SUSTAINABLE USE OF WATER IN CONSTRUCTION PROJECTS: THE CASE OF SRI LANKA

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DECLARATION

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ABSTRACT

One of the major constraints for sustainable development is the limited quantity of freshwater available. However in construction projects, water is one of the poorly acknowledged resources as far as its efficiency and conservation are concerned. The waste and the misuse of water in construction sites have been identified as critical problems, although there is a high potential for saving water during the construction stage by adopting various water efficiency measures. Nevertheless, this aspect has not been explored sufficiently in current body of knowledge as per exiting literature. This induced the need for the research on sustainable use of water in construction. Therefore, the aim of this research was to develop a framework for improving sustainable water use practices in construction projects, from a Sri Lankan perspective.

Within a pragmatic philosophical view, a triangulation based mixed method approach was adopted for data collection and analysis. Four (04) case studies were carried out into building construction projects located in Colombo to explore the efficient water use practices that are being adopted. Concurrently, a questionnaire survey was administered among experienced construction professionals to identify important measures which can ensure efficient water use.

One of the key findings that emerged from the study was that water efficiency practices are strongly influenced by conditions prevailing within the operational environment of a project. However, some measures for improvement that go beyond on-site project level which have industry-wide support and intervention at policy level are required for these measures to be successful. This study revealed and clearly favoured 'soft' measures such as changes in the behaviour of workers as opposed to 'hard' measures which were primarily technology-based, for achieving water efficiency. The cost of water, sources of water, and the attitudes and behaviour of staff and workers were identified as the most relevant drivers that influence efficient water use in construction sites. The experience and commitments of the parties are also identified as an influential factor for the efficient use of water. The main barrier for achieving water efficiency was the low priority assigned to water management by the top managements of the relevant organisations due to their heavy engagements with other managerial functions.

The research findings introduced three new dimensions namely, Regulation, Responsibility, and Reward that could extend the existing 6R water hierarchy in a more effective manner. This led to the introduction of a novel 3R.6R extended water hierarchy model that can be applied to achieve the efficient use of water in the construction industry.

Among on-site construction activities, 'site cabins and sanitation' taken together was identified as consuming the highest volume of water and also as an activity that causes water wastage. It was revealed that indirect construction activities approximately consume more than two thirds of the amount of water used in a site. As a result, water wastage has become rampant among these indirect construction activities although in contrast it is minimal in direct construction activities. Therefore, the efficient use of water could be improved further by implementing the 'soft' measures in this study rather than implementing technology oriented 'hard' measures. Based on the results of the study, a framework has been proposed which provides the best practice guidelines on implementing sustainable water use during the construction stage of a project.

Keywords: *3R.6R Extended Water Hierarchy, Framework for Sustainable Water Use, Water Management, Water Efficiency, Construction Projects*

DEDICATION

I dedicate this piece of research to my loving husband and son who have always stood by me and dealt with all of my absences on many occasions with a smile.

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LIST OF PUBLICATIONS AND AWARDS

RESEARCH AWARDS

Built Environment Project and Asset Management (BEPAM) **Highly Commended Paper Award** for the paper titled "3R.6R Extended water hierarchy model for Sustainable use of water during Construction" by Emerald Group Publishing at, The 5th World Construction Symposium Colombo, Sri Lanka, July 2016.

The best paper award was received on paper title "Water efficiency techniques and strategies for sustainable use of water during construction phase of building projects" in the 4th World Construction Symposium June 2015 awarded by The Ceylon Institute of Builders (CIOB).

RESAERCH PUBLICATIONS

Referred Index Journal

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Referred Journal

Waidyasekara K.G.A.S, De Silva M.L and Rameezdeen, R. (2014). "Industry stakeholder perceptions on water management in construction industry in Sri Lanka: Preliminary survey", *Journal of Institute of Contractors Training and Development (ICTAD),* November, Vol XII, pp 63-73.

Referred Conference Publications

Waidyasekara K.G.A.S, De Silva M.L and Rameezdeen, R (2016), "3R.6R Extended water hierarchy model for Sustainable use of water during Construction", The 5th World Construction Symposium: Greening Environment, Eco Innovations and Entrepreneurship, p. 1-12, 29th – 31st July, Colombo, Sri Lanka.

Waidyasekara K.G.A.S, De Silva M.L and Rameezdeen, R (2015), "Water efficiency techniques and strategies for sustainable use of water during construction phase of building projects", *The 4th world International Conference on Sustainability and development in Built environment: The way forward,* p.547-559, 12th – 14th June , Colombo, Sri Lanka.

Waidyasekara K.G.A.S, De Silva M.L and Rameezdeen, R (2014), "A critical review of water studies in construction industry", *The 3rd world International Conference on Sustainability and development in Built environment: The way forward*, p. 01-12, 20th to 22nd June , Colombo, Sri Lanka

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Waidyasekara K.G.A.S (2014). Water Management Practice in Sri Lankan Construction Industry: Project Managers' Perspective, pp 41-42, Society of Sri Lankan Quantity Surveyors, Qatar, November 27th.

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LIST OF ABBREVIATIONS

AB	-	Attitudes and Behaviour
AC	-	Alternative Construction
BOQ	-	Bill of Quantities
BEAM	-	Building Environmental Assessment Method
BREAM	-	Building Research Establishment's Environmental Assessment Method
BRS	-	Building Rating System
BSR	-	Building Schedule of Rates
CE	-	Civil Engineer
CEA	-	Central Environment authority
CIDA	-	Construction Industry Development Authority
CIRIA	-	Construction Industry Research and Information Association
EIA	-	Environmental Impact assessment
EMS	-	Environmental management system
ET	-	Efficient Technologies
GBCSL	-	Green Building Council, Sri Lanka
GRIHA	-	Green Rating for Integrated Habitat Assessment
ICTAD	-	Institute of Construction Training and Development
LEED	-	Leadership in Environmental and Energy Design
MC	-	Municipal Council
M & E	-	Mechanical and Engineering
NAM	-	Norm Activation Model
NBRO	-	National Building Research Organization
NCPC	-	National cleaner Production Centre
NGOs	-	Non- Government Organizations
NRBV	-	Natural Resource Based View
NRW	-	Non - Revenue Water
NWS&DB	-	National Water Supply and Drainage Board
PM	-	Project Manager
PP	-	Policies and Planning

QS	-	Quantity Surveyor
RDA	-	Road Development Authority
SFfC	-	Strategic Forum for Construction
SLS	-	Sri Lanka Standard
SP	-	Sustainability Policies
SS	-	Sustainability Strategies
TPB	-	Theory of Planned Behaviour
UDA	-	Urban Development Authority
WC	-	Water Conservation
WE	-	Water Efficiency
WEMs	-	Water Efficiency Measures
WRAP	-	Waste and Resources Action Program
WRD	-	Water Resource Department

CHAPTER ONE

1 INTRODUCTION

1.1 Background

The world is experiencing an unprecedented scarcity of water due to its overuse and the ever-increasing demand it receives (Young & Loomis, 2014). This phenomenon combined with the rising pollution of water sources has reduced the stock of the fresh water supply available. The rising marginal cost of water coupled with its scarcity is forcing people to be more efficient in their water usage (Rodgers, De Silva, & Bhatia, 2002). Climate changes, droughts, and increasing industrial demands are straining the available supplies of freshwater (Chanan, White, Howe, & Jha 2003; Economist, 2008; Goodrum, 2008; Johnston, 2003; Russell & Fielding 2010). The United Nations (UN) estimates that more than 1 billion people living on earth suffer water scarcity (Economist, 2003). This number is expected to increase up to 1.8 billion by 2025 (Economist, 2008). According to OECD (2008) reports, 47% of the world's population will live in 2030 in regions that are under severe water stress. As stated by McWhinney (2011), more than 100 countries currently rely on desalination for at least part of their freshwater needs. In addition, many scholars identify that water is not only essential for humans and ecosystems, but that it is also a strategic economic resource (Niccolucci, Botto, Nicolardi, Bad tianoni & Gaggi, 2011; Savenije & van der Zaag, 2002). The difference between the increasing demand for water and the limited water availability creates a gap that is transformed into water scarcity (Joyce, 2012). Thus, water demand management is the most cost-effective solution for saving water which includes avoiding losses in supply, exploring non-conventional sources, increasing water use efficiency, and behavioural change of users (Carragher, Stewart & Beal, 2012; Fielding, Russell, Spinks & Mankad, 2012; Russel & Fielding, 2010).

It is a known fact that the limited quantity of freshwater available is a major constraint on sustainable development while it is an important input for economic development and social development of a country (Horne, 2012; Khalfan, 2002).

The Brundtland Commission Report defines sustainable development as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). Therefore, sustainable development has emerged during the past decade as the universally agreed goal in the field of development. According to Hussein (2008), future generations will continue to face serious environmental problems unless significant attention is given and exclusive investments are made to reverse the current state of environmental degradation, particularly with regard to water scarcity, pollution and health problems, land degradation and weak environmental institutions and legal frameworks.

Previous studies have shown that the construction industry and its activities have significant effects on the environment (Ding, 2008; Kibert, 1994; Ofori, 1992; Shen, Hao, Tam & Yao, 2007; Sjostrom & Bakens, 1999). The construction industry is regarded as one of the largest users of water along with other resources such as energy and material resources (Guggemos & Horvath, 2006). Kibert (1994) defines sustainable construction as creating a healthy built environment using resource efficient and ecologically- based principles. As stated by González-Gómez, García-Rubio, and Guardiola (2012), the construction sector is one of the sectors that cause an additional drain of available water resources. Therefore, there is a growing need for the construction sector to adopt principles of sustainability in their policies and day to day activities (Walton, El-Haram, Castillo, Horner, Pricce & Hardcastle, 2005; Xing, Horner, El-Haam, & Bebbington, 2007). Architects, surveyors, engineers, project managers and other professionals who are responsible for decision making in a construction project are expected to use sustainable solutions throughout the different stages of the project (Xing et al., 2007). As the construction stage transfers a design into reality, it involves the utilization of a variety of natural resources including water. Therefore, construction activities taking place during a construction stage have a close association with environmental impacts including the generation of waste and pollution (Shen et al., 2007).

Construction work needs water from its inception to its completion. Thus, water use efficiency has become an important area of scrutiny ever since sustainable buildings gained prominence (Bouwer, 2000). While an enormous amount of water is used to operate buildings, a considerable amount of it is also used for extraction, production, manufacturing, delivery of materials to sites and for the actual on-site construction process (McComack, Treloar, Palmowski & Crawford, 2007). They showed that a considerable amount of water used in construction becomes ‘embedded water’ and that what is required during construction stage is small but not negligible. Goodrum (2008) emphasises that while a movement for recognising water as a commodity is well underway, the quantity and impact of potential price increases of water on construction are unknown. Similarly, Savenije and Van der Zaag (2002) state that the cost of water supplied to the construction industry should be on a separate tariff system reflecting the market price of a resource that is valuable as water.

At the construction project level, water is used for several purposes and this is not limited to mixing mortar and concrete, but also to curing, dust controlling, soaking of materials, vegetation establishments, geotechnical borings, pipe flushing, pressure testing, washing and cleaning (Workplace Health and Safety Queensland, 2007; Utraja, 2010). The Strategic Forum for Construction (SFfC) Water Subgroup has identified that dust suppression, cleaning, commissioning and testing are the main water wasting activities in construction projects (McNab, et al., 2011; Lynch & Young, 2011).

1.2 Research Problem and Rationale

As briefly highlighted above, scientific literature has clearly identified water to be an indispensable natural resource. Literature further highlights the immediate need for introducing sustainable approaches to save water for the future. Although people in Sri Lanka believe that the country is blessed with an unlimited supply of water, recent research highlights that an increasing demand and unsustainable supply will lead to a water shortage, especially a drinking water (potable water) shortage in the future (Samad, 2005; Dharmaratna & Parasnis, 2012). Potable water is water treated up to the drinking level and converting raw water to potable water incurs a huge cost (Eguavoen & Youkhana, 2008). Ground water contamination is one of the common problems in Sri Lanka (Manikdiwela, 2013). In addition, high capital costs, resource limitations and expansions are the other constraints faced when providing pipe-borne water to all. This would be a difficult task for the Sri Lankan government at least for another decade. By year 2013, only 1/3 of the population enjoyed pipe-borne water (Manikdiwela, 2013). Therefore, cities with population growth are imposing stress on the available water supplies and demand for water is growing very fast (Devaraja, 2013). In Sri Lanka, consumers of some industries including construction are given huge subsidies for water (Devaraja, 2013; Manikdiwela, 2013). However, Deveraja (2013) argues against this policy and suggests that different industry categories need to be treated differently during tariff design. The society, however, considers water as a basic human need that should be made available cheap. In addition, the water wastage due to leakages and misuse will continue to burden the National Water Supply and Drainage Board (NWS&DB).

Ilgar (2011) mentions that water assessment in the construction industry is a new method and that it is still open for new ideas and improvements from other researchers. While several studies have looked at various measures of water use efficiency and conservation during the operational stage of a building (Carragher et al., 2012; Robinson, Gates, Walters & Adeyeye, 2012), very little research has been conducted to ascertain as to what happens during the construction stage. The Strategic Forum for Construction (SFfC) in the United Kingdom states that relatively little research has been carried out on water sustainability in construction sites because the cost of water used is generally considered to be of low priority (Waylen, Thornback, & Garrett, 2011). In their report titled 'An Action Plan for Reducing Water Usage on Construction Sites', issues of sustainable water use during construction and targets to rectify the problem are highlighted. The report further identifies three major barriers for introducing water use efficiency during construction, viz., value for money, work environment and workers' habits (Waylen et al., 2011).

In the context of Sri Lankan construction industry, a majority of urban construction projects often use pipe-borne water and significant wastage and misuse of water are observed. In addition, most of the contractors in Sri Lanka are not concerned during construction about water management and it is suggested to implement monitoring systems to enable contractors to check how they protect the environment during the construction period (Waidyasekara, De Silva and Rameezdeen, 2012). Moreover, the same authors highlight that there are no clear benchmarks, performance measures, guidelines and best practices specially designed or established for water conservation during the construction phase of a project. Although many sustainable rating systems including Green^{SL}, which is designed for a whole building project lifecycle exist, credentials given for water management during the construction phase are insignificant (Waidyasekara, De Silva and Rameezdeen, 2013). Furthermore, it is said that the use of potable water is unnecessarily costly and that it impacts on the environment. Literature shows that some construction activities need potable water while some do not, and when potable water is used, it is essential to look at alternative sources to meet sustainability goals (Utraja, 2010). Moreover, the existing literature bears evidence that the construction industry also poses a big threat as far as freshwater shortage and water pollution are concerned. Thus, it is essential to make a bigger effort to change present perceptions and attitudes towards a sustainable world that has better construction practices.

Therefore, it is apparent that at present, the knowledge on water sources (acquisitions), usage, handling, storage, transport, and disposal during the construction phase of a project is poor. In this context, new strategies and actions for the better management of water in the construction sector are essential. Although the amount of water used during construction is much less compared to its usage during the operational stage of a building, there is still high potential for saving water by enabling a more efficient use of water during construction. In order to improve water use efficiency, it is important to understand how construction projects consume water and what drives construction stakeholders to consider water use efficiency during construction, i.e., barriers and applicable methods.

Having identified the research needs, this study poses the research problem as **"How to improve the sustainable use of water in construction projects"?**

1.3 Research Aim and Objectives

The research aims at developing a framework for improving sustainable use of water in construction projects.

To accomplish this aim, the following objectives have been formulated:

- Review principles and practices of sustainable use of water in construction projects
- Evaluate water use practices of construction projects in Sri Lanka
- Investigate the most applicable Water Efficiency Measures (WEMs) for construction projects
- Determine relevant drivers, barriers and other attributes of efficient water use practices in construction projects
- Develop a framework for improving the sustainable use of water in construction projects

The study refers to 'sustainable use of water', meaning the optimum use of water resources in construction sites with minimum wastage and misuse, while causing minimum damage to the ecosystem and preserving that scarce resource to meet the needs of the future generations. Instead of using both water efficiency and water conservation interchangeably, this study adopted 'water efficiency' as a terminology throughout the research (refer to Section 2.3).

In addition, key terms 'construction project level', 'on-site construction activity', and 'construction project life cycle' have been used throughout the thesis to refer to the physical construction phase, which spans from site mobilisation to the completion and handing over of the construction project. This simply refers to pre-work, execution and demobilisation stages.

1.4 Research Methodology Used for the Study

Research methodology refers to the overall approach to the research process that is from the theoretical underpinning to the collection and analysis of data. The selection of an appropriate research design is essential to achieve valid findings (Kumar, 2005). Creswell (2009) explains that the choice of the research design will be based on three elements, viz., philosophical assumptions, strategies of inquiry, and specific research methods. This study adopted pragmatism philosophical view (refer to Section 4.4.2). As Creswell (2009) mentions, pragmatists do not see the world as an absolute unit. Pragmatism allows the researcher to use multiple methods for data collection and analysis (Creswell, 2003; Morhan, 2007; Saunders, Lewis, & Thornhill, 2009). Researchers emphasise on the research problem and use all approaches available to understand it (Rossman & Wilson, 1985). Pragmatic knowledge claims arise out of actions, situations and consequences rather than antecedent conditions (Creswell, 2003).

According to Creswell (2009), when there has been little research done and the concept of the phenomenon needs to be understood, a qualitative approach provides more advantages. A quantitative approach will be suitable when identified factors influence an outcome. When a researcher wants to generalise the findings to a population and develop a detailed view of the meaning of a phenomenon, a mixed method approach is the most suitable approach to follow (Creswell, 2009).

This research adopted the triangulation based mixed method approach to elicit knowledge from participants, i.e., collects quantitative and qualitative data concurrently, analyses the two data sets separately, and mixes the two databases by merging the results during interpretation. Firstly, preliminary interviews were conducted to validate literature findings and survey guidelines. Case study strategy was used to explore water usage during construction phase (refer to Chapter 5). Yin (2009) explains that a case study is an empirical inquiry, which investigates contemporary phenomenon within its real life context deeply examining the reality. Along with case studies, a quantitative method with a large sample was used to investigate mainly the applicability of water efficiency and conservation measures and relevant drivers, barriers and other attributes that impact on water usage and efficiency (refer to Chapter 6). Objectives 2, 3 and 4 were covered by case studies and the questionnaire. The final objective was achieved triangulating the findings of other objectives with literature findings (refer to Chapter 7). Sekaran (2003) observes that collecting data using multiple methods and from multiple sources provides research rigor. Chapter 4 comprehensively explains the research methodology that was used for the present research scrutinising research philosophy, research approach, research strategies and research techniques and adopting the “research onion” referred to by Saunders, et al. (2009). Mapping of study objectives against data collection techniques are presented in Table 4.10 in Chapter 4. Figure 1.1 illustrates the summary of research methodology followed and the outcome of each stage.

