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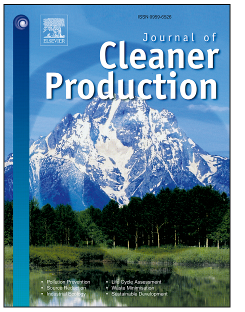

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The Dynamics of Proximal and Distal Factors in Construction Site Water Pollution

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Abstract

Construction site water pollution causes irreversible damages to the surrounding environment with additional cost, time and resources required for rectification works. Construction teams are often blamed for causing site water pollution. Little thought has been given to recognize the underlying reasons for the undesirable actions, particularly the distal factors. In construction, safety and accident research has provided a strong theoretical background that focused on distal factors. Therefore, this study aims to use the basis of accident causation model to identify the distal and proximal factors for site water pollution that will be represented using the Causal Loop Diagram. The use of Causal Loop Diagram establishes a new scientific approach towards portraying the dynamic interaction between the distal and proximal factors for site water pollution, further narrowing down the factors to be enhanced or controlled. This study has employed three different methods (in-depth interview, systematic review and case study) to identify the potential distal and proximal factors. Findings from the study suggest that the root cause for site water pollution lies on the distal factor that stems from funding. From a dynamic perspective, positive improvements made on funding could reduce the negative effects on the ensuing factors. In summary, distal factors have a domino effect on the proximal factors where the dynamic interaction between them could ultimately increase the risk of site water pollution. The outcome of this study would be a transparent and holistic perspective on the underlying causes of site water pollution that embraces the concept of pollution prevention.

Keywords: Construction site water pollution; distal factor; proximal factor; causal loop diagram; pollution prevention; accident causation model.

1. Introduction

Water pollution in construction site is a well-known phenomenon that negatively influences the sustainability (economic, environment and social) of the affected community and its natural surroundings. Sediment, being the largest water pollutant from construction site accounts for 10% of the sediment load to water bodies in the US even though construction only occupies 0.007% of the entire land (Burton and Pitt, 2002). It may cause flooding, clogging of current drainage system, reduction of groundwater recharge and destruction to natural aquatic (New Hamsphire Department of Environmental Services et al., 2008). Public health will also be at stake with additional cost and resources required to remedy the damage (Harbor, 1999). The progressive change from a natural environment setting to cleared bare land during the early stages of construction creates impervious surfaces that triggers the intertwined processes, i.e. excessive runoff, erosion and sedimentation (Auckland Regional Council, 1999). A calculated Universal Soil Loss Equation (USLE) figure for a cleared earthwork site reveals an estimated 16.14 tonnes of sediment production, in comparison to the pre-earthwork yield of 3.20 tonnes (Pain, 2014). The extent of area and duration land being left open could determine the rate and volume of runoff, subsequently affecting the rate of erosion and sediment produced (Department of Environmental Resources, 1999). Hence, efforts should be made to keep the magnitude of those variables (area and duration) at a minimum level.

Water pollution that predominantly occurs during construction may conveniently place the constructing organization as the responsible party (Houser and Pruess, 2009; Barrett et al., 1995; Lavers and Shiers, 2000). Little thought has been given to other complementing reasons such as change order, design error and schedule changes, which involve off-site personnel (designer and client) (Shrestha et al., 2014). Miao et al. (2015) argued that even though polluting companies are the direct source of pollution, they are not entirely to be blamed because their behaviors may have extended from the lack of supervision by the local agencies. Similar justification was established by McNeill (1996), who found that water pollution incident could also be caused by outset factors such as client's cost saving nature, besides the onset factors by contractors. Generally, outset factors can also be described as latent factors, which are often ignored without realizing its criticality where actions from upstream personnel create the situation for onset factors to be generated (Suraji et al., 2001; Haslam et al., 2005). Therefore, it is essential to recognize not only the direct factors but also the latent factors in any event under investigation.

The recognition of latent factors in the construction industry can be observed from the establishment of causal theories in areas such as safety, productivity and sustainability (Han et al., 2014; Lee et al., 2004; Onat et al., 2014). Nonetheless, a Scopus search using the term 'causal theory in construction' found this term being used often in the fields of construction safety and accident. Minimal research has been observed on the environment, particularly construction site water pollution. This finding is reinforced by Fuertes et al. (2013), who stated that limited environment related research was found portraying causal models, potentially due to the difficulty in distinguishing the relation between causal factors and the environment.

The current disregards of latent factors in the environment related construction research defies the growing call to implement prevention-based approaches such as 'Cleaner Production' and 'Pollution Prevention' that emphasize on source reduction and minimization of environmental impacts (Hilson, 2003). Similar approach is used to control sediment from construction sites with end-of-pipe techniques such as check dams, contour drain, retention pond, silt fence, dewatering and flocculation (NZTA, 2010). In a situation where the source (latent factor) itself is not being recognized, the implemented solutions are merely controlling rather than preventing (Frondel et al., 2007). Furthermore, control facilities for mitigating site water pollution comes with drawbacks that include high cost, reduction in usable site areas, changes to natural site hydrology and inflexible site design (Shaver, 2000). Hence, latent factor (source) recognition would lead to the establishment of a holistic approach that supports the notion of pollution prevention in order to reduce the risk of an environmental disaster.

1.1 Causal Theories

The construction safety and accident field has long recognized the root cause of accidents that extend beyond the construction-based operations by including management factors within the accident causation models (Hosseinian and Torghabeh, 2012). The accident causation models originated from different theories, starting from Heinrich's Dominoes Theory that focused on individual as the cause of accidents. Updated version of the theory by Bird and Loftus (1974) (as cited in Hosseinian and Torghabeh, 2012) included the management's role in an accident. In a similar note, Reason (1995) proposed that root cause of accidents can be traced back to latent failures and organizational errors.

In later years, Suraji et al. (2001) echoed the earlier findings that latent failures are caused by deficient decisions by the top and line management which, consequently becomes the antecedent to unsafe acts. Due to that, Suraji et al. (2001) proposed a constraint-response model that categorized causal factors into two i.e. proximal and distal factors. *Proximal factors are factors that directly lead to accident whilst distal factors have indirect connection with the accident where the inappropriate actions of the distal factors could lead to the introduction of the proximal factors.* This could further increase the risk of accident, escalate the cost and time constraint, prompting inadequate resource for the construction process. The causal link provided by Suraji et al. (2001) enables the tracing of accident causes from the lowest level operatives to the upstream personnel including the client. The works of Suraji et al. (2001) has also been based upon by other researchers. For example, Haslam et al. (2005) found that off-site stakeholders (designer, manufacturer and supplier) who were involved at the project's concept, design and management stage were frequently the originating influential factor for site based failures. Also based on an accident causation model, Miao et al. (2015) has investigated the latent causal chain for industrial water pollution in China and found institutional defect as the deeper reason for the frequent outbreak. In summary, the construction safety and accident field can provide a reasonable theoretical foundation in order to identify both the proximal and distal factors in environmental studies.

