validation via comprehensive survey at completion of campaign	
		Internal resources	Evidence for hazards specific resources such as staff have skills/tools/resources/training to deal with a complete range of hazard that may occur	5. Skills and tools exist for all hazards and are maintained/updated 4. Skills and tools exist but not updated 3. Only some hazards prepared for 2. Only for some hazards prepared for; staff are aging, and tools are non-functional 1. No preparedness	
			Evidence that staff have remote response ability such that they can respond to hazards in remote areas; or existence of decentralized response options	5. Remote areas considered and response options in place 4. Remote areas considered, and action taken where possible 3. Remote areas considered, however no action taken 2. Ad hoc approach 1. No preparedness	
			Existence of the cross-discipline training with a training programme that includes multi-discipline critical management and response/repair services; and if required training for specific staff	5. Training programme implemented and staff able to perform cross discipline services 4. Training programme available but gaps in curriculum 3. Training programme drafted and partially implemented 2. Training not yet implemented but being drafted 1. No training available	
			Staffing/responder needs defined for a range of hazards scenario such as to allow for inability to get to work looking after families etc.	5. Needs defined, keyed to scenarios 4. Some needs defined and keyed to scenarios but with gaps in definition 3. Needs are being drafted and scenarios being determined 2. Needs defined, but no scenarios determined 1. No needs defined	
			Estimated shortfall in staff/responders per defined needs-potentially from multiple sources. MoUs exist for alternative sources especially from private sector	5. Staffing and responders known to be available in line with defined needs 4. Very minor shortfall 3. Some shortfall 2. Major shortfall 1. No definition	
	Leadership and culture	Leadership	Resourced resilience planning and clearly defined roles and responsibility with regular meetings and documented processes for implementing improvements	1. No resilience planning 2. No resourcing to resilience planning 3. Resilience planning being defined and responsibilities assigned 4. Partial resourcing of resilience planning, improvements not implemented 5. Resilience planning resourced and improvements implemented	
			Existence of management and leadership initiatives that promote the resilience culture within the organisation	1. No resilience culture 2. Culture is absent, but plans in place to improve 3. Culture is developing 4. Resilience culture exist to some staffs 5. Culture exists and is maintained	

Dimension	Principle	Indicators	Measures	Measurement scales	Score
		Engagement and involvement	Level of engagement and involvement of staff in internal resilience discussion, training or exercises	1. No awareness 2. Limited awareness and ad hoc 3. Staff aware but ad hoc engagement and involvement 4. Staff aware and involved in most resilience projects 5. Staff highly involved and aware of all resilience projects	
			Level of involvement and awareness of the public in different resilience building projects	1 – No awareness 2. Limited awareness and ad hoc involvement 3. Public aware but ad hoc involvement 4. Public aware and involved in most resilience projects 5. Public highly involved and aware of all resilience projects	
		Political support	Ability and willingness to understand resilience in the water supply industry	1. Decision makers neither have ability nor willingness to understand resilience with regard to water supply systems 2. Decision makers have low ability but not willing to understand resilience 3. Decision makers have low ability and low willingness to understand resilience 4. Decision makers have ability but low willingness to understand resilience 5. Decision makers have ability and are willing to understand resilience with regard to water supply systems	
			Ability and readiness to invest on resilience building activities such as preparedness in which early warning systems are established, and improving response capacity	1. Decision makers neither have ability nor readiness to invest on resilience building activities 2. Decision makers have low ability but not ready to invest on resilience building activities 3. Decision makers have low ability and low readiness to invest on resilience building activities 4. Decision makers have ability but low readiness to invest on resilience building activities 5. Decision makers have ability and are ready to invest on resilience building activities	
			Evidence that corruption is effectively controlled and bureaucracy is avoided on deploying resources for enhancing resilience in the water supply systems	1. Processes for making decisions and deploying resources for resilience building and during disaster response are non-existent and high level of bureaucracy and corruption is involved 2. Processes for making decisions and deploying resources for resilience building and during disaster response are partially-existent but high level of bureaucracy and corruption is involved 3. Processes for making decisions and deploying resources for resilience building and during disaster response are fully-existent but not followed, leading to bureaucracy and corruption 4. Processes for making decisions and deploying resources for resilience building and during disaster response are fully-existent but partially followed leading to some level of bureaucracy and corruption 5. Processes for making decisions and deploying resources for resilience building and during disaster response are fully-existent and transparent and no bureaucracy and corruption is involved	
		Decision making	Procedures in place to assign authority to make quick decisions, reduce excessive bureaucracy in relation to deployment of staff and resources during flooding	1. No procedures 2. Ad hoc 3. Procedures under development 4. Some procedures and roles agreed, not for all elements 5. Procedures and roles agreed and in place for all elements	