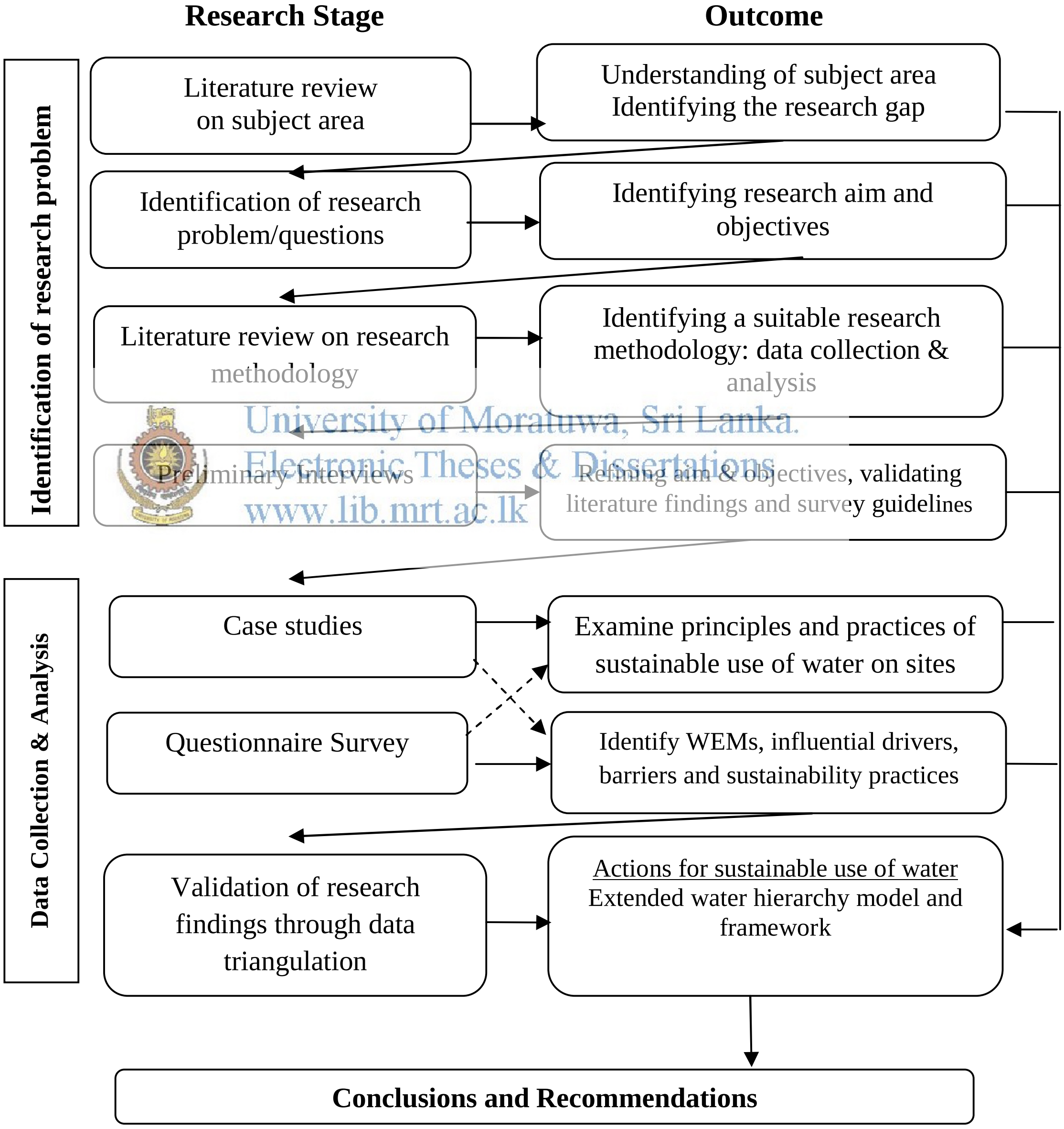


Figure 1.1: Summary of the Research Methodology Used for the Study

1.5 Contribution to the Body of Knowledge

This study contributes to the body of knowledge on water sustainability in the construction industry, a subject that has been understudied in Sri Lanka. In addition, findings could enhance construction organizations' understanding of the need for an efficient water use during construction and the strategies that can be adopted for same. The study has theoretical and practical contributions to the Sri Lankan construction industry and presented in Sections 8.4.1 and 8.4.2 respectively.

1.6 Outline of the Thesis Structure

Chapter 1 provides an overview of the thesis. It begins by describing the context of the research and states the aim and objectives of the study. Subsequently, an overview of the research methodology and the key contributions of the research are presented. The chapter ends with a guide for the thesis organization.

Chapter 2 presents a critical review of literature of the subject area setting out the context of the research. This review highlights research needs in the present context and points out the need to address them in the research. Accordingly, the chapter consists of literature on water in the context of sustainability, water management, water conservation and water efficiency, and the current status of construction related water management practices and measures. Next, the chapter discusses drivers that impact on water conservation and efficiency while identifying the barriers for same. Finally, the chapter discusses the research gap towards research questions.

Chapter 3 conceptualises the key areas identified from the literature and the basis for preliminary interviews. Accordingly, the conceptual model is developed for the data collection process.

Chapter 4 provides the research methodology including research design and the research process followed during the study. It starts with the research philosophy, research strategies and research methods. Subsequently, the chapter details the adopted method including data collection and data analysis techniques of the study. Finally, the validity and the reliability of the research are discussed.

Chapter 5 explores water usage, methods of water wastage and water management practices used in construction sites, issues arising out of them and actions for water sustainability practices. Four (04) ongoing building construction projects at different stages of construction have been selected as cases for the analysis.

Chapter 6 presents the results of the questionnaire survey which was conducted among construction professionals. The chapter discusses highly applicable Water Efficiency Measures (WEMs), relevant drivers, barriers and other attributes that impact on the efficient water use during the construction stage of a project while identifying actions for sustainable use of water in construction projects.

Chapter 7 presents a discussion of the research findings by collating the output of the investigations presented in Chapters 5 and 6. Discussions on empirical findings are presented from questionnaire survey, and the case analysis while triangulating with literature. Furthermore, the chapter presents research outcomes: the extended water hierarchy model and framework that can be used by construction stakeholders as a guide to implementing sustainable water use in construction projects.

Chapter 8 presents conclusions on achieving the aim and objectives of the research based on empirical investigations. Furthermore, the chapter presents the limitations of the research, contributions to the knowledge, recommendations and future research areas.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Introduction

This chapter intends to synthesise the current knowledge gaps in the research area and establish the research focus further into the research background discussed in Chapter 1. Accordingly, the chapter is structured as follows. Firstly, it discusses the role of water in the context of sustainability and the way sustainability assessment tools have addressed water efficiency and conservation in construction sites. This section also looks at existing values of water as a sustainable resource. Secondly, the chapter examines the relationship between water management, water conservation and water efficiency according to characteristics defined in the literature and definitions adopted by the study. Thirdly, it investigates core areas on water efficiency practices and drivers and barriers relating to water sustainability in construction projects. Finally, the chapter presents the research gap towards research questions.

2.2 Role of Water in Sustainability

2.2.1 Water as a Valuable Commodity

It is a known fact that 97% of all the water on the earth is salt water, which is not suitable either for drinking or for any construction activity. Only 3% of the water body of the earth is fresh water, and from that also only 1% is available as drinking water. The other 2% is frozen as ice and cannot be easily accessed. Donge, Peers, and Bonthron (2008) clearly illustrate the distribution of earth's water as shown in Figure 2.1. This bears evidence that all people on the earth are relying on such a small percentage of water on earth. This emphasises the importance of preserving and conserving this natural gift for use by future generations.

Donge et al. (2008) mention pollution and contamination as significant threats to water that is suitable for safe consumption. Moreover, many studies have identified that the acceleration of the population growth, economic growth, industrialisation and climate changes as critical variables that can impact on the demand and supply of freshwater resources both at present and in the future (Chanan et al. 2003; Economist, 2008; Goodrum, 2008; Johnston, 2003; Sala, et al. 2013).

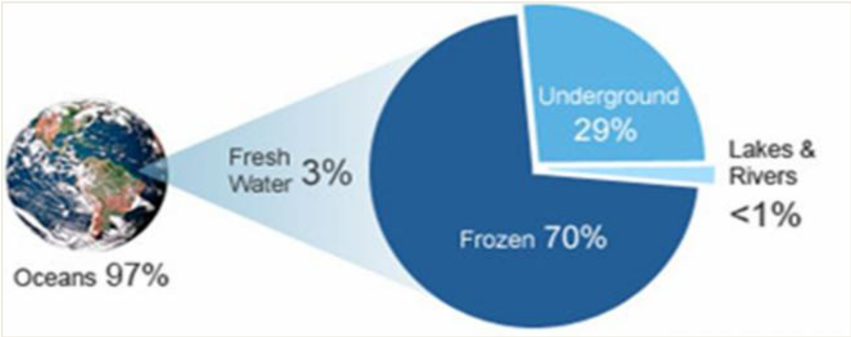


Figure 2.1: Distribution of Earth's Water

Source: Donge et al. (2008)

On the other hand, due to industrial expansion around the world, the demand for water is rising at an alarming rate. Biswas (2004) explains that water problems of the world are not homogeneous and constant and that they would be inconsistent over a period of time. They often vary significantly from one region to another and even within a single country, from one season to another and from one year to another. This statement is further supported in Figures 2.2 and 2.3, which provide some of the water demand statistics available in the literature.

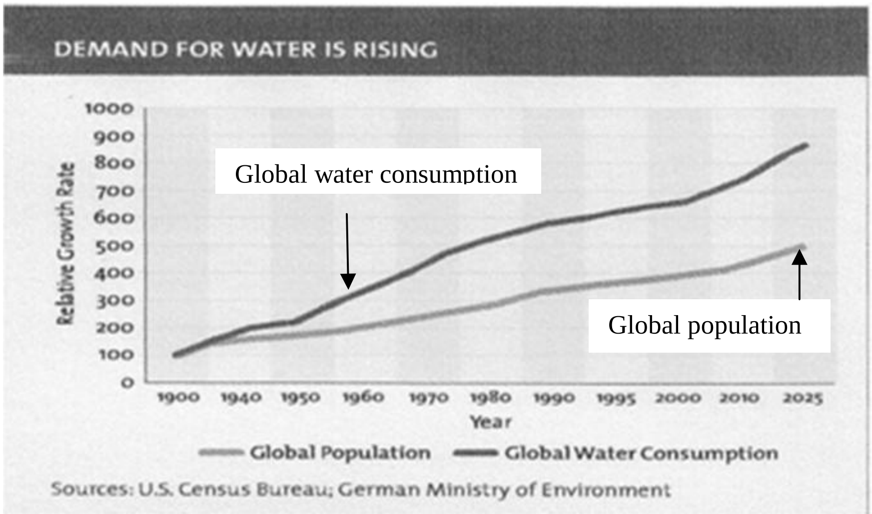


Figure 2.2: Demand for Water

Sources: Donge et al. (2008)

Figure 2.2 illustrates forecasted figures on the global water consumption. It highlights the difference between global water consumption and global population. Figure 2.3 elaborates Asia's future water demand. This clearly indicates the huge increase in water demand in Asia compared to other regions.

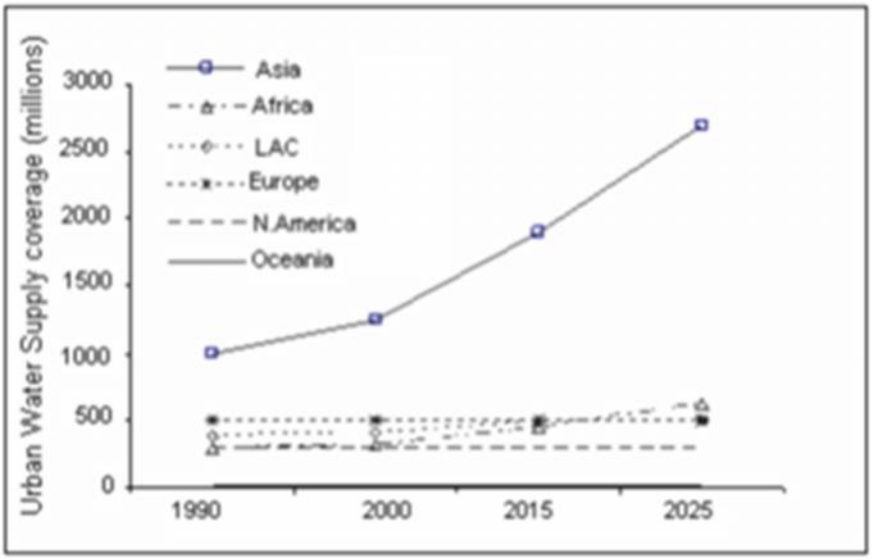


Figure 2.3: Asia's Future Water Demand

Source: Corcoran, Nellemann, Baker, Osborn, and Savelli (2010)

Sala and Wolf (2013) point out that industrial production and many services depend on the continuous availability of freshwater and that there will be a direct threat on supplying safe drinking water in future. Moreover, the Global Water Intelligent (cited Rosegrant, Cai, & Cline, 2012) has forecasted that there will be a significant growth in the water demand in future and that in the next few years the global water industry will incur capital expenditure as shown in Figure 2.4. These facts support well to establish that water will be a commodity in high demand in the world in the near future. As Zbigniew and Kundzewicz (1997) claim, water shortage is therefore likely to be the most acute problem in the next century, jeopardizing sustainable development.

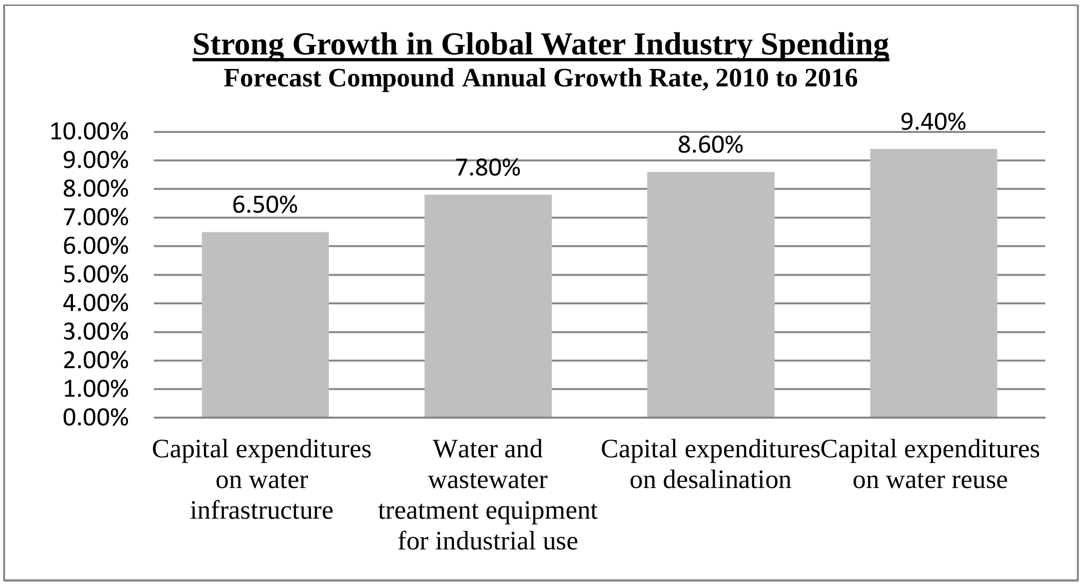


Figure 2.4: Growth in Global Water Industry Spending in the Next Five (05) Years

Source: Rosegrant et al. (2012)

Paul (1996) says that by 2025, about 3 billion people may be living in water stressed or scarce countries. Conferences held in Dublin and Rio de Janeiro in 1992, formulated a statement of principles on the sustainable use of water. In 1993, the World Bank developed a framework for water management that treats water as an economic commodity (Rogers, et al., 2002). Thus, conservation and efficiency measures on the available freshwater sources will be paramount and important to ensure a sustainable future.

2.2.2 Water in the Context of Sustainability

The term sustainability can have different meanings to different persons as well as to different disciplines. However, any sustainable action for protecting, preserving, and restoring the integrity of the earth's life support systems is critical. As Abidin (2009) mentions, the sustainable development philosophy was introduced in 1987 in the Brundtland Report and one of the sub-sets of this philosophy is sustainable construction. Water is an integral part of the ecosystem, a natural resource and a social and economic commodity (Gleick, 1998; Zbigniew and Kundzewicz, 1997). The European Commission Scientific and Policy (ECSP) report mentions that water is more than an archetypal resource for which sustainability assessment is needed in order to preserve its quality and the quantity for present and future generations (Sala et al., 2013). Therefore, reducing water consumption and protecting water quality are the key objectives of sustainable construction. Gleick et al., (cited Gleick 1998) offer a working definition of sustainable water use as follows:

> *"the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it*"(p.572).

Zbigniew and Kundzewicz (1997) explain that the availability of water in adequate quantities and of appropriate quality is a necessary condition for sustainable development. In addition, a knowledge and understanding of freshwater resources are also essential for sustainable development. Roberts, Mitchell, and Douglas (2006) recognise that when the actual amount of water extracted is below the sustainable level of extraction it will not be a problem but over-extraction and subsequent overuse of river systems can cause significant negative impacts. Similarly, Smakhtin, Revenga, and Döll (2004) explain two (02) situations, i.e., (a) environmentally safe and (b) environmentally water scarce as illustrated in Figure 2.5.