1.2 Causal Network

Causal network is used to demonstrate the causal relationship between elements and has been applied in different construction areas such as safety, quality and environment (Spillane et al., 2011; Love et al., 1999; Yuan et al., 2014). In terms of finding the causal link for environmental issues, Environmental Impact Assessment (EIA) has commonly employed causal network with system analysis such as digraphs, cause and effect diagram, flow diagram and tree diagram (Perdicoúlis and Glasson, 2006). Causal network was used to identify or predict the impacts of cumulative, direct and indirect factors on the environment. Environmental effects resulting from those factors can be significant and should be taken into consideration during decision making processes (Walker and Johnson, 1999). The advantage of using causal network and system analysis is the explicit multiple representations of impacts from a project, especially for indirect factors which are difficult to be shown using simpler form of analysis (Walker and Johnson, 1999).

Even though current studies have shown some good understanding on the extent and pattern of environmental impacts in the construction industry, research regarding the identification of causal factors from construction sites remains simplistic and incomplete (Fuertes et al., 2013). Therefore, other causal networks beyond EIA, such as data mining (Fuzzy Neural and Bayesian) and System Dynamics are being pursued (Perdicoúlis and Glasson, 2006). Causal network such as system dynamics could overcome the common concern on linearity in previous versions of the network. The concern on linear representation is the tendency to ignore the circular chain of cause and effect (Kirkwood, 1998). Lê and Law (2009) added that it is very difficult to visualize non-linear effect and feedback interactions within a complex system such as construction. This situation may create misunderstanding on the actual effect from any implemented strategy or decision (Yuan et al., 2014). Therefore, a non-linear causal network system is preferred for an effective representation of the proximal and distal factors in the study of construction site water pollution.

1.3 Non-linear Causal Network

Systemic thinking is one of the most common non-linear causal networks that apply System Dynamics. System models consist of quantitative (System Dynamics) and qualitative (Causal Loop Diagram) models (Laurenti et al., 2014). Causal Loop Diagram (CLD) or sometimes being referred to as Influence Diagram is the qualitative model established prior to running a simulation that results in a quantitative model called System Dynamics (Coyle, 1999). In general, CLD allows the illustration of cause-effect variables beyond the common linear interrelationship. CLD involves three main components i.e., 1) causal links between variables; 2) polarities between the links and 3) feedback loops (Love et al., 1999). The set of variables are connected using arrows that denote causal influence by pointing from independent to dependent variable. Each arrow is assigned its polarity, either positive (+) or negative (-), depending on how the dependent variable changes when the independent variable changes by assuming other variables are constant (Fernald et al., 2012). CLD consist of two different feedback loops, which are Reinforcing (R) and Balancing (B) loop. An (R) loop reinforces change with even more change that leads to exponential growth while a (B) loop seeks to achieve a goal (Love et al., 1999).

CLD has been used in different sectors. For instance, Lê and Law (2009) developed a CLD to transfer experiences between designer and operatives while Park et al. (2010) utilized CLD to investigate the impact of government measures on Korea’s housing market.

CLD has also been widely used in issues concerning sustainability. In this regard, Koca and Sverdup (2012) have used CLD and system analysis to explore alternative climate change strategies in Turkey. He and Liu (2010) proposed a collaborative conceptual modelling approach that uses CLD to model potential environmental impacts. In essence, CLD aids in visualizing how the interrelated variables affect each other (Yuan et al., 2014). Given the benefits of CLD, the authors' are dismayed to find limited studies being done on CLD that involves pollution from construction. Hence, the industry is in dire need to have an approach that could identify the causes of pollution holistically.

Research aim and objectives

This study aims to explore and provide a holistic view on the potential causes of construction site water pollution using a causal network diagram termed Causal Loop Diagram (CLD), consequently embracing the notion of pollution prevention.

The objectives of this study are as follows:

- To identify the distal and proximal factors that cause construction site water pollution.
- To develop CLD that demonstrates the interaction between proximal and distal factors in regards to construction site water pollution.
- To verify the use of CLD in portraying the dynamic relationship between the distal and proximal factors against construction site water pollution.

2. Research Methods

This study involves two major work phases, as shown in Table 1. This exploratory study uses qualitative methods to conduct the research, similar to other researches that have utilized qualitative approaches for their exploratory study, e.g., Spillane et al. (2011). Qualitative approaches were determined due to the limited research found on issues regarding construction site water pollution, particularly on the identification of proximal and distal factors. Hence, the whole structure of this study will be based on qualitative approaches, including the CLD that will be represented as a qualitative model.

Table 1 Research Work Phases

Work Phase		Data Collection	Data Analysis	Output
Phase 1	Stage 1	In-depth interview	Content Analysis	Objective 1: To identify the distal and proximal factors that causes construction site water pollution. Objective 2: To develop CLD that demonstrates the interaction between proximal and distal factors in regards to construction site water pollution.
	Stage 2	Systematic review		
Phase 2		Case study • Interview • Archival records • Document review		Objective 3: To verify the use of CLD in portraying the dynamic relationship between the distal and proximal factors against construction site water pollution.

The use of qualitative model (CLD) has been justified by fulfilling the requirements proposed by Coyle (2000), which are: 1) requirement for quantification; 2) value the quantified model could add to the qualitative model; 3) to distinguish whether the occurrence of the effect is well known to the industry players. The explanation for fulfillment of the requirements are given as follows: As mentioned, the aim of this study is to explore and recognize the distal and proximal factors that cause site water pollution. At this point of study, no quantification is necessary as the aim is to explore the subject area and potentially, this exploration would establish the basis for further studies. Hence, the qualitative model is sufficient to portray the potential causes that could lead to the final effect, which is water pollution. For this study, a quantitative model will not add value to the qualitative model because it is not the intention of this study to measure the extent of pollution. The focus of this study is to prevent or limit the potential occurrence by identifying the source of problem by recognizing the potential factors. As for the third requirement, it is common knowledge in the industry where immediate causes of site water pollution is from the interlinked processes of runoff, erosion and sediment and there is no need for quantification to prove the relationship (Department of Environmental Resources, 1999). Similar justification was used by Laurenti et al. (2014) who presented a Group Model Building that elicit relationships that may cause environmental impacts through cause effect chains. They found CLD itself is adequate as a system model representation in achieving their purpose of study. Hence, for this study, a qualitative model is sufficient to achieve the aim of this study, which is to explore the distal and proximal causes of water pollution.