Dimension	Principle	Indicators	Measures	Measurement scales	Score
			Required personnel, services and resources identified and agreements in place for post-event response	1. No review of resilience benefits 2. Ad hoc agreements 3. Very few agreements 4. Some agreements, not for all services or resources 5. Agreements in place	
		Innovation and creativity	Existence of strategies to encourage and reward staff for using their creativity and innovative ability in addressing water issues during flooding	1. No strategies 2. Ad hoc rewards 3. Strategies underdevelopment 4. Strategies exist but semi-functional 5. Strategies exist, fully functional	
	Legal framework and institutional set-up	Organisational structure	Presence of organisation structure and roles definition where key people are identified at national, regional, and local level to achieve the required coordination	5. Implemented and operating 4. Participants reviewing structure and definitions 3. Structure and role definitions available, no participants available 2. Structure and role definitions under-development 1. No structure or role definition available, no participants identified	
		Laws and policies	Resilience well defined in the laws and policies regarding water supply; roles well defined to allow effective implementation of resilience building in the systems	5. Resilience well defined, roles and responsibilities explicitly stated and there is effective implementation 4. Resilience well defined, roles and responsibilities explicitly stated, but no implementation 3. Resilience defined but roles and responsibilities not explicit 2. Resilience mentioned but not defined 1. Resilience not defined	
Economic	Dynamism	Public-private partnership	Existing MoU and contracts with private water services providers, and others to enhance water service provision	1. No existing PPP 2. No existing PPP, MoU underdevelopment 3. Ad hoc PPP, MoU under development, contracts not signed 4. Ad hoc PPP, MoU already developed, contracts to be signed soon 5. Strong PPP with long term contracts	
		Cost recovery	% of the annual expenditures recovered during that particular period	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%	
		System investment proportionality	Proportionality of investment in the distribution network compared to production system	1. No information about the proportionality of the water supply system investment 2. Little information available and the comparison is unknown 3. Information available, some components heavily invested than others 4. Information available, some components heavily invested than others, ongoing projects to balance 5. Information available, all components invested in same proportion in terms of capacity	
Environmental	Natural assets	Soil erosion protection	Existing and functional plan or program for soil erosion protection-evidence	1. Neither program nor protection activities exist 2. No program, but only ad hoc protection activities exist 3. Program exist, but only ad hoc protection activities are executed 4. Program exist and intermittently executed 5. Program exist and fully executed/functional	
		Accessibility of water resource	Proportion of the population using safely managed water resource: an improved source located on premises available when needed and free from contamination (SDG)	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 – 80%	

Dimension	Principle	Indicators	Measures	Measurement scales	Score
				5. 80 – 100%	
			Proportion of the population connected to public water supply (UNSD)	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 – 80% 5. 80 – 100%	
		Quality of water sources	Existence of water quality monitoring program during flooding for both main and alternative sources	1. No existing monitoring program 2. Monitoring program underdevelopment - evidence 3. Existing program but not functional 4. Existing program but semi-functional 5. Existing and functional monitoring program	
		Reduction of environmental impacts (various pollution)	% of sewerage system, and the evidence for addressing seawater intrusion, solid waste collection, fertilizers and pesticides.	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 – 80% 5. 80 – 100%	
	Environmental capacity	Population density	Annual per capita internal renewable water resources (Gardner-Outlaw & Engelman, 1997)	1. <1000m^3/yr.C. water scarcity 2. 1000 – 1700m^3/yr.C. intermittent or localised water shortage (water stress) 3. 1700 – 2000m^3/yr.C. minimum water requirement 4. 2000 – 2500m^3/yr.C. water stress free 5. >2500m^3/yr.C. (sufficient water)	
	Environmental resources sensitivity	Human encroachment	The mean annual percentage of the tree cover removed for urbanisation, commodity production, and certain type of small-scale agriculture (SDG)	5. 0 - 0.05% 4. 0.05 - 0.275% 3. 0.275 - 0.5% 2. 0.5 - 15% 1. above 15%	
			Existing forest canopy cover in the catchments or recharge areas	1. <5% 2. 5 – 10% 3. 10 – 30% 4. 30 – 50% 5. Above 50%	
		Water use	Freshwater withdrawal as a percentage of the total renewable water resources (SDG)	1. Below 12.5% 2. 12.5 - 25% 3. 25 - 50% 4. 50 - 75% 5. 75 - 100%	
			Existence of planning and functional water withdrawal monitoring activities	1. Neither plan nor withdrawal monitoring exist 2. No plan but ad hoc withdrawal monitoring exist 3. Existing plan but ad hoc withdrawal monitoring 4. Existing plan but intermittent withdrawal monitoring 5. Existing plan and regular annual withdrawal monitoring	
	Natural floods attenuation	Protection of wetlands	Extent of identification and protection of wetlands and riparian areas	1. Neither identified nor protected 2. Partially identified but not protected 3.Partially identified and partially protected 4.Fully identified but partially protected 5.Fully identified and fully protected	