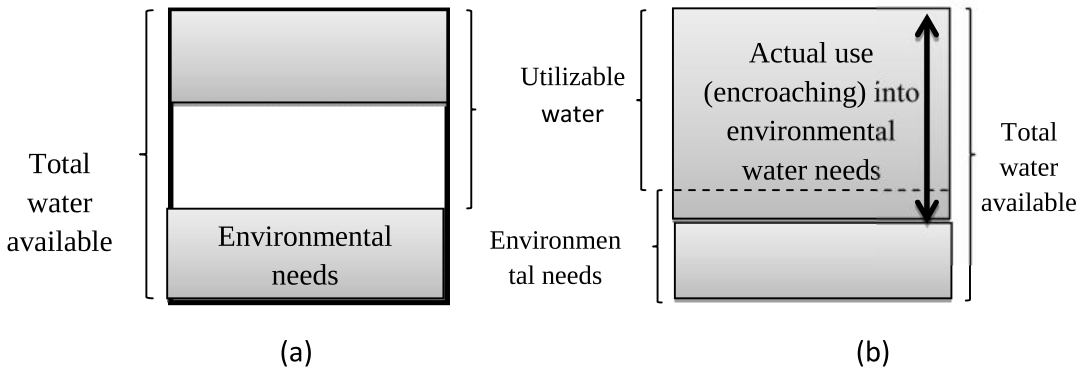


Figure 2.5: (a) Environmentally Safe and (b) Environmentally Water Scarce Situations
Source: Smakhtin et al. (2004)

Accordingly, all stakeholders are responsible for avoiding situation (b) and they need to have strict policies in order to sustain the water resource. Dharmaratna and Parasnis (2012) mention that although Sri Lanka has no physical water scarcity as at present, a higher demand and unsustainable supply management might lead to a water shortage and an inadequate supply of drinking water in the future. Furthermore, Figure 2.6 illustrates those factors identified by the Ministry of Environment (2001) in Sri Lanka as imposing undue pressure on water resources due to intentional and unintentional activities.

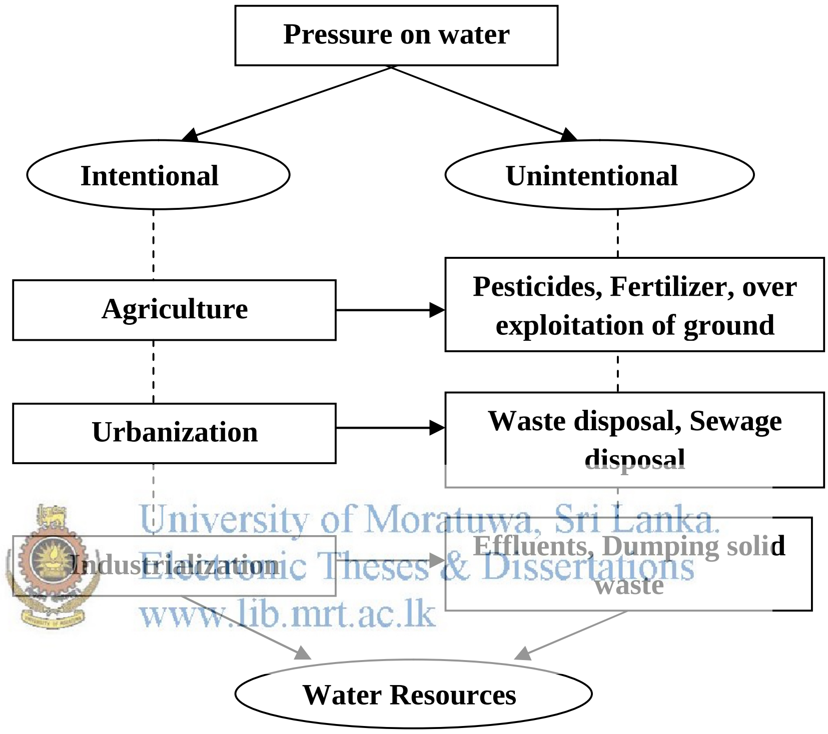


Figure 2.6: Intentional and Unintentional Pressure on Water Resources

Source: Ministry of Environment, Sri Lanka, (2001)

It is apparent from Figure 2.6 that agriculture, urbanisation and industrialisation directly exert negative impacts on water resources, whereas the excessive use of chemicals, waste disposal and industrial effluents indirectly cause constraints on water resources through pollution which at times is irrecoverable. As claimed by the Ministry of Environment (2001), these pressures collectively interact with each other resulting in complex impacts on water resources. Figure 2.7 illustrates the importance of balancing green water (which is consumed by vegetation) and blue water (which constitutes water in rivers and aquifers which is accessible for societal use) to eliminate water dilemmas in future.

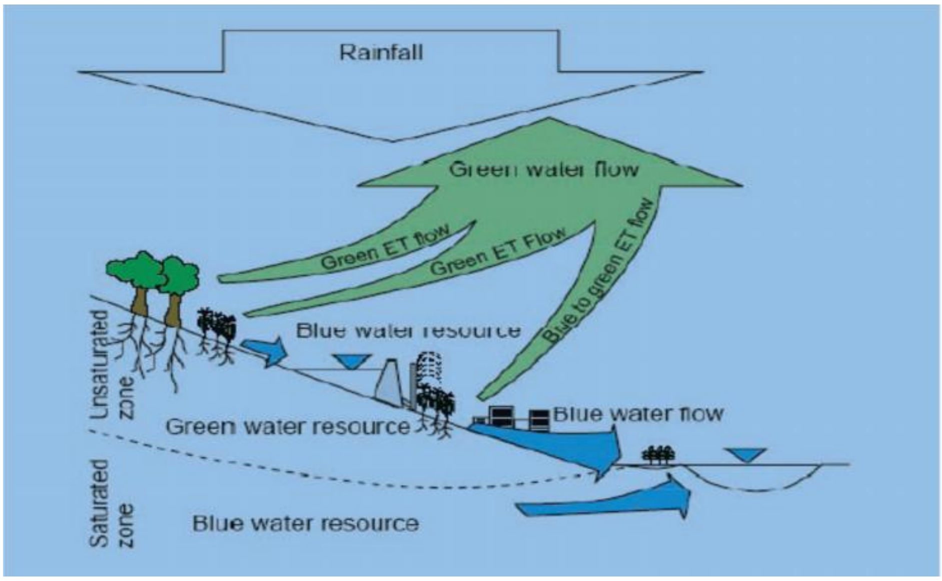


Figure 2.7: Green and Blue Water

Source: Flakenmark, (1991)

Gleick (1998) mentions that sustainability criteria layout specific social goals that could, or should be attained and offer some guidance for future water management. Falkenmark (1991) states that World Commission on Environment and Development (WCED) tends to severely underestimate water-related problems that exist and that fundamental strategy changes are needed to address the massive sustainability problems in the realm of water. Hoekstra (2006) argues about the importance of the governance approach that comprises coordination and institutional arrangements to solve issues related to water resources. Desired end points described in the UN and UNSGAB (2011) reports stress that no country can meet its development objectives without improving the way it manages its water resources since water allocation to various economic sectors is a difficult exercise, and there exists huge water wastage along the supply chains.

As described by Sev (2009a), the relationship between sustainable development and the construction industry has become clear when construction is of high economic significance having strong environmental and social impacts. The next section discusses the relationship among the three terms water management, water conservation and water efficiency.

2.3 Water Management, Water Conservation and Water Efficiency

This section critically analyses the terms water management, water conservation and water efficiency, which are the essential elements for sustainability. Water management simply means the management of water resources that involves how humans use water, how industries use water and how water is handled in the natural environment (González-Gómez et al., 2012). As Biswas (2008) states, the optimum use of water covers both conservation and efficiency and includes planning, monitoring and controlling. Moreover, water resource management attempts at optimising the use of water and minimise environmental impacts associated with its use. Water management planning should be viewed as an ongoing activity and not as a one-time effort. The Bureau of Reclamation (2000) introduced nine planning steps in a sequential step by step order for water management as shown in Figure 2.8. The important fact highlighted was that a back-and-forth approach is often required between any two steps.

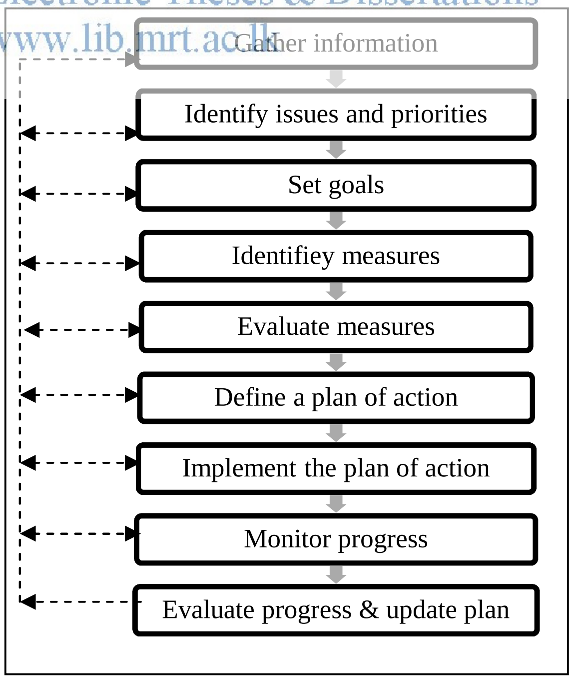


Figure 2.8: Planning Process for Water Management

Source: Bureau of Reclamation (2000, p.11)

As Brooks (2007) argues, water efficiency (WE) and water conservation (WC) are two different concepts although used interchangeably in the literature. Dexter (2011) describes that conservation demands to do less by sacrificing needs whereas efficiency deals with doing more with less. Bourg (2010) states that WE is the planned management of water to prevent waste, overuse and exploitation of water seeking to do more with less without sacrificing comfort or performance. The National Cleaner Production Centre (NCPC) of Sri Lanka (2012) observes that WE focuses on achieving the same result with a minimal amount of water usage while WC aims towards reducing the wastage of water. Thus, water conservation relies on individuals to change their behaviour to achieve results; while water efficiency encourages the use of the best available technology and innovative ideas to achieve long-term water sustainability without sacrificing present needs (Dexter, 2011). In addition to the reduction in loss and waste, the concept of water efficiency is also supported by innovative ideas and modern technologies such as reuse, recycle, and alternative sources (Dexter, 2011). This is further explained by Bourg (2010), saying that water efficiency planning incorporates the analysis of costs and uses of water, specifications of water-saving solutions and the installation of water saving measures and that it maximises the cost effective use of water resources.

As stated by Dexter (2011), water efficiency is a smart investment for the future and is the most significant water management strategy as against solitary water conservation. In addition, Cohen, Ortez, and Pinkstaff (2009) describe that the management of water quality is also a part of water management. The Department of Energy of United States (2011) identifies managing available water resources and satisfying water demand (water quantity) as basic principles of good water management. The Waste and Resource Action Program (WRAP) identifies four principles of water efficiency, viz., monitoring and managing, reducing use, minimizing water and replacing potable water with grey or rainwater (McNab, et al., 2011). According to the characteristics identified by WRAP, water efficiency overlaps with the characteristics of water conservation. Thus, based on existing literature, the researcher has identified the relationship among different concepts, which is graphically presented in Figure 2.9.

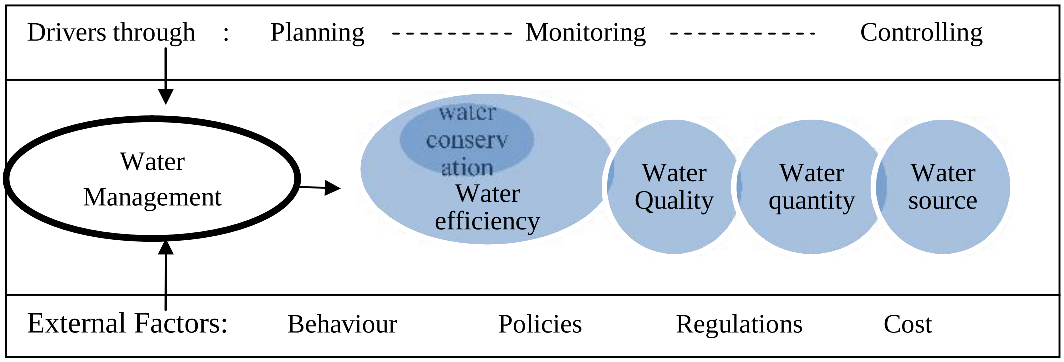


Figure 2.9: Relationship among Water Management, Conservation and Efficiency

It is apparent from Figure 2.9 that key activities are not fully independent as they are closely linked to each other in fulfilling the objectives of water management controlled by external factors such as behaviour, policies, rules and regulations and cost for a better output. As stated by Biswas (2008), all these aspects are driven through three terms viz., planning, monitoring and controlling. It is clear that water management is very broad and that it covers many aspects. Considering all aspects, the study preferably refers to the combination of water efficiency and conservation. Since WE covers certain characteristics of WC, the study adopted '**water efficiency'** throughout the report to represent both terms: water efficiency and water conservation. In the meantime, the study uses interchangeably the broad meaning of 'water management' adopting the terms stated in Figure 2.9 where necessary. It is obvious that a proper water management plan should address both technical and human related aspects of water use. Furthermore, effective water management can have a tremendous impact on the overall water consumption for delivering enormous benefits. Many sustainability assessment tools have discussed and identified the protection and conservation of water as one of the fundamental principles in sustainable construction.

2.4 Sustainability Assessment Tools for Efficient Water-Use during the Construction Stage

It is interesting to see the key requirements and credits awarded for water efficiency in green/sustainability rating systems for water handling and monitoring during the construction phase of a building project. As stated by Fowler and Rauch (2006), there are hundreds of building evaluation tools that focus on different areas of sustainable development, which are designed for different types of projects world-wide. Rating systems are designed simply to reflect the different phases in the building life cycle (Boonstra and Pettersen 2003). As Gowri (2004) mentions, many rating systems have been developed based on original international rating systems such as Leadership in Environmental and Energy Design (LEED) and Building Research Establishment's Environmental Assessment Method (BREEAM), or by integrating few other rating systems. Green^{SL}, BREEAM Canada, BREEAM Greenleaf, LEED India are examples of such rating systems.

The five (05) main environmental categories focused in general in the assessment tools addressing building design and life cycle performance are site, water, energy, materials and indoor environment (Gowri, 2004). Apart from that, sections like management, social and cultural awareness, pollution and transport could also be seen as other categories in rating systems. As mentioned by Gowri (2004), each category has a number of prerequisites and all projects must meet all the prerequisites to qualify for certification as no credit points are allocated for the overall score if the prerequisites are not met even when all other credit requirements have been satisfied. Table 2.1 summaries twelve (12) key requirements identified in the water efficiency domains by comparing eleven (11) sustainability assessment tools.

Although twelve (12) requirements have been identified under water category during a project life cycle, only a few requirements/strategies could be found in each rating system. Moreover, it could be observed that certain requirements like storm water management have been addressed under the category of 'site management' rather than under the category of 'water efficiency'.

Table 2.1: Key Requirements Identified by Rating Tools under Water Category

NO	REQUIREMENTS	DESCRIPTION
1	Reduced building water usage through water efficient plumbing fixtures and fittings	Reduced potable water consumption in the building through the use of water efficient components (using efficient fixtures like low-flow fixtures and appliances, etc.)
2	Water efficient landscaping /irrigation	Intent is to limit or eliminate the use of potable water for landscape irrigation and to minimize the load on the municipal water supply and depletion of groundwater resources
3	Water recycle and reuse including rainwater	Encourage rainwater harvesting and recycling of grey water in order to reduce freshwater consumption
4	Water monitoring, leak detection and prevention	Reduce wastage of freshwater through monitoring, reduce the impact of water leaks and allow for auditing of water use
5	Water quality	Intent is to ensure that the quality of potable water delivered to building users is satisfactory and that it meets water quality norms as prescribed in the standards for various applications
6	Innovative waste water technologies	To reduce wastewater generation and potable water demand while increasing local aquifer recharge
7	Innovative water transmissions	To limit the use of non-renewable energy for water transmission
8	Efficient discharge to foul sewers	Reduce the volume of sewage discharged from buildings
9	Water efficiency in air conditioning (Heat rejection water)	To limit or eliminate the use of potable water for air conditioning make-up while using condensed water for irrigation
10	Water consumption for fire systems	To limit or eliminate the use of potable water for fire systems by promoting the use of recycled water and/or alternatives
11	Efficient water use during construction	Minimise the use of potable water during construction
12	Storm water management	To limit disruption of natural and pollution of natural water flows by increasing on-site infiltration and managing storm water run-off.

Figure 2.10 depicts the weightage given for the water efficiency category alone while Figure 2.11 illustrates the total weightage given by the selected eleven (11) rating

systems for all water aspects considered under other categories (site management, energy, innovation, etc.).