2.1 Data Collection

In this study, various data collection methods have been utilized to ensure a reliable outcome. Details of the data collection methods are described in the following sections.

2.1.1 Phase 1

There are two outcomes for Phase 1, which are: 1) the identification of distal and proximal factors in causing construction site water pollution and 2) the development of a CLD that portrays the causal relationship between those variables. Two different data collection methods (in-depth interview and systematic review) have been utilized in order to obtain data which are both theory and industry based. Similar approach has been observed in a study done by Mahato and Ogunlana (2011), who have created their CLD using data from interview and literature.

2.1.1.1 Stage 1

This stage involves the gathering of industrial input on the causes of water pollution through the use of in-depth interview. These interviews can offer rich and in-depth information that is useful when attempting to find patterns and generate models (Zhang and Wildermuth, 2009). In-depth interview is commonly conducted among a small number of respondents in order to explore and gather a holistic understanding of a particular subject (Berry, 1999; Boyce and Neale, 2006). According to Minichiello et al. (1990), this type of interview do not require predetermined categories of question or answer. Therefore, the causes of water pollution were not pre-defined prior to this work stage. Similarly, Tang and Ng (2014) have produced their CLD on sustainable building development using input from interviews. Coyle (1977) has also supported the use of exploratory approaches such as interview as an initial step before developing a more structured instrument.

This study has applied the most common sampling technique, which is purposive sampling (Marshall, 1996). Twenty respondents (environmental expert, local authority, constructor) have been selected based on their expertise and experience in the field of study. Similarly, Fernie et al. (2003) have also employed twenty respondents for their exploratory study on supply chain management in construction. According to Bowen (2005), interviews do not entail high number of respondents as it is evaluated based on comprehensiveness of the acquired information. Hence, this study intent to have a comprehensive data rather than high quantity but on the surface type of data. The in-depth interview was conducted by asking an open-ended question in relation to the causes of construction site water pollution. Each of the audio recorded interview sessions took approximately 30 minutes to 1 hour.

2.1.1.2 Stage 2

A systematic review (SR) has been conducted to find out relevant theory-based evidence on the causes of construction site water pollution. Yuan et al. (2014) have also created their CLD using data from the literature. A SR is defined as “a literature review that is designed to locate, appraise and synthesize the best available evidence relating to a specific research question to provide informative and evidence-based answers” (Metzler al., 2013). A SR allows the literature search to be done with limited bias by following clear and transparent procedures (Petticrew and Roberts, 2006). For the purpose of this study, the steps proposed by (Petticrew and Roberts, 2006) has been used. Similar procedure could also be found in a study done by Viana et al. (2012). The steps taken to conduct the SR are given in Table 2.

Table 2 Systematic Review Process

Procedure		Content
Step 1	Research question	What causes water pollution in construction?
Step 2	Search criteria: Year	1994 to current
	Language	English
	Database	Scopus (Yi and Chan, 2014)
		Specific journals (Wing, 1997; Brochner and Bjork, 2008): Journal of Construction Engineering and Management; Journal of Management in Engineering; Construction Management and Economics; Automation in Construction; Engineering, Construction and Architectural Management; Building Research and Information; Building and Environment; Journal of Cleaner Production.
	Example of search terms	"water pollution" from construction project; "stormwater runoff" and construction"; “erosion and sediment” and construction; causes of soil erosion during construction; sediment and "construction process".
	Search field	“title/abstract/keyword”
Step 3	Screening	1929 articles identified (journal, conference papers, book chapters)
Step 4	Data extraction and synthesis	53 articles selected.

Literature search for the SR included 20 years of study in order to provide better chances of finding related contents, compared to other researchers who employed only 15 years (Lu et al., 2015) and 10 years (Ke et al., 2009) of study for their systematic review. To avoid language bias, only English written papers were selected, similar to the justifications given by Stechemesser and Guenther (2012). Following the works of Yi and Chan (2014), Scopus has been used as the search engine. As for journals, specific high ranked journals in Construction Engineering and Management were used (Table 2 refers). In addition, a journal based on preventive approaches (Journal of Cleaner Production) has also been included to expand the search for a more holistic outcome. The final number of articles after the removal of duplications and irrelevant content is 53.

2.1.2 Phase 2

Phase 2 acts to verify the findings established in Phase 1. Data for this phase has been collected from a case study and presented in the form of a CLD. Similar approach was used by Love et al. (1999), who have identified the causes of reworks using two case studies, with the support of literature and displayed them using a CLD. In this research, a particular project is studied in order to find possible causes that may contribute in increasing the risk of site water pollution. Yin (2009) described case study as a detailed investigation of a phenomenon in a real life setting. Basically, case studies are suitable when new processes are to be explored as it provides rich information to understand certain processes (Christie et al., 2000). This is well suited to the aim of this study as it allows for an in-depth exploration of the subject, which is still at its infancy.

The case project was selected based on pragmatic considerations, namely their availability. According to Yin (2009), there is no ideal number of case studies to be carried out while Romano (1989) suggested that the number of cases should be left to the judgement of the individual researcher. Taking from that, this study intends to use a case project that encountered delay during its initial construction stage such as site clearance or earthwork. The preliminary stage of construction was particularly chosen because this stage would have the most impervious surfaces, which is highly prone to excessive runoff, erosion and sediment. Therefore, any work and time delay during that period would contribute in increasing the risk of water pollution (Goodemote, 2005). Hence, the aim of this case study is to find causes for the delay and subsequently displaying it using a CLD. Data for this case study will be collected through interviews with personnel in-charge (project engineer, assistant engineer, site supervisor and administrative staff), archival records (site diary) and site documents (variation orders).

2.2 Data Analysis

Content analysis is a method used to analyze written, verbal or visual communication messages (Cole, 1988). In this study, inductive content analysis has been adapted to attain a condensed and broad description on the area of study that will result in categories that best describe the subject area (Elo and Kyngas, 2008). In this case, potential proximal and distal factors that increase the risk of construction site water pollution. Steps suggested by Elo and Kyngas (2008) were adapted for the analysis: 1) Open coding: Literature were sourced and read through to identify the key terms and headings; 2) Create category: From the key terms, category is being created to provide a better understanding of the subject and 3) Abstraction: The categories were further derived with the establishment of sub and main categories.