Dimension	Principle	Indicators	Measures	Measurement scales	Score
		Control of urbanisation	(Enforcement of WRMA 2009 P. VI, SECT. 34&37)Evidence of control of human development within catchment areas, recharge areas, wetlands and beyond 60m from water sources	1.WRMA 2009 P.VI, SECT. 34 & 37 not enforced and activities exist in protected zones and beyond 60m from water sources 2. WRMA 2009 P.VI, SECT. 34 & 37 partially enforced but activities exist in protected zones and beyond 60m from water sources 3. WRMA 2009 P.VI, SECT. 34 & 37 moderately enforced and few activities exist in protected zones and beyond 60m from water sources 4. WRMA 2009 P.VI, SECT. 34 & 37 fully enforced but few activities exist in protected zones and beyond 60m from water sources 5. WRMA 2009 P.VI, SECT. 34 & 37 fully enforced and no activities exist in protected zones and beyond 60m from water sources	
Social	Social structure	Population composition	Age distribution https://data.oecd.org/emp/employment-rate-by-age-group.htm (consider dependency ratio)	1. More population are young dependants (0 – 14 years) 2. More population elderly dependants (Above 64 years) 3. More population are just entering the labour market after education (15 – 24 years) 4. More population are in their prime working lives (25 – 54 years) 5. More population are approaching retirement (55 – 64 years)	
			Cultural groups (diversity) (ethnicity, linguistic, and religious)	1. Single ethnicity and religious group 2. Single ethnicity, and one dominant religious group than others 3. One ethnicity and one religious groups are dominant than others 4. Mixed ethnicity and religious groups at fairly equal rate 5. Mixed ethnicity and religious groups at equal rate	
		Level of education and skills diversity	Average education level of heads of households	1. Majority did not go to school 2. Majority possess primary education 3. Majority possess secondary education 4. Majority possess high school education, Colleges (certificates and diploma) 5. Majority possess University education	
			Proportion of heads of households possessing skills	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%	
		Location of houses	Percentage of houses located in flood prone areas	1. 80 – 100% 2. 60 – 80% 3. 40 – 60% 4. 20 – 40% 5. 0 – 20%	
			Percentage of houses located in settlements that are considered planned	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%	
	Togetherness	Shared water facilities	% households within the community jointly own one of the following: borehole, traditional well, water track, water storage tank.	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%	

Dimension	Principle	Indicators	Measures	Measurement scales	Score
	Safety and wellbeing	Preventive health measures	Households that receive warnings from the water supply authority and respond by treating the water.	1. Majority neither receive warnings, nor treat water 2. Majority occasionally receive warning, do not treat water 3. Majority receive warnings, do not treat water 4. Majority receive warnings, use traditional methods for treatment 5. Majority receive warnings, use bottled water	
	Education	Adoption of new technologies	% population within the community using one of the following; water serving technology, household water treatment technology, and rainwater harvesting technology	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%	
		Community awareness	Percentage of people aware of the risk caused by flood hazards on water supply systems	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%	
			Percentage of people aware of the disaster management facilities such as early warning and communication systems, and the existing emergency response organisations in their vicinities	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%	
	Preparedness	Mitigation plan	Evidence of existing hazard and responsive mitigation plans to prepare for flooding hazards	1. Neither hazard nor responsive mitigation plan exists 2. Either hazard or responsive mitigation plan exists but community not aware 3. Both exists, but community not aware 4. Both exist, and community aware 5. Both exist, community aware and adopted to prepare for water issues during flooding	
		Community participation	Percentage of people participating or engaging in water supply projects and other disaster management activities related to water issues	1. 0 – 20% 2. 20 – 40% 3. 40 – 60% 4. 60 -80% 5. 80 – 100%	