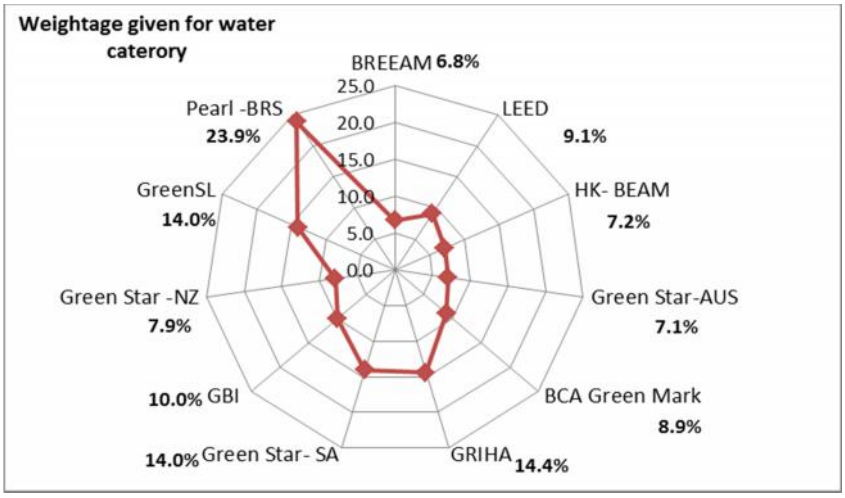


Figure 2.10: Weightage given for Water Category

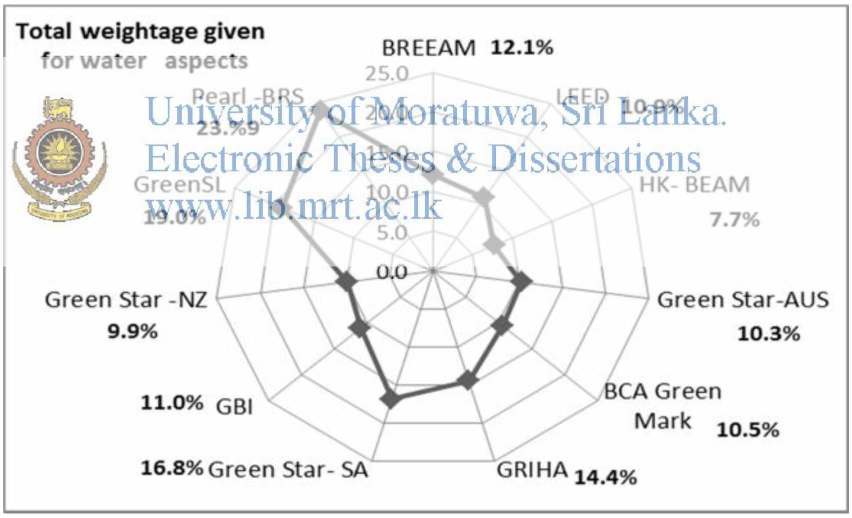


Figure 2.11: Total Weightage given for Water Aspects in all Categories

It can be seen from Figures 2.10 and 2.11 that except for the Green Rating for Integrated Habitat Assessment (GRIHA) in India and Pearl BRS in the UAE, all other rating systems have addressed at least some of the water requirements under other categories. For example in Green^{SL}, water recycling and rainwater harvesting have been addressed under innovative waste water technologies and storm water management. It is apparent from Figure 2.10 that out of the eleven (11) rating systems, Pearl Abu-Dhabi (23.9%), Green^{SL}(19%), Green Star-SA (16.8%), and GRIHA-India (14.4%) have given high weightage for the water category. Although Australia is considered as one of the countries facing a major water crisis, comparatively less priority has been given for water category in the Green Star rating system of that country when compared to other rating systems. Figure 2.12 illustrates the distribution of water credits during construction phase and in-use phase.

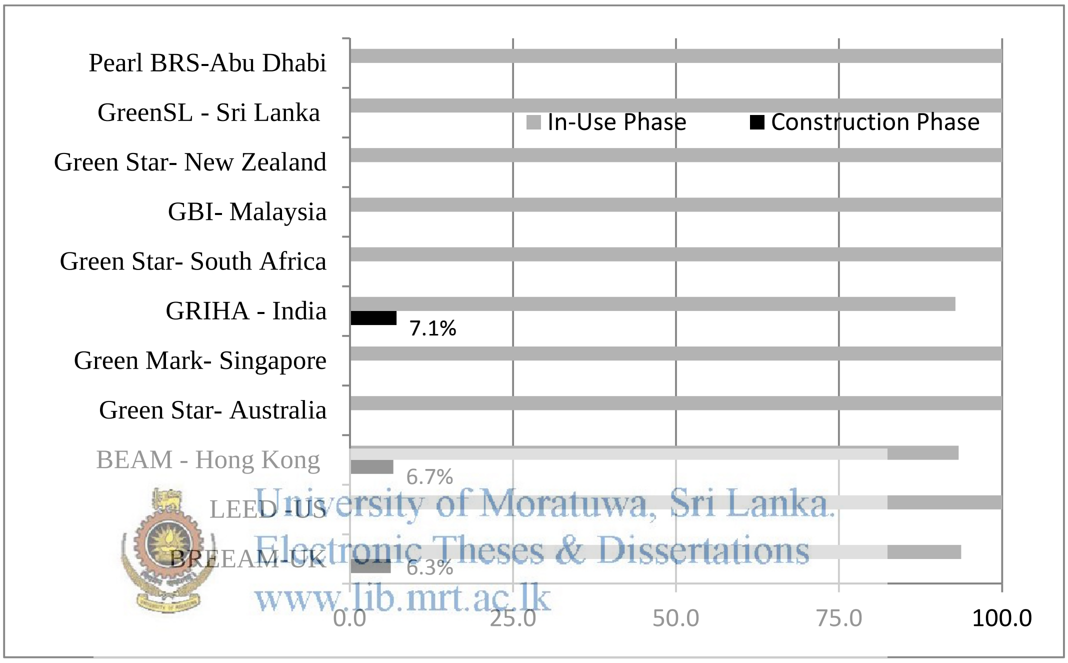


Figure 2.12: Distribution of Water Credits in the Construction Phase vs. In-use Phase

The same study reveals that only three rating systems, namely Building Research Establishment's Environmental Assessment Method (BREEAM) of UK, Building Environment Assessment Method (BEAM) of Hong Kong and Green Rating for Integrated Habitat Assessment (GRIHA) of India have included water efficiency during construction phase as a criterion in their assessment criteria. Since construction is considered to be a water intensive industry, the inclusion of water efficiency in environmental assessment tools will be an effective way of controlling water resources. For instance, the simple step of effectively monitoring water use at the site will deliver direct benefits to all concerned. As stated by Gowri (2004), though energy efficiency is a major component of designing a green building, several other basic sustainability requirements, e.g., water, needs to be met before claiming additional credits for energy efficiency. Ali and Nsairat Al (2009) define a rating system as a management tool that organizes and structures environmental concerns during the design, construction and operation phases of a building. However, many rating systems still need improvements and extensions to the construction phase. The existing rating systems have stipulated fairly with regard to water efficiency, benchmarks and performance indicators for the building operation phase. However, none of them have stipulated any benchmarks for activities during the construction phase. This supports the statement mentioned in the technical manual of BREEAM (2011), which states that at present data from construction sites do not generally exist in sufficient detail to set benchmarks and targets and that BREEAM therefore does not set any requirements in terms of specific targets for reducing energy and water and transport consumption during the construction process. A similar feature could be observed from other rating systems as well. Spence and Mulligan (1995) have observed that the construction industry causes significant environmental stress. Hussin, Rahman and Memon (2013) have identified the construction industry as one of the largest polluters of the environment. Waidyasekara et al. (2013) have emphasised the importance of addressing sustainability criteria in rating systems on water monitoring and handling in construction sites, in order to reduce or control the damage to the environment due to construction activities. A recent survey of global businesses identified resource efficiency as the single most effective step for addressing risks coming from resource scarcity (Mactavish & Halgh, 2013). Thus the time has come to think and integrate Hart's Theory of Natural Resource Based View (NRBV) (refer to Section 2.5.2) and the development of green and blue water concepts (refer to Section 2.2.2) in the construction sector.

Therefore, it is vital to examine how water usage is accounted and monitored in construction sites and observe practices adopted at sites for conserving and for the better management of water resources. The next section discusses the key subject area, i.e., the way water management is being practised in the construction industry.

2.5 Water Efficiency Practices in the Construction Industry

2.5.1 Importance of Resource Management in the Construction Industry

The construction industry is becoming very sensitive to the need to be more environmentally responsible and is therefore seeking ways and means of conducting itself to minimise its negative environmental impacts (Kibert, 1994). The construction industry is large, dynamic, and complex. It plays an important role in the economic growth of a country (Hussin, et al., 2013).Construction work involves buildings, engineering (civil) projects, renovations, alterations, or maintenance and repair of buildings or civil projects (Behm, 2008). In general, the construction industry differs from other industries with regard to its products, stakeholders, processes, and the operating environment. Chen (1998) argues that there could be no economic activity without construction. The construction industry is a major contributor to the economic growth of a country (Chan, 2009). It has strong linkages with other sectors of an economy (Chen, 1998; Rameezdeen, Zainudeen & Ramachandra, 2008). According to Central Bank Report (2013), in Sri Lanka the construction industry contributes 8.7% to the Gross Domestic Product (GDP). In the recent past, Sri Lanka has commenced huge development projects related to buildings and infrastructure in many parts of the country. This rapid construction growth will result in the depletion of natural resources as they will be consumed at a fast rate causing environmental issues (Ding, 2008). Ofori (1998) has stated that the construction industry unfortunately lags behind other industries in its response to the problems of the environment.

The main goal of contractor organisations is making profit. Thus, they try to minimise wastages in the development processes and adopt sustainable construction strategies. It is a known fact that all tangible work of a project meets reality during the construction phase. Projects become more complex during the construction phase as many parties are involved (Anderson, Huhn, Rivera & Susong, 2006). The construction of a building uses a lot of energy, water, and other resources throughout the construction life cycle, i.e., pre-construction, construction and post-construction (Anderson et al., 2006; Shen et al., 2007). The increase in value for money is one of the main objectives of the construction industry. The environmental responsibility in the delivery processes is also important. Thus it is vital to address efficient resource management during the project life cycle. The next section will discuss the opportunities gained from resource efficiency in the construction industry.

2.5.2 Opportunities Gained from Resource Efficiency in the Construction Industry

Crawford and Pullen (2011) recognise that buildings are directly responsible for only around 12% of the global water consumption, which is through the production of building materials, construction and other supporting processes. Levin (cited Ofori, Bariffett, Gang & Ranasinghe, 2000) has identified six (06) major stress categories in a building that would contribute significantly to its total environmental burden. Among them water is one of the categories with a 25% contribution. Thus, resource efficient construction makes the best use of materials, water and energy over the lifecycle of built assets. As the construction stage transfers a design into reality, it involves the utilisation of a variety of natural resources including water (Donge et al., 2008; Kibert, 1994; Shen et al., 2007; Sjostrom & Bakens, 1999). Therefore, the activities happening during the construction stage have a close association with environmental impacts (Shen, et al., 2007).

Thus, there is a growing need for the construction sector to adopt principles of sustainability in their policies and day to day activities (Walton et al., 2005; Xing et al., 2007). Although various techniques and management skills have been used in construction projects to improve their sustainable performance, these techniques seem to have not been effectively implemented due to fragmentation and poor coordination among construction stakeholders (Shen et al., 2007). Moreover, Shen et al. (2007) identify a lack of consistency and a holistic approach in helping participants to implement sustainable construction practices at various stages of a project. Theo (2003) emphasises the importance of commitment of the management and staff for its success. The first step in the process of establishing evaluation tools or techniques is to set forth the issues that are encompassed by sustainable construction. Kibert (1994) identifies common issues in Sustainable Construction (SC) and categorises them into four (04) main groups as shown in Table 2.2. This shows water use during construction as a sub-theme of sustainable construction. Table 2.3 illustrates key principles of sustainable construction as shown by Kibert (1994).

Table 2.2: Issues of Sustainable Construction (SC)

Main Issues	Sub-issues
Resources	Energy Consumption **Water Use** Land Use Materials Selection
Healthy Environment	Indoor Environmental Quality Exterior Environmental Quality
Design	Building Design Community Design
Environmental Effects	**Construction Operations** Life Cycle Operation Deconstruction

Source : Kibert (1994)

Table 2.3: Principles of Sustainable Construction

Principles	**Sustainable Construction Principles**
Principle 1	Minimize resource consumption (Conserve)
Principle 2	Maximize resources reuse (Reuse)
Principle 3	Use renewable or recyclable resources
Principle 4	Protect the natural environment
Principle 5	Create a healthy, non-toxic environment
Principle 6	Apply lifecycle costing (Economics)
Principle 7	Pursue quality in creating the built environment

Source: Adapted from Kibert (1994)

There is no motivation for the conservation of air and water since they are not privately owned (Daly, 1993). In the past, criteria for energy and water resources were not connected to one another, to materials selection, or to the other issues of sustainable construction (Kibert, 1994). Water was just considered to be another input in construction projects (Kibert, 1994). Kibert separates out construction industry into two layers. Layer one consists of parties who have the most influence on the physical content and the creation of the built environment, viz., architects, engineers and builders. Layer two (02) consists of sustainable construction, which is just one (01) component of creating a sustainable environment as a whole. As stated by Kibert (1994), the construction industry has to change its historical methods of operating with little or no regard for environmental impacts. It should embrace a new mode where environmental concerns should become the centrepiece of its efforts. Henceforth, architects, surveyors, engineers, project managers environmentalists, sociologists, economists and other professionals, who are responsible for decision making are expected to use sustainable solutions throughout the different stages of a construction project (Hart, 1995; Xing et al., 2007). Guggemos and Horvath (2006) explain that although the construction phase is shorter, its impact is more significant and if the construction phase is neglected, the associated processes and materials will not be optimized for environmental performance. Ofori (1998, p.145) states that further effort is necessary to establish common concepts, principles, and techniques relating to sustainable construction.

Hart's Theory of Natural Resource Based View (NRBV) has emerged in recent years in both resource based view literature and in research on sustainable enterprises (Hart and Dowell, 2010). NRBV identifies three strategies, namely pollution prevention (prevent waste), product stewardship (integrated voice of environment into the development process and competitive advantages) and sustainable development (less environmental damage, maintained indefinitely into the future and restricted not only to environment but also to social and economical concerns). The strategy and competitive advantage in the coming years will be rooted in capabilities that facilitate environmentally sustainable economic activities (Hart, 1995). Thus, there is close integrity on the application of the theory of NRBV on water resources in construction projects in moving to sustainable construction. Therefore, as stated by Hart (1995, p.991), strategists and organisational theorists must learn to understand how environmentally oriented resources and capabilities can yield sustainable sources of competitive advantage reducing the environmental burden.

Furthermore, the European Commission Scientific and Policy Report highlights the requirement for generating concrete actions that will result in more sustainable consumption styles and patterns than creating awareness about environmental consequences of human consumption behaviours related to the water resource (Sala et al., 2013). The determinants of water conservation behaviours can be categorised into five (05) underlying causes, namely attitudinal factors, beliefs, habits or routines, personal capabilities, and contextual forces (Russell & Feilding, 2010). The explanation of each cause is given in Table 2.4.

Table 2.4: Determinants of Water Conservation Behaviour

Determinants	Explanation	Example
Attitudinal Factors	Evaluations of water specific behaviours, general environmental attitudes, norms (personal and social), values	"conserving water is beneficial"
Beliefs	Broad beliefs about the environment, water specific beliefs	"Water is an unlimited resource"
Habits or Routines	Standard practices relating to water use	Doing full load washing, bathing
Personal Capabilities	Knowledge and skills, availability of time, literacy, money, social status and power	Having money available to purchase and install water efficient appliances
Contextual Factors	Physical infrastructure, availability of efficient technology, water pricing	Rented or owned

Source : Adapted from Russell & Feilding (2010)

Literature has identified that worker behaviour greatly impacts on water usage in construction sites (McNab, et al., 2011). A person's behaviour in respecting the environment is normally postulated through two theoretical frameworks, namely Theory of Planned Behaviour (TPB) and Norm Activation Model (NAM) (Ajzen 1991). TPB explains a person's behaviour based on personal expectancy and benefits while NAM is concerned with altruistic and moral beliefs (Cordano, Welcomer, Scherer, Pradenas, & Parada, 2011; Park & Ha, 2014). TPB contains three (03) variables: these being attitude, subjective norms, and perceived behavioural control that determine a person's behavioural intention, which in turn determines the behaviour (Ajzen, 1991). NAM revolves around a person's beliefs on what is right and wrong (De Groot and Steg, 2009; Zhang et al., 2013). It evaluates the intensity of awareness of consequence of action (or non-action), and acceptance of responsibility leading to the activation of personal norms which in turn determines the behaviour (Onwezen et al., 2013; Van der Werff & Steg, 2015; Han, 2014). NAM as a sequential model where awareness of consequences influences personal norms through ascribed responsibility as shown in Figure 2.13.

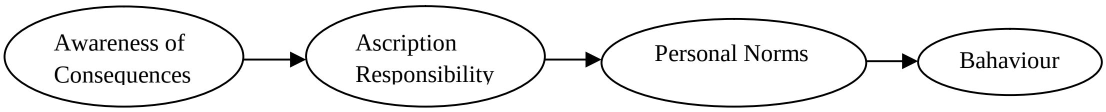


Figure 2.13: Norm Activation Model

(Source: Adapted from Onwezen et al., 2013)

Figure 2.14 illustrates the theory of planned behaviour using a water saving example adapted by Russell and Feilding (2010).

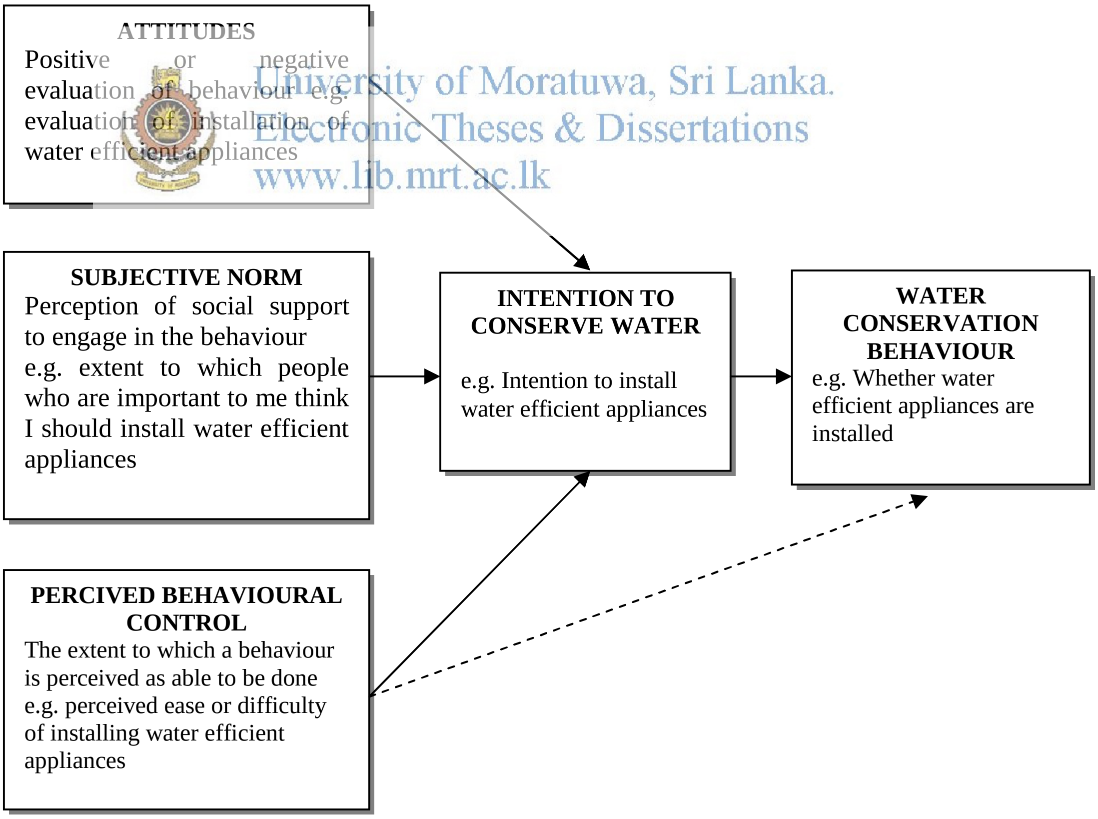


Figure 2.14: Theory of Planned Behaviours with a Water Saving Example

Source: Russell and Feilding (2010)

In addition to that sustainability assessments (Gowri, 2004), environmental management systems (EMS) and ISO 14000 standards provide practical tools for companies to identify and control the impact on the environment (Ofori, Briffett, Gang & Ranasinghe, 2000). Augenbroe and Pearce (2010) quoted that construction activities carried out with less wastage and consuming fewer quantities of resources are considered as sustainable practices. However, Abidin (2009) has mentioned that although sustainable practices are promoted, their adoptability by industries is uncertain. The reason for this is that only large companies would accommodating such practices with an outlay of their capital, experience and knowledge. Smaller companies would meet the minimum regulations or standards expected by parties and ensure that the project is profitable. Another issue identified was the difficulty in providing guidance for good practice in construction work based on well accepted and understood concepts and ideas (Ofori, 1998). Furthermore, the same author has stated that industry practitioners prefer to continue with their old ways citing the lack of a convincing case for action.