2.3 CLD Model Validation

Coyle and Exelby (2000) suggested that a CLD drawn by an academic should be verified and validated by the academician him or herself as the problem was initiated by him/ her. In an academic research, the analyst should be adequately informed on the problem domain in order to stipulate the symptoms, operations and details. As proposed by Sterman (2002), all models should be grounded and tested against the widest range of data including numerical and archival information with qualitative data collected from interviews, observation and other methods. This study has been conducted following the suggestions by Coyle and Exelby (2000) and Sterman (2002). Authors such as Haslam et al. (2005) and Gambatese et al. (2008) have validated their model by mapping the established categories against a set of real incident. Yuan et al. (2014) has also used a case study to illustrate the validation and application of their proposed model. Similar to the studies mentioned above, a case study is established in Phase 2, where the method will be used to verify the CLD model developed in Phase 1.

3. CLD Development

A CLD that portrays factors that influence site water pollution has been created using the data gathered from in-depth interview and SR where the factors are being categorized as either distal or proximal. This study will use the definition of proximal and distal factors established by Suraji et al. (2001). In short, proximal factors are the direct cause of water pollution incidents while distal factors function to form the proximal factors, consequently recognized as the indirect cause of water pollution. Further description on these factors can be referred to in Section 1.1. The CLD was drawn following the steps proposed by Kim (1992): 1) theme selection; 2) time span; 3) key variables; and 4) level of detail. The next section describes data identification and analyses in deriving variables for the CLD.

3.1 Interview Data

Table 3 provides brief information of the respondents, categorized based on their work nature: 1) legislator (L); 2) environmental specialist (ES) and 3) constructor (C).

Table 3 Respondents' Information

Respondent	Profession	Average years of experience	Expertise
L1-L3	Technical specialist	11	Storm water management in the local council
ES1-ES11	Civil engineer	15	Environmental consultant
C1-C6	Project manager	18	Construction project management
Category of specialization: Legislator (L) : 3; Environmental specialist (ES): 11; Constructors (C) : 6			

The summarized interview data is shown in Table 4, which portrays the influencing factors for site water pollution. The data was extracted by following the steps proposed by Elo and Kyngas (2008), after it was transcribed from the initial audio recordings. The proximal factors are represented by variables 1 to 7 while the distal factors are variables 8 to 17.

Table 4 Factors that Influence the Occurrence of Site Water Pollution (Interview Data)

No.	Variables	Associated components	ES 1	ES 2	ES 3	ES 4	ES 5	ES 6	ES 7	ES 8	ES 9	ES 10	ES 11	L1	L2	L3	C1	C2	C3	C4	C5	C6
1	Control facilities	Allocation	■	■	■		■	■	■	■	■	■	■	■		■	■	■	■	■	■	■
		Insufficient; ineffective	■	■	■		■	■				■	■	■		■	■	■	■	■	■	■
2	Enforcement	By local agencies; Act				■	■	■	■		■	■	■			■		■	■	■	■	■
3	Malpractice	Contractor's work sequence	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■		■
		Ill practices			■	■																
4	Cleared site	Impervious surfaces		■	■	■			■	■		■		■	■	■	■					■
5	Work progress	Progress at site					■		■									■				
6	Time delay	Waiting time, delay	■	■			■					■		■					■			
7	Rain	Rain occurrence	■		■		■		■			■										■
8	Design error	Design constraint							■					■								
		Deficient knowledge; constructability issue							■			■				■			■			
9	Funding	Client's budget				■		■		■		■						■	■	■		
10	Land area	Limited area for control facilities																	■			
11	Traditional procurement	Design-bid-build					■	■		■		■										
12	Fragmentation	Design and construction stage					■	■	■	■							■		■			
13	Miscommunication	Delay in receiving and sending information				■				■		■										
14	Planning effectiveness	Project planning by client		■		■						■				■	■					
15	Unforeseen situation	Utilities; ground condition				■						■							■			
		Compromised pre-designed devices										■										
16	Time constraint	Limited time available		■		■	■	■				■										
17	Wet season	Winter; monsoon; rainy season	■	■			■	■		■	■	■			■	■	■	■	■			

3.2 Systematic Review Data

Findings from the interviews were further enhanced with the theoretical perspective by the use of SR. The 53 selected articles have been read through and subsequently being placed into several categories using similar content analysis steps employed for the interview. The causes identified were tabulated according to the categories and arranged in order (most cited to least cited) (Table 5 refers).

Table 5 Causes of Construction Site Water Pollution (Systematic Review Data)

No.	Causes	Authors		Total Cited
1	Erosion	Example of cited authors	Al-Ani et al. (2009); Ab Rahman et al. (2010); Faucette et al. (2009); Basri et al. (2009); McNeill (1996); Wu et al. (2012); Pudasaini et al. (2004).	31
2	Cleared site, work near sensitive areas, earthworks.		Al-Ani et al. (2009); Ab Rahman et al. (2010); Goodemote (2005); Basri et al. (2009); Pudasaini et al. (2004); Houser & Pruess (2009)	29
3	Storm water runoff		Al-Ani et al. (2009); Faucette et al. (2009); McNeill (1996); Houser & Pruess (2009); Maniquiz et al. (2009); Yates (2014)	26
4	Sediment		Al-Ani et al. (2009); Weese (2007); Houser & Pruess (2009); Barrett et al. (1995) Lavers & Shiers (2000)	22
5	Natural factors (soil, topography, rain, geography)		Ab Rahman et al. (2010); Goodemote (2005); Wu et al. (2012); Pudasaini et al. (2004); Chen et al. (2007);	18
6	Control facilities (unavailability, insufficient, not well maintained)	All cited authors	Goodemote (2005); Faucette et al. (2009); Basri et al. (2009); McNeill (1996); Wu et al. (2012); Weese (2007); Pudasaini et al. (2004); Houser & Pruess (2009); Barrett et al. (1995) Shen et al. (2010);Shen et al. (2005);	11
7	Designers' issue (documentation error,, failure to cooperate, lack enforcement, knowledge deficient, design fault)		McNeill (1996); Weese (2007); Barrett et al. (1995) Millet (1999);	6
8	Unfavorable season (winter, rainy) either being planned or pushed.		Ab Rahman et al. (2010); Goodemote (2005); Maniquiz et al. (2009); Apipattanavis et al. (2010); Cole (2000);	5
9	Contractors' issue (process error, negligence, ill practices.		Millet (1999); Shen et al. (2005); Dharmappa et al. (2000); Lavers & Shiers (2000); Yao et al. (2011);	5
10	Waiting time and delay during earthwork and site development, schedule change.		Al-Ani et al. (2009); Goodemote (2005); Davis et al. (2003); Chen et al. (2007);	4
11	Compaction		Davis et al. (2003); Fuertes et al. (2013);	2
12	Clients' issue (limited land area, lack of funding)		McNeill (1996) Chen et al. (2007);	2