Appendix 5: Tool Validation-Applicability and Generality Assessment

IMPROVING WATER SUPPLY SYSTEMS RESILIENCE TO FLOODS: DEVELOPING A MEASUREMENT TOOL FOR TANZANIA

OVERALL SYSTEM RESILIENCE	**Low resilience**

DIMENSION	RESILIENCE	PRINCIPLE	PERFOMRMANCE LEVEL	DESCRIPTION
TECHNICAL	Low resilience	*ROBUSTNESS*	Moderate resilience	Less than desirable performance and specific improvements should be prioritized
		REDUNDANCY	Moderate resilience	Less than desirable performance and specific improvements should be prioritized
		FLEXIBILITY	Moderate resilience	Less than desirable performance and specific improvements should be prioritized
		SAFE-TO-FAIL	Very low resilience	Very poor performance and extensive improvement measures required
ORGANIZATIONAL	Low resilience	*CHANGE READINESS*	Low resilience	Poor performance and improvements required

		LEADERSHIP AND CULTURE	Moderate resilience	Less than desirable performance and specific improvements should be prioritized
		LEGA FRAMEWORK INSTITUTIONAL SET-UP	Low resilience	Poor performance and improvements required
		NETWORK AND RELATIONSHIPS	Low resilience	Poor performance and improvements required
ENVIRONMENTAL	Moderate resilience	*ENVIRONMENTAL RESOURCES SENSITIVITY*	High resilience	Acceptable performance in relation to the measures
		NATURAL ASSETS	Moderate resilience	Less than desirable performance and specific improvements should be promised
		NATURAL FLOODS ATTENUATION	High resilience	Acceptable performance in relation to the measures
		ENVIRONMENTAL CAPACITY	Moderate resilience	Less than desirable performance and specific improvements should be promised
SOCIAL	Very low resilience	*EDUCATION*	Very low resilience	Very poor performance and extensive improvement measures required
		PREPAREDNESS	Very low resilience	Very poor performance and extensive improvement measures required
		SOCIAL STRUCTURE	Very low resilience	Very poor performance and extensive improvement measures required
		SAFETY AND WELLBEING	Very low resilience	Very poor performance and extensive improvement measures required
		TOGETHERNESS	Very low resilience	Very poor performance and extensive improvement measures required
ECONOMIC	High resilience	*DYNAMISM*	High resilience	Acceptable performance in relation to the measures

ASSESSMENT TOOLS AND SCORING PROCESS

TECHNICAL	
INDICATOR	**SCORE**

System maintenance	4
System renewal	2
System design 1	2
System design 2	4
System design 3	5
Standards/ codes	1
System decentralization	5
System redundancy	1
System future expansion capability	4
Critical spare parts and equipment availability	2
Connectedness of the system 1	2
Connectedness of the system 2	1
Design approaches in guidelines	1
ORGANIZATIONAL	
Emergency Response Plan (ERP)	**2**
Awareness	**2**
	2
Communication and warning 1	**2**
Communication and warning 2	**5**
Proactive posture 1	**1**
Proactive posture 2	**1**
Planning strategies 1	**5**
Planning strategies 2	**2**

Planning strategies 3	2
Effective partnership 1	2
Effective partnership 2	2
Effective partnership 3	5
Leveraging knowledge 1	2
Leveraging knowledge 2	2
Learning	1
	1
Internal resources 1	2
Internal resources 2	2
Internal resources 3	1
Internal resources 4	4
Internal resources 5	3
Internal resources 6	1
Leadership	3
Engagement and involvement 1	2
Engagement and involvement 2	2
Political will 1	5
Political will 2	2
Political will 3	4
Decision making 1	5
Decision making 2	2
Innovation and creativity	2
Organizational structure	2

Laws and policies	**1**
ENVIRONMENTAL	
Human encroachment 1	**1**
Human encroachment 2	**5**
Water use 1	**5**
Water use 2	**3**
Population density	**3**
Protection of wetlands	**4**
Control of urbanisation	**3**
Accessibility of freshwater resource 1	**4**
Accessibility of freshwater resource 2	**4**
Quality of water sources	**5**
Reduction of environmental impacts	**1**
Soil erosion protection	**2**
SOCIAL	
Population composition 1	
Population composition 2	
Level of education and skills diversity 1	
Level of education and skills diversity 2	
Location of houses 1	
Location of houses 2	
Shared water facilities	

Preventive health measures	
Adoption of new technologies	
Community awareness 1	
Community awareness 2	
Mitigation plan	
Community participation	
ECONOMIC	
Public-private partnership	1
Cost recovery	5
System investment proportionality	3