According to Hussain et al. (2013), green building practices are environmentally responsible and resource efficient throughout a building's life cycle. Sev (2009a) mentions that while traditional design and construction activities focus on cost, performance and quality issues, sustainable design and construction address issues related to the minimisation of resource consumption and environmental degradation and promote a healthy and comfortable built environment. Fawcett (2012) has mentioned that the objective of sustainability is to avoid or minimise any damaging future consequences from the current consumption and investment activities. Therefore, many green building assessments have discussed and identified the protection and conservation of water as one of the fundamental principles of concern for sustainable construction.

However, according to the findings of Waidyasekara et al. (2013), as far as water efficiency addressed in a building project life cycle is concerned, the priority given for water consumption during the physical construction phase is ignored by many green rating tools including Green^{SL}. For instance in Abu-Dhabi, the construction work completely depends on desalinated water. However, in the Pearl Building Rating System (BRS), no credits have been allocated for water monitoring and handling during the construction phase (refer to Section 2.4). Mactavish and Greenhalgh (2013) show that through the effective management of resources at the site, a 15% -25% reduction in water use could be achieved. These statements clearly point out that the current system needs to be revised for construction companies to gain opportunities from resource efficiency. This implies that not only requirements but also the implementation of policies on sustainable strategies for better management of water resources in all sectors are essential. On the other hand, the achievement of sustainable water use in the future will also depend on continued changes in the culture of water management. Water studies in other sectors such as agriculture, manufacturing, mining, hydropower and households are widely documented in terms of management, reuse, and recycling. The section below discusses the views and research findings on water consumption and management in construction sites.

2.5.3 Water Management and Water Usage in Construction Projects

2.5.3.1 Water Management in Construction Projects

As Chellaney (2013) states, there are substitutes for many resources including oil although there is none for water. It is a known factor that the construction industry is a main pillar of economy that uses water in almost all of its activities. As stated by Augenbroe and Pearce (2010), the use of recycled content materials and alternative building materials and energy efficient appliances and the reuse of materials will help to conserve existing resources for the future. Water being an unavoidable natural resource required for construction, Table 2.5 indicates several views expressed by researchers on the body of knowledge that exists on the water resource management in the construction industry.

Table 2.5: Views on Water Usage and Research Needs in Construction Projects

Views on Water Usage and Research Needs in Construction	Source of Reference
Current knowledge of the places where water is used in construction sites and the volumes involved during the construction lifecycle are limited.	Waylen et al. (2011) - SFfC
Impacts from the construction phase are ignored or simply approximated, because the analysis is complicated or the impacts are thought to be small.	Guggemos and Horvath (2006)
A significant quantity of water is consumed in extraction, production, manufacturing, delivery of materials to site and in the actual on-site construction process during building operations - i.e. embedded water.	McComack et al. (2007); Crawford and Pullen (2011)
Quality and quantity of water are important parameters that impact on the strength of certain construction works. Some concrete structures have failed due to wrong water cement ratio used in the mix.	Utraja (2010)
With global warming, it requires more attention and investigation to save water and reduce the water footprint of goods and services.	Ilgar (2011)
By overcoming challenges such as value for money, work environment and habit, it is suggested that water use in construction can be reduced.	Waylen et al. (2011) - SFfC
The amount of water consumed by construction is unknown and is not adequately measured.	Goodrum (2008)
Requirement for establishing water saving policies, guidelines, concrete actions and technologies to reduce water consumption and wastage during construction are necessary.	Crawford and Pullen (2011); Houser and Pruess (2009); McComack et al. (2007); Sala et al. (2013)
Inappropriate incentives and institutions often hinder the effective use of water during construction.	Houser and Pruess (2009); Sala et al. (2013)
Water used by certain construction activities impact on the cost of energy which is currently hidden from the cost of water.	Waylen et al.(2011) - SFfC
Price increase of water used for construction remains unknown and there is a requirement for changes in the water tariff system.	Devaraja (2013); Goodrum (2008); Savenjije and Van der Zaag (2002)
Limited research in the area of water management in the construction industry compared to other industries in Sri Lanka.	Waidyasekara et al. (2012)
Low attention given to water conservation during the construction phase. Therefore better sustainability criteria for water controlling and monitoring during the physical construction phase are required to be integrated with sustainability rating tools including Green^{SL}.	Waidyasekara et al. (2013)

According to Table 2.5, many scholars have highlighted and convinced the requirement that exists for future studies to address the subject area. In addition to this, the desired endpoints described in the UN and UNSGAB (2011) studies have stressed that no country can meet its development objectives without improving the way it manages its water since the allocation of water resources to various economic sectors is a difficult exercise, and since there is huge water wastage along supply chains. As Devaraja (2013) expresses, water losses may form either an apparent loss (physical-water leaks in pipes) or a real loss (non-physical-illegal consumptions, errors of measuring apparatus, administrative losses and free water supply). Water saving actions and guidelines provide the answer to certain issues with water management as mentioned by many scholars, namely the value for money, wastage, water quality, water quantity and environmental protection (minimum damage to the eco system).

United States Environmental Agencies (2012) divided water users into two groups, namely system users (e.g., workers in the construction industry) and system operators (state and local government, municipalities, water suppliers, etc.) for water management purposes. Both groups were also categorised into two groups according to practices, viz., as engineering (fixtures and operation) and behavioural (changing water use habits). Behavioural practices in construction are the monitoring of water use, enforcing of water use practices and the conduct of educational programs on water support. Some of the engineering practices indicated are low flow shower heads, water reuse and recycling, and low flush cisterns (Eddy, 1993). These statements clearly bear evidence that the use of water devices and attitudes and the behaviour of the user have a huge impact on water management practices.

The green construction industry identified four steps to keep green on water resource (Sev, 2009b). They are:

Step One – **Measure it, manage it**: Know your water consumption. Set targets to minimise water usage, and measure progress both during construction and once the project is operational and in-use.

Step Two – **Use of water saving technologies**: Reduce main city water consumption by using appliances that save water or detect leaks, or tap into alternative water sources such as rainwater collection.

Step Three – **Save water during construction**: Keep a track of your water use during the construction phase. Make sure your equipment is water efficient, and encourage everyone to report leaks and fix them fast

Step Four – **Keep it clean**: Take care to prevent pollution, inspect drains regularly and keep them well maintained. Protect natural water sources and ground water sources.

The United States Environmental Protection Agency (EPA) (2012) identifies three (03) ways, namely innovative, individual and industrial methods that play a significant role in the water conservation effort.

2.5.3.2 Research Studies on Water Usage in the Construction Industry

As Guggemos and Horvath (2006) state, impacts from the construction phase are ignored or simply approximated because their analysis is complicated or because they are thought to be small. On the other hand, Waidyasekara et al. (2012) reveal that there is a vacuum in the area of the body of knowledge on water management in the construction industry when compared to other industries in Sri Lanka. The Strategic Forum for Construction (SFfC) Water Subgroup, Waste and Resource Action Program (WRAP), and Construction Industry Research and Information Association (CIRIA) are the main research bodies conducting research on water use in construction sites and limited individual studies are found in the literature although considerable water research is available in the other sectors.

The Strategic Forum for Construction (SFfC) Water Subgroup in the UK is conducting a series of research studies on water usage in construction sites. The group is made up of key representatives from construction and manufacturing industries and regulatory agencies such as the Environmental Agency. Nine case studies have been selected by the Strategic Forum for Construction Group (SFfC) to observe construction water management processes (Waylen et al., 2011). During the survey, discussions were held with contractors and construction site employees, and the following key water using processes in construction sites were identified:

- Site cabins and temporary accommodation
- General site activities including tool washing
- Wet trades, such as brickwork, screeding, concreting, and plastering
- Groundwork including road and wheel washing
- Hydro- demolition
- Cleaning of tools and plant equipment and lorry washing
- Commissioning and testing of building plant and services
- Domestic and welfare water consumption

The majority of water wastage activities identified during the survey are summarised in Table 2.6. The survey through observations based on the nine case studies conducted by the SFfC group has identified that there is little consistency in the construction sector with regard to water management. Water consumption by site cabins and temporay accomodation facilities (domestic and welfare) is another high water using activity and this water requirement is unique for construction sites.

Table 2.6: High Priority Activities on Water Use

Water Using Activity	High Priority Activity
Dust Suppression	General, site roads, wheel washes Hydro-demolition with high pressure water
Cleaning	Ready mix concrete wagons Site/general cleaning Specialist/ high pressure cleaning
Commissioning and Testing	Building plant/services

Source :McNab et al.(2011)

As stated in Section 2.3, the Waste and Resources Action Program (WRAP) identifies key opportunities to reduce water use in sites such as (i) good housekeeping (ii) monitoring and targeting (iii) use of abstracted water where it is available (iv) specifying water efficient taps, and fittings and (v) use of water efficient plant and equipment (McNab, et al. 2011). They have shown savings to the tune of ~90%, ~ 40% and ~30%, for dust suppression, wheel washing and road sweeping respectively by selecting efficient plant and equipment. Table 2.7 presents water efficiency measures used in the above activities.

Table 2.7: Water Efficiency Measures

SOURCE	SAVING	CONSIDERATIONS
Dust Suppression	90%	Avoid high capacity ‘rain guns’ and hoses
		Use misting/atomising systems
		Consider using non-potable water (ideally rainwater harvested on site)
Road Sweeping	30%	Avoid use of an open hose
		Ensure operators are trained in water efficient practices; vehicles have adjustable spray bars/nozzles and stand-alone washers work on high pressure with trigger controls
		Consider water recirculation systems
Wheel Washing	40%	Avoid manual wheel washing
		Choose drive-on re-circulating systems with sensor-controlled shut off (where demand is ongoing)
		Ensure water top-up to settlement tank is controlled (e.g., a float valve); supply pressure reflects site conditions and that settlement tank filter is kept clean

Source : Adapted from McNab et al. (2011)

WRAP group states that creating a culture within the construction sector that can change the attitudes and behaviour of staff towards accepting the ownership of efficient water use is fundamental in improving the use of water in an efficient manner (Waylen, et al., 2011).

However, SFfC Water Subgroup states that during the survey, none of the audits done at the site were able to provide evidence of providing their site staff with regular awareness training in water efficiency. As a solution, it suggests three strategies such as value for money, work environment and habits to reduce water usage in construction sites (McNab et al. 2011).

Greenroads™ manual (2005) specifies that sand and gravel operations are major users of water and that cement production relies heavily on water in road construction. Concrete mixing, concrete curing, dust control, construction equipment washing, vegetation establishment, geotechnical borings, adding water to backfill materials/soil compaction, pipe flushing and pressure testing, and site clean-ups are the water consuming activities in construction projects. Goodrum (2008) has identified that the use of water permeates throughout construction. The Queensland Government (2007) identifies dust suppression, cleaning, slurry work, pressure washing of concrete and other surfaces, concrete cutting, pressure testing of water lines, construction vehicle washing before leaving the site, and increasing the soil's water content for compaction as some of the activities that use significant amounts of water in construction projects. In one of the studies conducted by SFfC of Waste and Resources Action Program (WRAP) on water audits in construction sites, it was found that the largest barrier for improving water efficiency on site was the lack of quantitative information due to the use of unmetered stand pipes and faulty water meters (McNab et al., 2011). The study suggested to utilise robust metering and monitoring systems on site to overcome the identified issues. In addition, the same study suggested the development of Key Performance Indicators (KPIs) for different site activities since water consumption may change throughout the different phases of a construction project. By creating KPIs, it will help to track water more accurately. Moreover, researchers have mentioned that due to the unique nature of site operations, this will not always be a simple process for construction sites and that it would need proper monitoring systems.

The results of 17 non-residential case studies conducted by McComack et al. (2007) in Australia prove that a considerable amount of water is embedded in construction and that a significant amount of water is embedded in building materials. Table 2.8 depicts the embedded water coefficient of main building materials.

Table 2.8: Embodied Water Coefficients of Main Building Materials

Material	Unit	Water intensity (kL/unit)	Material	Unit	Water intensity (kL/unit)
Aluminium	t	1084.00	Membrane (1 mm)	m^2	1.40
Aluminium, reflective foil	m^2	0.59	Oil-based paint	m^2	0.22
Bricks	m^2	0.67	Plasterboard (10 mm)	m^2	0.63
Carpet, nylon	m^2	1.58	Plastic	t	366.36
Clear float glass (4 mm)	m^2	3.42	Steel, stainless	t	649.55
Concrete (20 MPa)	m^3	10.98	Steel, structural	t	98.64
Concrete roof tiles (20 mm)	m^2	0.91	Tiles, ceramic	m^2	1.12
Fibre cement sheet (4.5 mm)	m^2	0.75	Timber, hardwood	m^3	16.28
Fibreglass insulation (R2.0)	m^2	0.38	Timber, softwood	m^3	20.14
Fibreglass insulation (R4.0)	m^2	0.69	Toughened glass (6 mm)	m^2	8.24
Laminate (1 mm)	m^2	0.48	UPVC pipe (100 mm diameter)	m	0.57
MDF/particleboard	m^3	85.59	Water-based paint	m^2	0.21

Source: Adapted from Crawford and Pullen (2011)

It shows that the amount of water embedded in building materials is significant, particularly with aluminium, dry partitions, steel, timber and concrete. Ilgar (2011) also identifies that steel production consumes a higher amount of water when compared to other building materials and that the estimated total quantity of water used for producing 4.06 million tons of steel is 12.18 million m^3. Therefore, the selection of building materials and elements has a greater impact on water quantity although comparatively a lesser amount of water is needed for direct activities for on-site practices during construction. Crawford and Pullen (2011, p.161) state that a policy focused on reducing water consumption of on-site activities may be superfluous at best and misleading at worst. The authors further state that by reducing over-ordering and re-work, direct and indirect water requirements for construction can be minimised.

Some literature shows that by applying the‘re-use’ concept in the batching plant process, 2m^3 of water per day can be re-used in Sri Lanka. This result has been derived through one case study conducted and the water used for cleaning the batching plant is subjected to a filtering process and reused for concrete production (Fernando, 2007).

Energy is another important factor and water and energy use are inextricably linked together. Energy is directly linked to water use by the end user in all of the following stages of the supply process (Waylen et al., 2011).

- Water Supply (extraction, treatment and distribution)
- Water Consumption (heating of water and water used/pumped)
- Wastewater (sewerage system pumping and wastewater treatment)

Furthermore, the authors emphasise that reducing water use in construction projects can be done by considering the impact of the water use activity on energy consumption. Often the cost of energy is associated with water, for instance the cost of energy utilised for pumping or heating water is greater than the cost of the water itself. In addition, carbon saving can be calculated for savings associated with water conservation measures. Water UK publishes a number of sustainability indicators relating to the water industry. The following are based on 2008/2009 results:

- Greenhouse gases emitted in supplying water are 0.3 tonnes of CO_2 per megalitre water
- Greenhouse gases emitted in wastewater treatment are 0.75 tonnes of CO_2 per megalitre

2.5.3.3 Water Sources and Water Quality Needed for Construction Activities

With regard to water sources for construction work, Greenroads™ Manual (2005) identifies natural water bodies, potable water supply pipe lines, and storm water as usual sources for construction work. According to Queensland Government (2007), construction site managers harvest storm water from their sites and store it for reuse and recycling. In Sri Lanka, many construction projects get water for construction work through the main water line (potable water) especially in urban areas in Sri Lanka (Waidyasekara, et al. 2012). This shows that drinking water (potable water) is subject to competing demands by humans and also by the construction industry.

According to project specific documents (specifications) published by the Construction Industry Development Authority (CIDA), some construction activities need water of potable water quality. For instance concreting, rendering, and curing work need water of potable water quality. Water used for mixing and curing should be clean and free from injurious quantities of alkalis, acid, oil, salt, sugar, organic materials, vegetable growth and other substances that may be deteriorous to bricks, stone, concrete or steel (Utraja, 2010). Similarly, it is advised that all commissioning and testing of building services should be undertaken using potable water to minimise the risk of system contamination (McNab et al., 2011). On the other hand, such standards are not required for activities like cleaning, washing of vehicles and tools, and dust controlling (Waylen et al., 2011). Thus it is ncessasry to look at alternative water sources (Utraja, 2010). Greenroads™ Manual (2005) mentions that when using non-potable water, there is an obligation to ensure that workplace health and safety are not negatively affected by the use of that type of water.