Findings from the SR differ slightly from the interview as the theory emphasized heavily on the immediate causes of water pollution i.e., erosion, cleared site, runoff, sediment and precipitation processes. Little emphasis was given on factors that involve human or man-made inefficiencies. This outcome strengthens the exploratory nature and the initial reason for this study to be conducted as there is a clear gap of knowledge where human initiated errors were less recognized in the literature. Since the aim of this study is to recognize the distal and proximal factors of site water pollution, the aforementioned immediate processes are shown in the table with limited descriptions (only example of references provided). Full cited references are given for the potential distal and proximal factors. The factors found on man-made errors (factors 6 to 12) are similar with the findings from the interview and can be classified into distal or proximal. The collation of both methods (interview and review) provides a complementary mix of theory and industry that provides a complete perspective to build a CLD for causes of construction site water pollution.

3.3 Collated Data: Interview and Systematic Review

Data from the interview and SR has been grouped and collated into 17 variables and is shown in the form of a CLD (see Figure 1), with its description given in Table 6. In general, 10 distal (D) and 7 proximal (P) factors were shown in the CLD where the factors were linked to each other, consequently influencing the risk of site water pollution. The CLD is represented with variables that are connected using arrows with its respective polarity. The polarities were drawn based on the feedback from interviews and literature. As an example, the polarity between water pollution and control facilities is derived as follows: Respondent ES1 stated that increase in the allocation of control facilities could reduce the occurrence of water pollution (negative polarity) and the reduction in water pollution could reduce the requirements for additional control facilities (positive polarity). In theory, this polarity has been supported by Goodemote (2005). After the polarities have been established, the loops focusing on water pollution are extracted. From the diagram, 16 water pollution related loops have been distinguished, which consist of twelve Reinforcing (R1-R12) and four Balancing (B1-B4) loops. Further descriptions for each of the loops are given in Table 6, which is the derivation of Figure 1 with subsequent discussions in Section 3.3.1. In general, Table 6 shows the interaction between different variables (distal and proximal) for each loop. For example, Loop R1 involves 'funding', 'design error' and 'control facilities' factor. Hence, under the R1 column, all sections for the aforementioned factors are being highlighted. Similar process is undertaken for all the other loops. The loop description also portrays how proximal factors are being initiated, through the consequence effect of distal factors. Table 6 also shows a significant effect distal factors have over the proximal factors. This is shown by the amount of associated distal factors (highlighted boxes below the dashed line) as compared to the proximal factors (highlighted areas above the dashed line). This display of effect could not be shown if a CLD has not been used.

3.3.1 CLD Discussion

A quick comparison between the highlighted boxes in the interview (Table 4, Factor 1-7) and CLD (Table 6, Factor 8-17) shows a shift of emphasis from proximal to the distal factors. The CLD highlights a greater influence of the distal factors as compared to the linearly demonstrated data given in Table 4. The summation of linkages between the different variables (distal and proximal factors) portrays the domino effect of the distal factors when it is represented from a dynamic perspective (Table 6 refers). The next section provides discussion on the loops and its related factors. The loops will be discussed in several groups that contain similar factors, as given in the bolded loop boxes in Table 6.

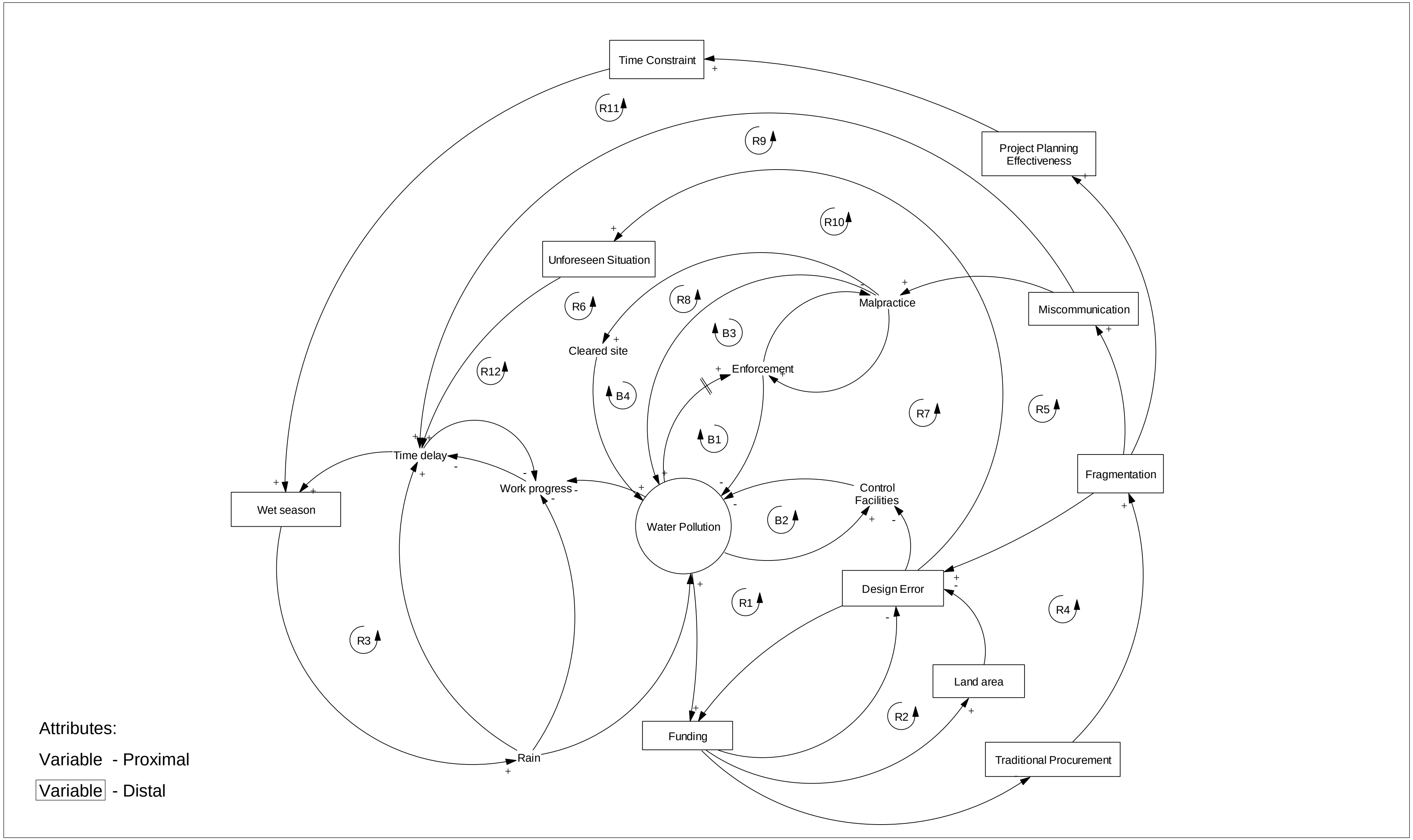


Figure 1 CLD Model for Construction Site Water Pollution

Table 6 Description of the Loops

Variables	Causal Factor	Associated components	B1	B2	B3	B4	R1	R2	R4	R3	R6	R9	R10	R11	R12	R5	R7	R8
Water pollution	-	Runoff – erosion - sediment	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
1) Control facilities	P	Allocation		■														
		Insufficient, ineffective					■	■	■									
2) Enforcement	P	Enforcement by local agencies; Acts	■		■	■											■	
3) Malpractice	P	Contractor's process error				■											■	■
		Ill practices at site			■											■		
4) Cleared site	P	Impervious surfaces; exposed soil				■												■
5) Work progress	P	Site progression								■								
6) Time delay	P	Waiting time; delay; schedule change								■	■	■	■		■			
7) Rain	P	Rain occurrence								■	■	■	■	■	■			
8) Design error	D	Design constraint; design error					■	■			■		■		■			
		Deficient knowledge, constructability issue							■									
9) Funding	D	Client's budget					■	■	■		■	■	■	■	■	■	■	■
10) Land area	D	Limited land area to install control facilities						■					■					
11) Traditional procurement	D	Adaptation of design-bid-build; open tender							■			■		■	■	■	■	■
12) Fragmentation	D	Segregation btw design and construction.							■			■		■	■	■	■	■
13) Miscommunication	D	Delay in receiving and sending information										■					■	■
		Error in information; disagreement														■		
14) Project planning effectiveness	D	Client's initial planning												■				
15) Unforeseen situation	D	Utilities; pipes; ground condition									■				■			
		Compromised pre-designed devices											■					
16) Time constraint	D	Client's time restriction												■				
17) Wet season	D	Winter; monsoon; rainy season								■	■	■	■	■	■			

Loop Description

Loop	Causal factor	
B1	P	Water Pollution- Enforcement - Water Pollution
B2	P	Water Pollution- Control facilities - Water Pollution
B3	P	Water Pollution- Enforcement- Malpractice- Water Pollution
B4	P	Water Pollution- Enforcement- Malpractice-Cleared site- Water Pollution
R1	D & P	Water Pollution- Funding- Design Error - Control facilities- Water Pollution
R2	D & P	Water Pollution-Funding-Land area-Design Error-Control facilities- Water Pollution
R3	D & P	Water Pollution-Work progress-Time delay-Wet season-Rain- Water Pollution
R4	D & P	Water Pollution- Funding-Traditional Procurement- Fragmentation-Design Error - Control facilities- Water Pollution
R5	D & P	Water Pollution- Funding -Traditional-Procurement- Fragmentation-Miscommunication-Malpractice- Water Pollution
R6	D & P	Water Pollution- Funding -Design Error -Unforeseen Situation-Time delay- Wet season-Rain- Water Pollution
R7	D & P	Water Pollution- Funding -Traditional Procurement-Fragmentation-Miscommunication- Malpractice-Enforcement- Water Pollution
R8	D & P	Water Pollution- Funding -Traditional Procurement-Fragmentation-Miscommunication-Malpractice-Cleared site- Water Pollution
R9	D & P	Water Pollution- Funding -Traditional Procurement-Fragmentation-Miscommunication-Time delay-Wet season- Rain- Water Pollution
R10	D & P	Water Pollution- Funding -Land area-Design Error -Unforeseen Situation-Time delay- Wet season-Rain- Water Pollution
R11	D & P	Water Pollution- Funding - Traditional Procurement-Fragmentation-Project Planning Effectiveness –Time constraint-Wet season-Rain-Water Pollution
R12	D & P	Water Pollution- Funding - Traditional Procurement-Fragmentation-Design error–Unforeseen situation-Time delay-Wet season-Rain-Water Pollution

Proximal Factors

Loop B1-B4

Loop B1-B4 consists only of proximal factors that commonly occur during the construction stage. Loop B1 and B2 suggest that the balancing variables within the loop could help to control the occurrence of water pollution. The main variables identified are enforcement and control facilities, as given in Loop B1 and Loop B2 respectively. The increase in water pollution incident may increase enforcements and the requirement to install control facilities (Brown and Caraco, 1997; Faucette et al., 2009; Kaufman, 2000). Furthermore, Loop B3 shows that enforcement could reduce malpractices at site, consequently reducing the risk of water pollution (Gallardo and Sanchez, 2004). Similarly, enforcement in Loop B4 also plays a role in controlling the common ill practice at site which is clearing of site at one go (Auckland Regional Council, 1999). The restriction set by local authorities that promote pollution prevention strategies such as ‘construction phasing’ prohibits the ill-practice. This essentially provides a balance loop that could reduce the water pollution incident. Hence, at the proximal level, enforcement is the key factor to control the site water pollution incident besides the effectiveness of the control facility.

Proximal and Distal Factors

Loop R1, R2 and R4

Loop R1 shows that increase in the risk of site water pollution could reduce client’s funding as environmental improvements are always seen as a cost burden (Ab Rahman et al. 2010; Zhang et al. 2014). This further creates cost constraint which limits designer’s choice of control facilities (McNeil, 1996) and may consequently reduce the effectiveness of the control facilities, which in turn will increase the risk of water pollution (Goodemote, 2005). For Loop R2, the addition of restricted land area purchased due to low funding (McNeil, 1996) will have the same effect on design and subsequent results will prevail. Accordingly, Loop R4 exhibits that the use of traditional procurement, mostly by public sectors to secure the lowest bid is common when cost is the constraint (Gibson et al., 1996; Zhang et al., 2014). Traditional procurement increases fragmentation between design and construction that exacerbates design errors especially due to lack of construction knowledge (Song et al., 2009; Barrett et al., 1995). The consequences are similar to the previous loops.