Ramachandran (2004) mentions that one structural engineer in India had said that if contaminated water is used, the life of the structure will come down from about 60 years to about 20 years. Unfortunately, many builders still do not realise the importance of the quality of water that is to be used and hence the quality of the structure lowers. The engineer has further mentioned that in a typical construction, the water demand is roughly 10 to 20% of the volume of brick and concrete used. However, he has said that this can be reduced by using modern techniques and has recommended steel intensive construction methods. The Vice President and Head of Larsen & Turbo Limited in India explains that the construction of a 100,000sq.ft. multi-storey structure requires about 10 million litres of water for production, curing and site development activities. A double lane flyover can consume 70 million litres of water on a scale similar to the case discussed above (Ramachandran, 2004). Furthermore, the engineer claims that the water shortage in Chennai causes delays in work and that it thus increases the unit cost of construction.

2.5.3.4 Cost of Water in the Construction Industry

In the construction industry, water is one of the raw materials used to produce a value added product at the end. Rogers et al. (2002) identify general principles for cost and value of water as illustrated in Figure 2.15.

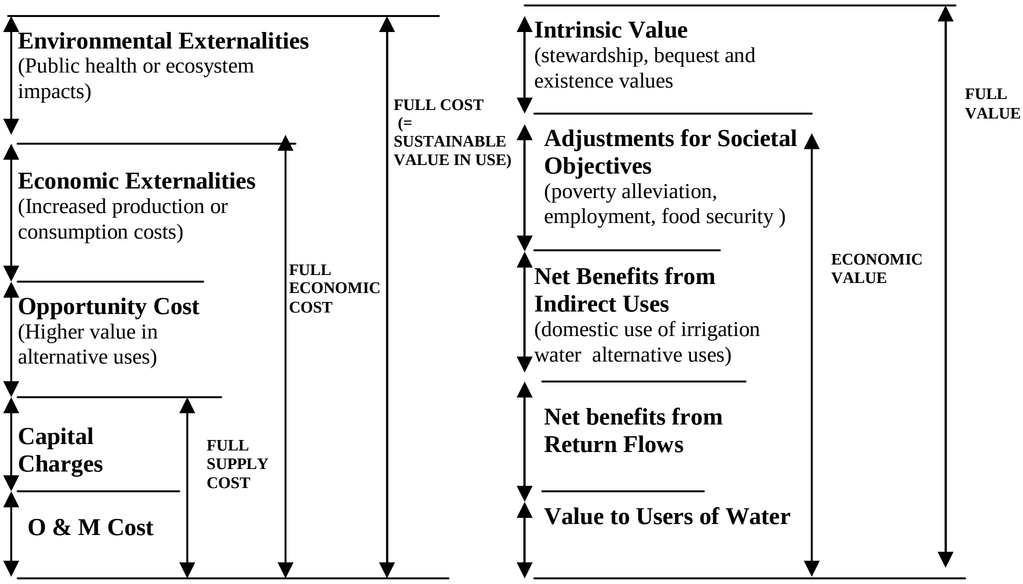


Figure 2.15: General Principles for Cost and Value of Water

Source: Rogers et al. (2002)

The authors explain the full cost of water which is equal to the sum of all the costs, that is the full supply costs (Operation and maintenance + capital costs incurred by water companies), plus the full economic costs (opportunity costs + economic externalities), plus environmental and social externalities. Therefore, the general phenomenon is that the value of water is higher than its cost. One of the critical areas need to be looked at is the way the construction industry prices the cost of water. Howard (2003) explicates value of water has three components namely existence value, environmental and aesthetic value, and economic value. However, to some extent these value overlap, and depending on specific circumstances. Therefore, the relationship between '3E'value is presented in a Venn diagram (refer Figure 2.16).

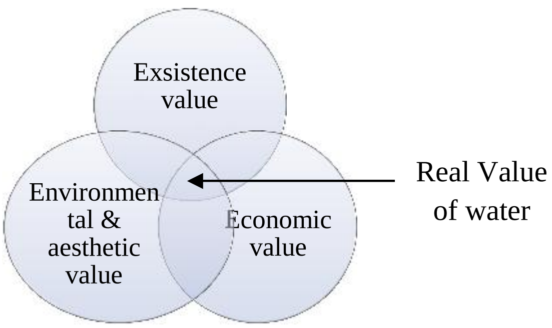


Figure 2.16: '3E' Value of Water

According to Sharp and Kerr (2005), existence value also known as non-use value that can derive from the built environment as well as from the natural environment. Moreover, development and mitigation activities can reduce or enlarge the existence value. Howard (2003) explains that economic value of water based on a society's willingness to pay for it and estimates of the economic value of water must include measures of both its reliability and its impact on economic activity.

However, Joyce (2012) argues that the true value of water is still not reflected in all water related decision-making due to the existence of various socially constructed barriers. Among the environmental resources, the lack of availability of freshwater will create formidable challenge to human existence and sustenance of economic activities in coming days in large part of the world (Shaban & Sattar, 2011).

According to the National Water Supply and Drainage Board (NWS&DB) (2012), there is no separate unit rate for water used by the construction sector, which falls under the category of 'commercial institutions'. The monthly service charge increases with the number of units consumed. Figure 2.17 illustrates revisions to the water tariff system, i.e., cost of a cubic meter (equal to 1 unit) of drinking water during the last two decades:

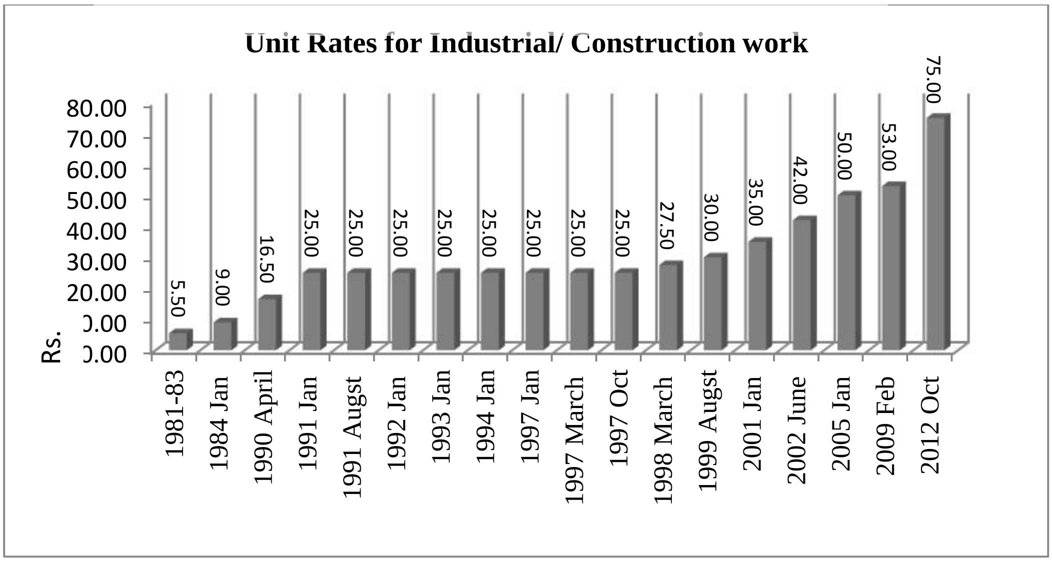


Figure 2.17: Fluctuation of the Unit Rate of Water under the Industrial/Construction Category

Source: Based on Records of Water Tariffs at NWS&DB from 1981 to2012

It is apparent from Figure 2.17 that there have been slight increases during the last two decades of the unit rate of water consumed by the construction category. In Sri Lanka, the cost of water is significantly lower when compared to countries where water is not available freely. For instance, in the countries in the United Arab Emirates (UAE) the cost of a 1cubic meter of water is around Rs.320.00 (Dubai Electricity and Water Authority, 2013) and in Maldives the cost of one cubic meter of water is Rs.860.00 (Male Water and Sewerage Company, 2013). However, according to the NWS&DB data base, production costs of water exceed Rs.150.00 per cubic meter and all sectors including the construction sector receive water at a subsidised rate. Menikdiwela (2013) emphasises that high capital costs and limitations of the resources for expansion are some constraints faced when providing pipe-borne water to all and that it would be a difficult task for Sri Lanka for at least another decade.

Ameyaw and Chan (2015) mention that developing countries recorded high Non-Revenue Water (NRW) compared to developed countries, which is more than 60%. It is observed that in Sri Lanka, NRW content is about 35% of the total supply mainly due to leakages in the pipes and fittings, illegal tapping, errors in water meters and poor plumbing practices (Gamini, 2010). Although the cost of water is still insignificant, by considering possible future dilemmas in the water sector, it is pertinent to make correct decisions at the proper time by the construction industry as it is considered as a water intensive industry. Deveraja (2013) says that different categories should be treated differently during tariff design. UNSGAB (2011) highlights that if the demand for energy increases, the demand for water will also increase and that therefore water tariff design needs to have an effective water pricing system. Similarly, Kodagoda (2013) suggests that since the average electricity cost is increased by 10% annually, the water tariff should also be adjusted accordingly. Mactavish and Greenhalgh (2013) highlight that historically, cost has always been the language that captures the attention of investors and clients to which their project teams were required to respond. Perhaps in future, metrics such as tonnes of carbon or litres of water saved will gain equal attention in cost evaluations.

2.5.3.5 Impact of Construction Water on the Environment

As Robert et al. (2006) have mentioned, over allocation and over use of river systems place significant stress on natural resources. As Horne (2012) states although the quantification of water to sustain the environment is needed, it is a difficult and a challengeable task. Cole (2005), Holmes and Hudson (2000), Pahwa (2007) and Tan, Shen, and Yao (2011) identify the necessity for protecting natural resources from environmental impacts due to construction. Many site activities impact on the environment and are potential sources of water pollution (CIRIA cited Ofori 2004; Ofori 1992). When removing vegetation for initial clearing, grubbing and grading activities, it exposes soil and makes it more susceptible to erosion (Tan et al., 2011). Smakhtin et al. (2004) state that over pumping results in declining ground water levels. On the other hand more energy is consumed to pump the same quantity of water. Moreover, the authors state that formulating policies in one sector without adequate consideration and coordination with the policies in the other sectors will make the products increasingly costly, inefficient and unsustainable. This is mostly seen in the current and past practices. Thus, Byrne (2011) explains that in water consumption, the 'fit for purpose" approach should be adopted if potable water is used for all purposes.

An Environmental Management System (EMS) can provide a framework to achieve and to demonstrate a desired level of environmental performance (Tse, 2001; Wu, 2003). Similarly, Environmental Impact Assessment (EIA) integrates environmental protection measures into development at early stages of planning (CEA 2006). EIA ensures sustainable development and it is a mandatory requirement for donor funded projects. Baloi (2003) highlights that EMS and EIA enable companies to respond to environmental challenges and legislative/regulatory requirements proactively. The establishment and implementation of ISO 14001, EIA, and EMS require total commitment and cooperation of all parties involved in the supply chain including construction contractors, supervisors, designers, manufacturers, and investors (Cysewski cited Chen & Wong 2000). However, in developing countries, there are many difficulties and challenges ahead for implementing ISO 14001, EIA and EMS in the construction industry. The most formidable one is that efforts made in environmental protection do not necessarily result in lower project costs and/or shorter durations. In fact, the introduction of environmental management into construction management increases direct project costs, as at present, contractors do not need to pay for pollution and hazards generated by their projects, if they can get away with current environmental and construction laws (Chen & Wong 2000).

As Tam and Lee (2007) observe, another issue is the poor response of construction organisations to EMS which is attributed mainly to their lack of environmental consciousness. Similarly, Chan and Wong (2000) state that the awareness of environmental protection among general public in developing countries is low compared to that of many developed countries. People seem to be too busy accumulating personal wealth at the expense of the natural environment. As a consequence, public pressure on the construction industry on improving its environmental management is not very high. Another critical factor is that traditional contractor selection rarely considers environmental aspects (Watt, Kayis, & Willey 2010). With these difficulties and challenges in mind, it is important for the government to further reinforce the relevant environmental protection laws on the one hand, and promote the importance of general education in protecting the natural environment including water resources on the other hand.

2.6 Water Hierarchy for the Construction Industry

The joint government and industry strategy for sustainable construction in the UK published in 2008, identified water usage in construction sites as a priority area and included a number of targets pertaining to the more efficient use of water (McNab et al. 2011). Waste hierarchy (prevention, re-use, recycle, recovery, disposal) (Defra 2007), 3R (Reduce, Re-use, Recycle), avoid, reduce, reuse, recycle and treat (Mirata & Emtairah 2011) are some common popular hierarchies available in literature to reduce wastage and enhance the efficient use of resources. Similarly, Silva and Pimentel (2011) mention that water efficiency can be achieved through the 5R principle, which incorporates Reducing consumption, Reducing loss and waste, Re-using water, Recycling water and Resorting to alternative sources. The Strategic Forum for Construction (SFfC) Water Subgroup of UK has introduced a water management hierarchy for the construction industry as shown in Figure 2.18. SFfC explains that Water Management Hierarchy is a framework for prioritising the most preferable options for water management and efficiency and is at the heart of any water efficiency program. Levels of the hierarchy from the highest to the lowest in terms of the priority for water efficiency include elimination, alternative water supply, reduction, reuse, recycle, and disposal. Brief explanations given for each level are illustrated in Figure 2.18.

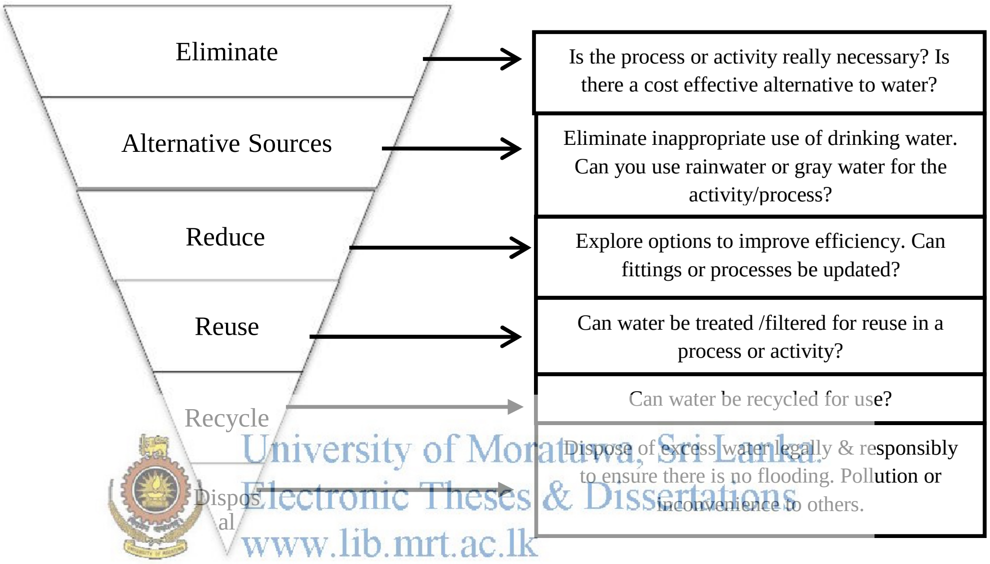
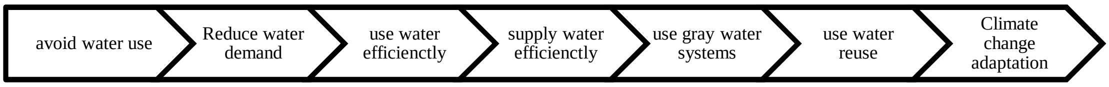


Figure 2.18: Water Hierarchy in Construction

Source: Waylen et al. (2011)

The primary purpose of the hierarchy is to reduce the potable water consumption and encourage alternative water sources such as rainwater or recycling within the site. On the other hand, the hierarchy encourages reuse and recycle concepts. Tam and Lee (2007) suggest that it is necessary to encourage and educate staff on monitoring water usage, water reusing and recycling systems, and on the use of treated wastewater during construction.

Figure 2.19 illustrates another ‘water use hierarchy’ proposed by Street (2010) for a project life cycle. This proposed hierarchy is too detailed than the water hierarchy introduced by the SFfC. Figure 2.19 explains factors that impact under each step on enhancing water efficiency practices. However, both hierarchies encourage reusing, recycling and reducing of potable water requirements that can be easily adopted according to project requirements of the construction industry. Water hierarchy provides a base to prioritise the water efficiency process to avoid unnecessary consumption or water wastages.



1st propriety	2nd	3rd	4th	5th	6th	Accept the need
Education Awareness Valuing Water Demand side management	Plant optimization Demand side management Alternative non-potable water supplies Smart metering	Efficiency standards Water fittings High water efficient appliances	Leakage reduction Network pumping optimization to minimize energy demand Tariff optimization	Alternative non-potable water supplies Gray water systems Rainwater harvesting Local borehole with minimal treatment	Advanced water re-use treatment Desalination	Flood risk management Water resource planning Critical infra asset risk

Figure 2.19: Water Use Hierarchy

Source: Street (2010)

Although certain water saving strategies have been established, WRAP identifies that assigning responsibility and enabling the active participation of staff and senior management would be vital for the water saving program. Motivation is another factor that can maximise its success. In order to achieve these water efficient processes, it is important to address these methods through various approaches such as technical applications and behavioural changes (Mirata & Emtairah, 2011).

2.7 Techniques, Technologies and Strategies of Water Management

Techniques and technologies are closely related to each other although they have different meanings. According to Aggazy (1998), techniques mean a display of practical abilities that allow one to perform easily and efficiently a given activity, be it purely material or bound to certain mental attitudes. Technology, on the one hand, is included in the domain of techniques, while on the other hand, it is set off by specific traits (Aggazy, 1998). Technology is the application of scientific principles and people have different techniques in making use of the same technology. Hart (1995, p.114) defines strategy as a match an organization makes between its internal resources and skills and the opportunities and risks created by its external environment. Strategy usually requires some sort of planning. Bourg (2010) clearly states that the human factor is critical in obtaining desired results from water conservation strategies. Water management strategies are categorised into three (03) areas, viz., reducing losses, reducing water quantity and reusing water. According to Department of Energy (DOE) of USA (2011), water efficiency implementation starts with the understanding of water use facility and water use pattern and then developing a water management plan. As Cohen, Ortez, and Pinkstaff (2009) highlight, effective water management also offers economic, environmental and social benefits. Technologies and techniques will help achieve certain strategies to make the use of water efficient in certain instances. Water efficiency tools allow the user to identify targets for water efficiency in building designs and to compare and specify certain water appliances (McNab, et al., 2011). Water conservation techniques and strategies are often the most overlooked aspects of a whole-building design strategy (Bourg, 2010). Thus, the implementation of water saving initiatives within a building is increasingly becoming a priority and a wide range of technologies and measures are employed to reduce the amount of water consumed by buildings. It could be observed that certain overlaps exist with techniques, technologies and strategies. However, all these terms are used to implement water conservation and water efficiency practices. Therefore, the study adopted the common term 'Water Efficiency Measures (WEMs)' to represent the terms, i.e. techniques, technologies and strategies.

As stated by Piper (2008), reducing water use in a facility is a win-win situation. It means using less water, which in turn means lower utility costs, a lower threat to the environment and enhanced public image (Piper, 2008). There is a growing body of literature that presents the results of many studies related to water efficiency practices, namely building operations (McComack et al., 2007), mining industry (Rossana, Guillermo, & Zúñiga, 2008), agriculture sector (Chisanga, 2003: IWMI, 2009), and manufacturing sector (Thilakarathna & Silva, 2012 ;Volmajer, Majcen, Krizanec & Vajnhandl, 2012). The next section presents the available water efficiency measures that can be employed during phases of construction project life cycle identified through a critical literature review.

2.8 Water Efficiency Measures Related to Construction

The identification of water saving measures to reduce water use in the construction sector also can be beneficial. While there is a large body of literature on the design of principles targeting water efficiency during the operational stage of a building, comparatively less work could be found on water efficiency practices during construction. Therefore, a wider literature review encompassing the relevant operational stage measures as well as measures used in other industries was carried out to obtain a comprehensive list that could be used for this study. Following sub-sections explain several water efficiency measures suggested by researchers for the construction industry. In addition, Section 3.3.2 of Chapter 3 discusses other WEMs that are commonly used by the construction industry.

2.8.1 Water Audit

A water audit determines the amount of water lost from a distribution system due to leakage and other reasons such as theft, unauthorised or illegal withdrawals from the system and the cost of such losses to the utility (Shukla, 2014;Waylen et al., 2011). A comprehensive water audit gives a detailed profile of the distribution system and water users, thereby facilitating easier and effective management of resources with improved reliability (McNab et al., 2011). In simple terms, a water audit is a useful tool to find out any loopholes in the water distribution system. Who, what, when, and where are the basic terms that need to be considered before the start of the audit process. As stated by the Ministry of Water Resources (2005), a water audit helps in the correct diagnosis of problems faced, in order to suggest optimum solutions. It is also an effective tool for a realistic understanding and assessment of the present performance level and the efficiency of the service and the adaptability of the system to future expansions and rectification of faults during modernisation. The eight (08) steps that are identified in a usual water audit process are illustrated in Figure 2.20. The SFfC Water Subgroup prepared a flowchart for a water audit procedure to be followed in construction sites (refer Figure 2.21). It allows robust data collection on water consumption, areas of high water consumption and water wastage.

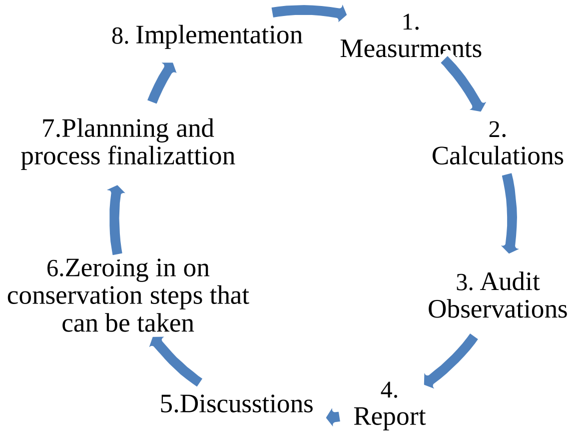


Figure 2.20: Steps Identified in a Water Audit Process

Source: Shukla (2014)

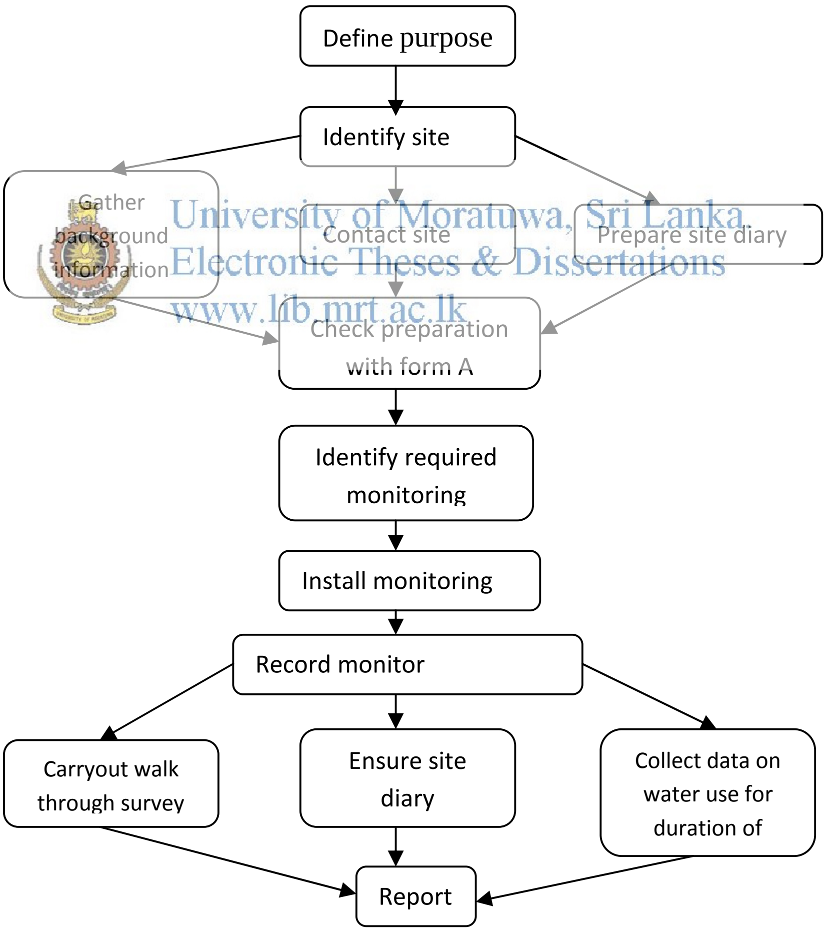


Figure 2.21: Water Audit Procedure Flowchart

Source: Waylen et al. (2011)

Water saving opportunities were identified based on the findings of case studies conducted by the SFfC and in general, a 20% reduction in the water consumption in construction sites can be achieved through water auditing.

In addition, the literature identified the following benefits for construction sites in having a water audit:

- Utilisation of water resources effectively and more efficiently
- Checking of unwanted excess usage of water - controlling real losses
- Saving money, minimising unnecessary water consumption and wastage
- Conserving and reducing the burden on water resources - reducing stress on water resources
- Reducing wastage and unnecessary use
- Making awareness among people of their responsibilities
- Distribution according to needs
- Complying with regulations

2.8.2 Closed Loop Systems

Water recycling and reuse measures, gray water and recycling processes are some technologies and techniques commonly used to reduce water usage in a building (Bourg 2010). Gray water can be used for activities that do not require potable water, such as dust controlling, site cleaning and washing of tools. Waylen et al. (2011) has stated the importance of a closed loop system for the construction industry. It looks at using the waste of one product for another process. It just introduces the recycling of waste water. Waylen et al. (2011) suggest closed-loop water recycling for drive-through wheel washers (refer Figure 2.22), and a wash-out pit with recirculation system to re-use water in concrete mixes.

Figure 2.22: Drive On-Wheel Wash Area

Source: MacNab et al. (2011)

2.8.3 Sub-metering

Goodrum (2008) states that the amount of water consumed by construction is unknown and that it is not measured adequately. McNab, et al. (2011) identify that the quantifying of the consumption is the first step in improving water efficiency though many sites do not currently implement this practice. It is recommended that the installation of water sub-meters site-wise after selecting locations for same has to be implemented in order to improve the gathering of water quantitative information through regular meter readings (Waylen, et al., 2011). Furthermore, it will provide water to high priority water using activities in proportion to the total site water consumption and eliminate erroneous consumption.

2.8.4 Water Efficient Plumbing Fixtures

Bourg (2010) identifies water saving devices that reduce water use in buildings for the construction sector too. Liu and Ping (2012), McNab, et al. (2011) and Waylen et al., (2011) suggest water efficient plumbing fixtures for the construction industry as summarised in Table 2.9.

Table 2.9: Water Efficient Plumbing Fixtures

Efficient Plumbing Fixtures	**Source of References**
Water saving taps (low flow and sensor activated taps)	Bourgs (2010); Liu and Ping (2012); McNab et al. (2011) ; Waylen et al. (2011)
Low flow shower heads	Bourgs (2010); Liu and Ping (2012), Waylen et al. (2011)
Faucet aerators	Arab Forum for Environment and Development (2010)
Automatic shut-off systems/ on demand sensors/sensor activated flushing systems	Arab Forum for Environment and Development (2010); McNab et al. (2011); United State Department of Energy (2002)
Dual flush low flushing cistern	Arab Forum for Environment and Development (2010); McNab et al. (2011); Singapore's National Water Agency (2008); United States Department of Energy (2002)
Low-flush and waterless (water-free) urinals	Environment Agency (2007); Singapore's National Water Agency (2008); Waylen et al. (2011)
Urinals with on-demand sensors	Arab Forum for Environment and Development (2010); Waylen et al. (2011)
High pressure washers, Trigger guns on hoses	Waylen et al. (2011)
Pressure reduction valves, flow regulators, spray taps	McNab et al. (2011)
Vacuum toilets	Waylen et al. (2011)

Figure 2.23: Water Efficient Devices: (i) Spray Gun Hoses and (ii) High Pressure Washers

Source: McNab et al., (2011)

Figure 2.23 depicts some water efficient devices: Spray gun hoses and high pressure washers used in construction sites.

Based on the results obtained by SFfC, the use of low-flow devices is found to give water use savings of 20% to 40% and pressure reduction savings up to 33% of the water normally consumed. Although water efficient plumbing fixtures assist a construction site to reduce its overall water use as stated by Waylen et al. (2011), attitudes and behaviour of the staff and the workers towards accepting the ownership of water efficiency are fundamental for improving the use of water in an efficient manner. Literature shows that a typical vacuum system can reduce potable water consumption in toilets by 68% and that this is more efficient than the traditional methods (McNab, et al., 2011).

2.8.5 Leak Detection Systems

The detection and the repair of leaks is only one of the water conservation alternatives. Of the many options available for conserving as stated by Lahlou (2001), water leak detection is a logical first step. The author states that one of the effects of water leakage, besides the loss on water resources, is the reduced pressure in the supply system. Raising pressure to make up for such losses increases energy consumption. This rise in pressure makes leaking worse and would have adverse environmental impacts. Although leak detection systems provide many benefits, the SFfC states that equipment available for water leak detection is quite costly. Metering can also be used to help detect leaks in a system. It is not unusual for unaccounted water losses to drop by 36% after the introduction of metering and leak detection programs (Waylen et al., 2011).

2.8.6 Dust Suppression Systems

Dust suppression is a water intensive activity in road construction compared to building construction. However, during the sub-structure period a considerable amount of dust is generated in building projects as well. The SFfC states that dust suppression vehicles with splash plate systems are more water inefficient than hydraulic spinning systems (McNab et al., 2011). Bowsers with sprinklers, manual spray units, block cutting, rain guns, and fan misting systems could be seen in construction sites including those of building projects. Figure 2.24 illustrates several dust suppression systems (e.g., fan misting systems/splash plate operation) used in construction sites.

Figure 2.24: Dust Suppression Systems Used in Construction Sites

Source: Adapted from McNab, et al. (2011)

However, the operation and water needs of each system will vary. Generally, rain guns are simple in operation and suitable for use during the demolition of a building. A rain gun is considered as a water inefficient method because of the absence of typical flow rates (McNab et al., 2011). A fan misting system provides significant water savings compared to rain guns. However, cost, lower mobility, electricity, water quality are some of the disadvantages identified in a fan misting system. Road sweeper is another technique that can be used for dust suppression and its average water consumption is comparatively lower. In addition, in removing dust and mud from wheels, high pressure washers and drive on wheel wash systems (refer to Figure 2.23) have been used.

2.8.7 Admixtures/ Chemical Adhesives

It was found that a variety of chemical additives are available to assist in the reduction of water consumption of certain construction activities. The SFfC group also mentions that chemical additives are an option to assist in reducing the volume of water needed and that waterless systems are the other innovative options. Some additives effectively increase the time taken for the water to dry out (McNab et al., 2011). The use of curing agents was identified as the most effective technique to reduce water consumption though its cost was identified as a limitation (Utraj, 2012).

2.8.8 Water Action Plan

Having a proper recording system on the water consumption at the sites by contractors will provide a baseline assessment or benchmark for different types of construction projects since it is an issue that is not being sufficiently addressed currently. Water use for a particular process varies during the life cycle of a construction site. Having a water action plan will provide important data in this regard. The Australian Industry Group (2006) identifies the water saving action plan as a water efficient strategy. It seeks to address the reduction of water usage by encouraging and promoting water activity to obtain better information. A water audit determines the amount of water lost from a distribution system due to leakage and other reasons such as theft, unauthorised or illegal withdrawals from the system and their cost to the utility (refer to Section 2.8.1). A water action plan is broad and well structured. A water audit is a sub-set of the water action plan. The basic components of an action plan are (i) identification of the task, (ii) identification of the time horizon and (iii) identification of the resource allocation. In addition, Piper (2008) states that the water efficiency plans should set priorities for implementation based on costs, benefits and available manpower. When considering actions for reducing water usage in construction sites during a construction phase, it will be apparent that some actions need to be initiated immediately, while some will be long term actions. Well planned actions are needed before implementing such long term actions. Immediate actions will depend highly on the commitment of individual professionals.

2.8.9 Monitoring, Awareness and Assigning of Responsibilities

Tam and Lee (2007) suggest that it is necessary to encourage and educate staff on monitoring water usage, water reusing and recycling systems, and the use of wastewater treatment during construction. The Strategic Forum for Construction Water Subgroup identifies that in enhancing water efficiency in construction projects, workers' participation, recognition, team work, management commitment and leadership and effective training have impacts on water efficiency at site level (Waylen, et al., 2011). McNab, et al. (2011) state that site management should prepare a formal system for repairing leaks on a regular basis, checking, monitoring and reporting in order to reduce water wastage at construction sites.

2.8.10 Integration of Alternative Construction Methods

Modern techniques such as curing compounds, sprinkler techniques, pre-cast construction methods, dry partition work and steel intensive construction during the design stage are recommended in the literature to reduce water consumption (Illgar, 2011; Ramachandran, 2004; Utraj, 2010). However, Crawford and Pullen (2011) identify that embedded water is significant in building materials like aluminium, steel, timber, and dry partitions (refer Table 2.8) although less water will be needed during site operation. SFfC Water Subgroup and WRAP identify that water savings could be achieved with new techniques although the costs of such exercises would be a significant limitation.

2.8.11 Integration of Environmental Policies

SFfC Water Subgroup identifies the incorporation of water efficient construction sites into sustainability assessment systems (BREEAM, LEED, Green^{SL}) and environmental policies on natural resources as best practices for enhancing water efficiency culture (Waylen, et al., 2011). Waidyasekara, et al. (2013) compare eleven (11) sustainability assessment tools and find that only three (03), namely Building Research Establishment's Environmental Assessment Method (BREEAM) of UK, BEAM of Hong Kong and Green Rating for Integrated Habitat Assessment (GRIHA) of India have included in their assessment criteria water efficiency approaches during the construction phase. Since construction is considered to be a water intensive industry, its inclusion in environmental assessment tools will be an effective way of controlling it (Gowri, 2004). For instance, the simple step of effectively monitoring water use at the site will deliver direct benefits to all concerned.

The SFfC Water Subgroup has identified waste water disposal from construction sites. As discussed in Section 2.5.3.5, ISO 14001, EMS and EIA have identified important policies for the construction industry to protect natural resources (CEA, 2006; Tse, 2001; Wu, 2003).

2.8.12 Increase of Unit Rates

As Devaraja (2013) expresses, water losses may form either an apparent loss (physical- water leaks in pipes) or a real loss (Non-physical- illegal consumptions, errors of measuring apparatus, administrative losses and free water supply). UN and UNSGAB (2011) highlight that if the demand for energy increases, the demand for water will also increase and that there need to be an effective water pricing system. Savenije and Van der Zaag (2002) state that having a market price for water will give a clear signal to users that water is indeed a scarce commodity that should be used sparingly. Zbigniew and Kundzewicz (1997) and Horne (2012) emphasise the necessity of increasing water prices to appropriate levels in order to be taken seriously by consumers. Moreover, it will stimulate conservation, may curb demand and encourage the use of water for high value uses.

2.9 Documentary Analysis of Standard Norms Available for Water Used by Construction Activities in Sri Lanka

As discussed in Section 2.5.3.3, many researchers have identified that quality and quantity of water are critical parameters that impact on the strength and the performance of certain construction work. The available literature shows that the Building Schedule of Rate (BSR) is the acceptable document to refer to for norms for construction activities other than work studies. BSR has been prepared based on work norms adopted for building construction work with an eight (08) hour labour input. As stated by Goodrum (2008), the amount of water consumed by construction is unknown and the amount of water consumed by the construction industry has not been adequately measured. As discussed in Section 2.5.3.2, the Strategic Forum for Construction (SFfC) Water Subgroup has identified that lack of quantitative data in construction sites mainly due to the unavailability of sub-metering and faulty water meters (McNab, et al.2011).

Table 2.10 summarises standard norms available for water requirements of several construction activities based on the Building Schedule of Rates (BSR) published by the Buildings Department of Sri Lanka in 1988. It was observed that water requirements have been considered for a limited number of construction activities. In addition, there has been no consideration given in the BSR for water consumed by labourers and by other indirect activities like cleaning, washing etc.