Loop R5, R7 and R8

Loop R5 extends from Loop R4, branching out from the fragmentation variable. Increased fragmentation escalates the risk of miscommunication that creates error in delivering and receiving information (McNeill, 1996). This situation can increase site process error and results similar to Loop B3 are perceived. Loop R7 and R8 contain similar distal factors with Loop R5. The distal factors in Loop R7 results in the introduction of proximal factors where the increase in malpractice increases also enforcements that could potentially reduce water pollution incident over time. However, relying solely on enforcement does not provide a balancing effect on water pollution as other variables reinforced the occurrence of water pollution. Loop R8 displays a similar proximal result with Loop B4.

Loop R3, R6, R9, R10, R11, R12

Loop R3 extends from the bottom left side of the CLD. The increase in water pollution during construction may inhibit work progress due to site closure by local authority and the pollution should be resolved before any work can resume. Reduced work progress increases construction time delay. Due to time delay and schedule changes, earthwork activities during an earthwork season may be pushed into the wet season (Goodemote, 2005; Apipattanavis et al., 2010) that consists of high occurrence and intensity of rain (Cerdá, 2007). The rainfall could lead to high runoff volume that ultimately increases the risk of water pollution from the intensified process of erosion and sediment production (Jia et al., 2013).

Loop R6 shows that low budget may cause reduced cost allocation on areas deemed as being less critical by client, especially for feasibility study. Respondent C3 strongly suggested for clients to increase the budget for site investigation so that designers would have a clear understanding of what they are about to design, subsequently reducing the risk imposed on contractors. Shen et al. (2010) also found that reduction in site investigation may mislead designers on the real site condition. This shortcoming increases the occurrence of unforeseen situations such as unexpected utilities line. Discoveries of the utilities may increase time delay due to the possible change in route and location of the lines. The distal factors discussed lead to the emergence of proximal factors with results similar to Loop R3.

Extending from the distal factors discussed in Loop R4, the increase in fragmentation also increases miscommunication in Loop R9, especially when delays occur during the transfer of information. Delays in receiving and sending of information between different parties may increase time delay during construction and proximal consequences observed in Loop R3 are expected.

Loop R10 has the combination of two loops, Loop R2 and Loop R6. In general, the effect of low funding forces the increase in unforeseen situation that leads to the surge in water pollution risk. The discussion for Loop R10 could be referred in the aforementioned loops. Loop R12 is the combination of Loop R4 and R6. Due to low funding, traditional procurement is being preferred in order to find the lowest bid cost. This type of procurement leads to fragmentation that enhances design errors and unforeseen situation and could potentially increase the risk of water pollution. The description could also be referred to in the aforementioned loops.

For Loop R11, the increase in fragmentation exacerbates project planning error. The error may stem from clients who do not see beyond their constraint of time, cost and quality with minimal understanding on the risk of water pollution (Wu et al., 2012). An ineffective project plan may further create time constraint for site work. Respondent ES5 emphasized that clients also usually underestimate the duration for earthwork and causes them to spend much time on front end works (design and procurement). This situation creates a short time frame for earthwork contractor that may extend the work into the wet season that heightens rain occurrence that increases the risk of water pollution.

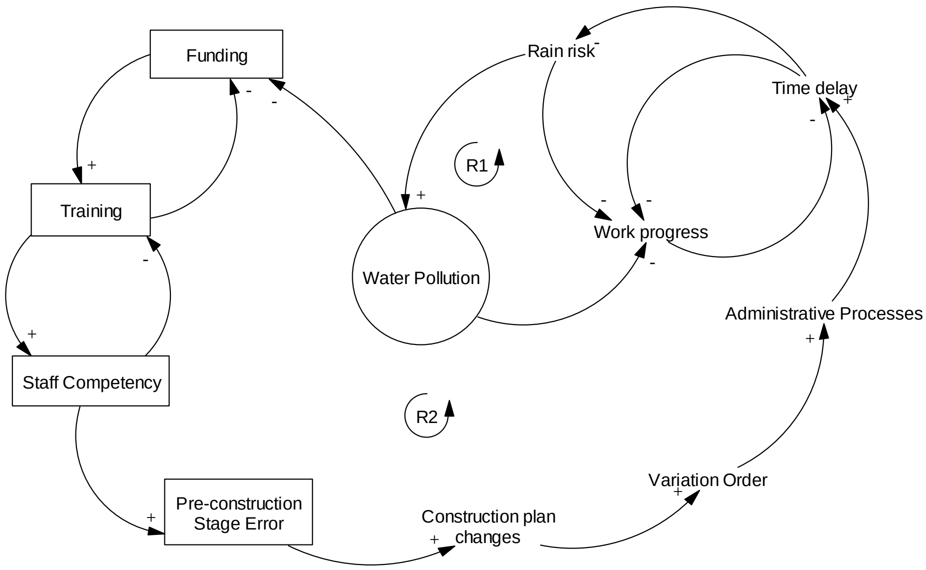
In summary of the CLD, the essential proximal factor to be guarded is ‘enforcement’, while the root of the issue may lie on the distal factor that stems from ‘funding’. This is due to the largest emphasis being placed on ‘enforcement’ in the balancing loops. In this context, the balancing loop plays a role in keeping the occurrence of water pollution at bay and enforcement is the most critical variable, judging from the highest number of highlighted boxes within the balancing loops (Table 6 refers). For the distal factor, there are no balancing loops involved. This means that all variables in the reinforcing loop will lead to increase the risk of water pollution. In this case, funding is the most highlighted core cause where positive improvements in funding could subsequently reduce the negative effect on the ensuing distal and proximal factors, ultimately reducing the risk of water pollution (Table 6 refers).

4. CLD for Case Project

A case study has been conducted on a public governed project, a three-storey district education office building. The procurement system applied for this project was Design-Bid-Build using open tender. The project was scheduled to complete within the duration of 3 years and 8 months. However, the completion time has been delayed as the contractor was given 2 time extensions that summed to 189 days. The two time extension was given for two different work stages i.e., 1) earthwork and 2) electrical installation stage. This study will focus on the reason for time extension and delays during the earthwork as it is the most vulnerable stage in regards to water pollution (Ab Rahman et al., 2010).

The contractor was awarded the first extension that lengthened the original duration by 123 days. According to the project engineer, waiting period during the earthwork occurred due to Variation Order (V.O.) application. Fisk (1997) defined variation order as “any deviation from an agreed well-defined scope and schedule”. The V.O. application was required due to the reason given as follows: After site clearance, the contractor found that on-site soil is insufficient to build the required platform level. The awarded contract did not state the requirement to import soil from off-site, giving way to V.O. The additional time request was granted due to the importing of fill materials from off-site, besides the waiting period for V.O. approval.

A CLD has been drawn based on the input from project personnel. The project personnel were queried on non-operational (earth moving activities) factors that could have caused time delay during earthwork. It is a well-known fact that a time delay during earthwork might expose earth to a higher occurrence of rainfall events, subsequently increasing the risk of water pollution. The case specific CLD model is given in Figure 2. The CLD contains only 2 loops, which are Reinforcing Loops R1 and R2. Focusing solely on water pollution, Loop R1 portrays the proximal factors that may increase the risk of water pollution processes. In this particular case, the production measure of time has been extended during the earthwork activity. Similar to findings from Figure 1, the origin of the time delay can be traced back to client's funding, as shown in Loop R2. Lengthy administrative processes such as V.O. application and approval causes land to be left opened for a certain period of time as contractors are not allowed to proceed work on site until the V.O. approval is given. Alnuaimi et al. (2010) also reported similar result where change order issued during construction is found to be the major cause of time and cost overrun that prone to create confusion, leading to negative effects on the environment. In short, the case specific CLD also shows a combination of different distal factors that have prompted the occurrence of proximal factors that ultimately increases the risk of water pollution.



Attributes:
Variable - Proximal
Variable - Distal

Loop	Variables in the loop
R1	Water Pollution-Work progress-Time delay-Rain- Water Pollution
R2	Water Pollution- Funding- Training- Staff competency-Pre-construction stage error-Construction plan changes-Variation order- Administrative processes-Time delay-Rain risk- Water Pollution

Figure 2 CLD for Case Project

5.0 Discussion

Comparison between the three different methods (interview, review and case study-verification method) of data collection showed similar trend where all methods provide site water pollution influencing factors that derive from both distal and proximal factors. The CLDs given in Figure 1 and Figure 2 portrays the systemic perspective of the effect distal factors have on proximal factors that further enhances the risk of water pollution. This negative effect from one variable to another moves in a cyclical manner, where the circumstances will be on-going negative effects if the distal factors are not improved positively. Furthermore, Figure 2 (case study) was drawn following the techniques used to produce the CLD in Figure 1 where it shows that the method could also be applied using real case project data.

It is also worth highlighting the difference between the data represented using a straight forward linear approach (Table 4) as compared to a dynamic approach (Figure 1 and Table 6). From the linear perspective, emphasis from the respondents were heavier on the proximal rather than the distal factors (Table 4, bolded box). This is so as the linear system does not take into account how the distal factors contribute to each of the proximal factors as it only shows simple cause-effect relations. This kind of representation disregards the interaction between factors which further restricts the holistic perspective of cause-effect relationship among variables. On the other hand, CLD assembles the different variables into a system causing dynamic changes. The CLD clearly shows the tendency of distal factors in affecting the occurrence of proximal factors that could potentially lead to water pollution incidents and how water pollution could eventually being related back to the distal factors. However, both linear and the systemic thinking method complement each other where the systems approach still relies on the cause-effect variables.

From the loop, it could be understood that a mere controlling solution, especially at the proximal level could not solve the problem at its source, in this case, which originates from the distal factors. This control type approach is commonly known as the end-of-pipe solutions which are usually used to control pollutions. A holistic view should be embraced in order to break the norm, subsequently enhancing the concept of Pollution Prevention. The recognition of the source factors could prevent pollution incidences from taking place. Typically, pollution prevention strategies could reduce the overall cost and provide substantial savings that may consequently affect the funding factor positively (Ab. Rahman et al. 2010; Goodemote, 2010). Hill and Bowen (1997) have also encouraged the use of systems approach to identify the relationship between economics and environment where through the use of CLD, this relationship has been proven. In this study, the CLD has established the relationship between funding and water pollution.

6.0 Conclusion

The findings suggest that distal factors have a domino effect on the proximal factors where the dynamic interaction between them could ultimately increase the risk of site water pollution. The CLD representation of those variables highlighted the criticality of managing the distal factors, which has commonly being ignored in construction. This study has used the qualitative approach to explore the new subject by providing preliminary theoretical insight that could serves as a basis for further quantitative research. However, the authors acknowledge that the qualitative study based on a small sample size may represent a limitation in this research. Hence, a triangulation-based research approach has been used to complement the research method and enhance the findings where data has been gathered from different sources, which are systematic review case study and in-depth interview. The limitations of this study creates opportunity for future research where this study could be extended from the current exploratory phase to an explanatory stage by translating the qualitative CLD into a system dynamic model where the effect of those distal and proximal factors could be quantified. Furthermore, in-depth studies could be done on each factors, starting from the core cause, in order to manage and find solutions for those factors.

Theoretically, this study has filled the gap of knowledge in identifying the distal and proximal factors that may contribute in increasing the risk of water pollution. Previously, limited studies were found in regards to the subject of man-made inefficiencies and construction site based water pollution. The recognition and elimination of the negative core cause (distal factors) leads to reduced negative effect on subsequent factors which could potentially reduce the reliance on control facilities for water pollution. This will subsequently enhance the application of the pollution prevention concept, consequently reducing the threat on sustainability in the construction industry. Representation of the related factors using the CLD is a new scientific establishment in the field of site water pollution as earlier studies have provided only the linear cause-effect factors without acknowledging the systemic interaction between those factors. From the practical point of view, this research enables the industry players to understand, identify and manage the core cause (funding) of site water pollution from a larger perspective. The use of CLD enables the practitioners to narrow down essential factors that should be enhanced (balancing factor-enforcement) as well as factors that should be controlled (reinforcing factor-funding), especially when many different factors are involved. The holistic perspective allows industry players to act proactively in solving problems at its core. Besides that, the proposed methods of building the CLD can be adapted and applied in problematic areas to find the root cause of problem for a holistic and prevention-based approach.

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Research Highlights

- Root cause for site water pollution lies on the distal factor which is funding.
- Improvement on budget allocation reduces negative effect on the ensuing factors.
- Dynamic interaction between distal and proximal factor elicits water pollution.
- Causal Loop Diagram helps to identify factors to be enhanced or controlled.