Table 2.10: Standard Norms Available for Water Requirements of Construction Activities/Processes

Description	Norm per Unit	Unit (Water)	Norm Water Quantity	Remarks
Anti Termite Treatment	Sqr	Gal	20	
Concrete 1:3:6 (1 ½")	cube	Gal	110	Site Mix (mixing only)
1: 2 ½ : 5 (1")			100	
1:2 : 4 (3/4")			120	
1: 1 ½: 3 (3/4")			150	
1: 1: 2 (3/4")			200	
Curing				
Columns 6" x 6"	180 ft	Gal	140	
9" x 9"	30 ft	Gal	100	
12" x 12"	50 ft	Gal	100	
Beams 6" x 6"	180ft	Gal	80	
9" x 9"	120ft	Gal	150	
12" x 12"	80 ft	Gal	120	
Slabs RCC 5"thk	120ft2	Gal	90	
RCC 6" thk	100ft2	Gal	90	
Brick walls 4" thk	Sqr	Gal	50	Soaking and mortar (1:8)
9" thk	Sqr	Gal	115	
Random Rubble	Cube	Gal	100	
Plastering 1: 3	Sqr	Gal	10	10mm thick
Rendering 1: 3	Sqr	Gal	10	12 mm thick
Painting				
Emulsion	Sqr	Gal	0.1	One primer & two coats
Varnish	Sqr	Gal	0.4	Two coats

Source: Adapted from BSR (1988)

As discussed in Section 2.5.3.3, the quality of water is another factor that impacts on the performance of construction activities (Ramachandran 2004; Utraja 2010). The ICTAD specification document is the main project specific document that addresses quality requirements of water resources. Accordingly, the ICTAD SCA/4/1 document sets the specification of water for construction to be fresh, clean and free from acid, alkali, oil, organic impurities. Specification clauses further state,

> *"all water used for mixing concrete, mortar or grout shall be conformed to SLS 522 and be obtained from a source approved by the officer in charge. pH value of water shall generally be not less than 6. Water used for curing shall not produce any objectionable stain or deposit on the concrete surface. Sea water shall not be permitted for mixing or curing of concrete (p.1)".*

2.10 Drivers that Influence Water Efficient Practices in Construction Projects

This section is further supported with literature findings on the drivers that influence water efficient practices on construction sites. As stated earlier, successful water management considers both technical (installing efficient fixtures) and human (behaviour and expectations) aspects. Installing a retrofit device or replacing outdated technology or fixtures alone might not produce expected water savings unless user behaviour is improved. Russell and Fielding (2010) recognise that water use behaviour is a critical aspect of water demand management. Bourg (2010) states that one of the first steps in implementing a water conservation program is the training of employees on the use of water efficient techniques. In case it is not properly used or maintained, it will not achieve ultimately their maximum saving potential. One example cited was that the use of dual flushing may result in more water consumption than when conventional devices are used. Tam and Lee (2007) suggest that it is necessary to encourage and educate construction staff on monitoring water usage, water reusing and recycling systems, and on the use of wastewater treatment during construction. As McNab, et al. (2011) explain, good housekeeping, i.e., reporting/repairing leaks, turning off taps etc., could be greatly conducive in reducing the overall water usage at construction sites. Furthermore, SFfC Water Subgroup identifies that creating a culture within the construction sector that changes attitudes and behaviour of the staff towards accepting the ownership of water efficiency, is fundamental in improving the use of water in an efficient manner. In essence, the attitude and behaviour of workers on water usage are two of the key factors that determine the efficiency with which water is used.

Eroksuz and Rahman (2010) identify the value of increasing public awareness on water and environment. As Mackee (2003) mentions, research and development contribute to the knowledge and service innovation and service development. According to Fawcett et al. (2012) new approaches to long-term water planning and management that incorporate principles of sustainability and equity are required. Workplace Health and Safety Queensland (2007) states that once workplace health and safety are safeguarded, the preservation of drinking supplies will be the next most important priority in a construction site. Moreover, it will stimulate conservation, may curb demand and encourage the use of water for high value uses. Hussain, Thrikawala, and Barker (2002) find that if there is a price increase of water by 10%, the water demand from the industrial sector will reduce by 13%, and that in the residential sector it will reduce by 1.8%. This shows that the price of water has a significant effect on the demand by the industrial sector which reflects the fact that the industry is motivated by economic factors. As Savenije and Van der Zang (2002) suggest, water pricing is an important instrument to break the vicious circle of the 'free water dilemma'. As discussed in Section 2.5.3.4, many researchers identify and suggest the requirement to increase the cost of water as a strategy in many sectors to minimise the misuse and wastage of water resources that are available (IMWI 2010; Kivaisi 2001).

As stated by Workplace Health and Safety Queensland (2007), the quality of water for workers as well as for construction activities critically impacts on project performance. Utraja (2010) also mentions that the quality and quantity of water are important parameters that have an impact on the strength of certain construction work. Potable water is generally considered to be satisfactory for mixing. The pH value of water should not be less than sic (06) according to the explanation given.

According to the guideline prepared by the Road and Traffic Authority in Australia (2000), the construction monitoring program should be linked to other contract documents and pre-construction monitoring should be undertaken during the

Environmental Impact Assessment (EIA) phase of a project to minimise water issues and enhance efficient water conservation. As discussed in the background study and in the literature, many researchers have identified the requirement for formulating new policies and reviewing the existing policies (Rosegrant et al., 2002; McComack et al., 2007; Houser and Pruess, 2009). In addition, some authors emphasise that action should be taken in terms of water tariff system (Gamini, 2010, Menikdiwela 2013, Devaraja 2013), and conditions for protecting natural resources and environmental impact (Holmes and Hudson 2000; Cole, 2005; Pahwa, 2007). Management of any risks arising from the use, handling, storage, transport, and disposal of water at the project site are also some of the obligations. In addition, the discharge of construction site water is required to be governed by environmental agencies and equivalent policies.

2.11 Barriers and Challenges on the Efficient Use of Water in Construction Projects

All industrialised economies require water of some form, quality and quantity, for all production processes (McCormack et al., 2006). Hussain et al. (2013) mention that the indiscriminate usage of water for domestic consumption, agricultural purposes or industrial usage coupled with an ever increasing demand for it has imposed a serious threat on its current supply and future availability. A study conducted by SFfC of Waste and Resources Action Program (WRAP) on water audits in construction sites in UK has found that the largest barrier to improve water efficiency on site was the lack of quantitative information due to the use of unmetered stand pipes and faulty water meters. Thus, they have suggested to utilize robust metering and monitoring systems on site to overcome this issue (McNab et al., 2011). WRAP identifies saving money, reducing carbon footprint of the environment (preserving natural resources), and supply chain pressure as some of the benefits of water efficient practices. Despite these, WRAP states that the lack of commitment, understanding and resources as perceived barriers on water efficiency practices in construction sites. Tam and Lee (2007) suggest that it is necessary to encourage and educate staff on monitoring water usage, water reusing and recycling systems, and wastewater treatment during construction. Tam and Lee (2007) observe that the poor response of construction organizations to EMS can be attributed mainly to their lack of environmental consciousness. The report of David Langdon (2007) explains that a waterless future ultimately means cost increases, desalination, recycled water, third pipes, grey water, black water, water tanks etc.

Joyce (2012) argues that the true value of water still does not reflect in all water related decision-making due to the existence of various socially constructed barriers. Among environmental resources, the lack of availability of freshwater will create a formidable challenge in future to human existence and sustenance of economic activities in many parts of the world (Shaban & Sattar, 2011). According to Majdalani (2006) and Singh, Murty, Gupta and Dikshit (2012), new approaches to long-term water planning and management that incorporate principles of sustainability and equity are required.

Another problem faced by the water sector is that prices and tariff are almost universally below the full-cost of supply (Rogers, et al., 2002). Low-priced water encourages excessive consumption and if services are provided at higher prices it would encourage conservation, and provide a far better service. At present, non-revenue water, cost recovery systems, waste of potable water are some critical issues in the water sector in Sri Lanka (Deveraja, 2013; Gamini, 2010; Kodagoda, 2013; Menikdiwela, 2013). Biswas and Seetharam (2008) further mention that lack of income from utilities due to inadequate water pricing will result in water systems that are not properly maintained and that the supply of water free of charge or at highly subsidized rates on a long-term basis is now over. Absence of integrating WE standards at early stages considered as less attention on efficient water use in construction projects (McNab, et al., 2011).

Section 3.3.5 of Chapter 3 further discusses literature findings on barriers that impact on water efficient practices during the construction phase.

2.12 Research Gap Towards Research Questions

Aforementioned literature findings convey that water will be a challengeable resource of the world in the near future, if proper actions are not taken towards efficient water-use to maintain it as a sustainable resource. Furthermore, researchers claim that construction industry and its activities have a significant impact on the environment. However, water is one of the poorly acknowledged resources in construction projects as far as its efficiency and conservation are concerned. Literature findings show inefficiency practices misuse and wastage within construction sites. Thus, it was identified there is still a high potential for saving water resources by improving efficient use of water during construction stages.

After identifying the importance of sustainable aspects for efficient water-use in construction projects which is an understudied area in Sri Lanka, the following research questions were formulated from the literature review:

- How is water used and managed during construction?
- What are the water efficiency measures applicable to construction sites?
- What are the potential drivers and barriers that impact on the sustainable use of water during the construction phase of a project?
- What are the sustainable practices that can be adopted for water efficiency and conservation?
- What are the actions that can be recommended to improve sustainable practices for water use during the construction stage of a project?

Figure 2.25 explains the research focus that will be addressed within a built environment by the current research study. Therefore, the current study looks at how these significant measures (discussed in Sections 2.5, 2.6 and 2.7) will be addressed in order to optimise water using activities, processes and practices at construction project level and suggest solutions through best actions.

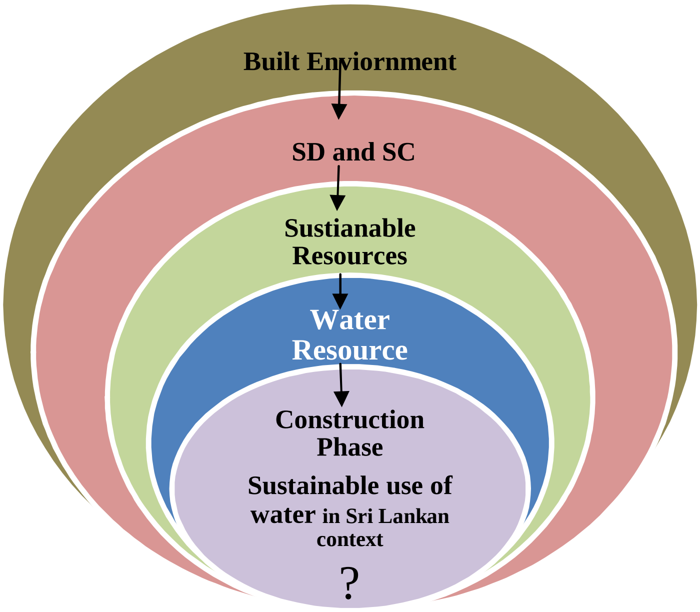


Figure 2.25: Exploration of the Research Focus of the Study

2.13 Chapter Summary

This chapter intended to synthesise the current knowledge gaps of the research area further to the research background discussed in Chapter 1. The chapter discussed the role of water in sustainability, highlighting research findings that exist in water management in the construction industry and provided evidence of research findings of the study area conducted in other countries as well as in Sri Lanka. Furthermore, based on the literature review analysis, the researcher identified water efficiency measures for the sustainable use of water during construction phases. In addition, drivers and barriers were also discussed. Finally, the research gap towards research questions was discussed and research position was presented. The next chapter will discuss the development of a conceptual framework based on the theoretical background of the research.

CHAPTER THREE

3 CONCEPTUAL FRAMEWORK

3.1 Introduction

This chapter discusses the process adopted for the development of a conceptual framework that will guide the next stages of the research study. The conceptual framework illustrates the coherent set of ideas or main areas that need to be considered during the progress of the study, their relationships and the boundaries that are applicable. This is a challenging step in a research process. Subsequent sections elaborate the importance of developing the conceptual framework, key factors extracted from the literature, and a coherent set of ideas found from preliminary interviews on the existing gaps in water efficient practices in construction, finally developing a conceptual framework for the study towards achieving the research goal.

3.2 Importance of Developing a Conceptual Framework

Having the connectivity amongst all aspects of a research at the beginning itself is one of the key characteristics of a good research. Therefore, the term 'conceptual framework' is found in many scholarly works. According to Miles and Huberman (1994, p18), a conceptual framework explains either graphically, or in narrative form, the main things to be studied - the key factors, concepts or variables and the presumed relationships among them. Jabareen (2009, p.51) defines a conceptual framework as a network, or a plane of interlinked concepts that together provides a comprehensive understanding of a phenomenon or phenomena. He recommends the term 'concepts' rather than the terms 'variables' or 'factors'. Moreover, the same author specifies that conceptual frameworks possess ontological, epistemological, and methodological assumptions, and that each concept within a conceptual framework plays an ontological or epistemological role. Ontological assumptions relate to the nature of reality and epistemological assumptions to how researcher knows about the reality, i.e., the relationship between the researcher and that being researched (Cresswell, 2009) (refer to Section 4.4). Methodological assumptions relate to the process of building the conceptual framework and assessing what it can tell us about the "real" world (Jabareen, 2009).

Vaughan (2008) explains that conceptual frameworks are useful in many aspects in that they can:

- move beyond descriptions of "what" to explanations of "why" and "how",
- can define and make sense of the data that flows from the research question,
- be a filtering tool for selecting appropriate research questions and data collection methods,
- be a reference point for the discussion of the literature, methodology and results, and
- provide boundaries of the work.

In addition, Jabareen (2009) identifies the following as the purposes of a conceptual framework.

- to clarify concepts and propose relationships among concepts in a study
- to encourage development of theory that is useful for practicing
- to explain observations
- to provide a context for interpreting study findings
- to make research findings meaningful and generalized

Considering all of the aspects discussed above, a conceptual framework was developed as shown in Figure 3.1 before commencing empirical data collection based on the coherent set of findings obtained from the comprehensive literature review and preliminary interviews. It illustrates the most relevant factors extracted from the literature review. As Yin (2009) has pointed out, the conceptual framework of a study illustrates the concepts, how they are interrelated and the boundary within which the concepts and their interrelationships are applicable.

3.3 Key Areas Identified through the Literature Review and Preliminary Interviews

3.3.1 Water Usage and Water Wastage in Construction Projects

There is currently very limited information on the proportion of water used activities and processes in construction projects. Chapter 2 discussed key water using processes in construction projects and activities where water is wasted in construction projects (refer to Section 2.5.3.2). UK Contractors Group (UKCG), a member organization of the Strategic Forum for Construction, states that a prerequisite for understanding how to reduce water usage in construction projects is to have a clear understanding of where water is used, how much of it is used, where it is being wasted, and what behaviours and/or technologies can be introduced to successfully reduce water wastage (Waylen, et al., 2011).

3.3.2 Water Efficiency Measures (WEMs)

As discussed in Section 2.3 of Chapter 2, successful water management considers both technical and human related aspects of water use. The background study showed that access to non-conventional sources, increased efficiency in water use, and behavioural changes in users (Carragher, Stewart, & Beal 2012; Fielding, et al. 2012; Russel & Fielding, 2010) can have a impact on water demand management which is the most cost-effective solution for saving water. As indicated in Section 2.7, certain overlaps exist with techniques, technologies and strategies discussed in the literature and the study adopted the key term 'Water Efficiency Measures (WEMs)' to discuss the available techniques and strategies. WEMs that are specific to the construction sector have been discussed extensively in the literature presented in Section 2.8 of Chapter 2.

The third objective of the study was to investigate the water efficiency measures that are applicable for construction projects. By considering characteristics and definitions identified by many scholars and organizations in respect of water related activities, measures on Water Efficiency (WE) extracted from the literature review and preliminary interviews were grouped into four categories, namely (i) Policies and Planning (PP) (Houser & Pruess, 2009; McComak, et al., 2007) which could be used by site management, (ii) Attitudes and Behavior (AB) (McNab et al., 2011, Waylen et al., 2011; Eddy, 1996) of workers and staff, (iii) Alternative Construction (AC) methods (Bourge, 2010) that use less water and (iv) Efficient Technologies (ET) (Bourge, 2010; McNab er al., 2011) in the form of fittings, fixtures, equipment, etc., used during construction. Therefore, through a wider literature review encompassing measures used in the relevant operational stages as well as measures used in other industries, and findings of preliminary interviews (refer to Section 4.3.3), thirty one (31) Water Efficiency Measures (WEMs) related to construction were identified in all four groups as having potential to be included in the empirical survey. They are summarised in Tables 3.1, 3.2, 3.3 and 3.4 respectively.

With regard to energy efficiency measures, the researchers have discussed soft and hard measures (Suvilehto, Rouhiainen, Honkasalo, Sarvaranta, & Solid, 2012). It is said that soft measures are aimed at enhancing a change in the customer behaviour so that awareness, knowledge, habits, attitudes, values, choices, etc., lead to energy savings. As stated by Mabin (2009), soft measures increase the awareness and even change the behaviour of customers when it comes to heating, lighting and even water use. Ali and Nsairat, (2009) state that the use of innovative new materials, technologies and designs optimizes energy usage in buildings and that they are considered as hard measures. They go on to say that the use of a combination of hard and soft measures reduces water demand. Accordingly, the first two groups, i.e., PP and AB are rather 'soft' measures and the latter is more technologically oriented and 'hard' in nature, i.e., AC and ET.

Table 3.1 summarizes ten (10) water efficiency measures extracted from the literature review, which are related to policies and planning of the construction stage of a project. Preliminary interviewees accepted almost all of the measures and suggested to combine all environmental polices together rather than inserting each as a separate measure in the questionnaire survey. It is indicated in bold in Table 3.1. According to the characteristics of soft and hard measures discussed above, there are many soft measures related to policy and planning that could be used to improve efficient water use in construction sites.

Table 3.1: WEMs Related to Policies and Planning (PP)

Measures for Policies & Planning	Sources of Reference
Develop a builder's guidebook for reference	Crawford and Pullen (2011); McComack et al. (2007); McNab et al. (2011); Houser and Pruess (2009); Sala et al. (2013); Utraja (2010),
Implement environmental policies on natural resources (EMS, LEED, Green[SL], BREAM, ISO 14001)	Environmental Agency (2007), Roy and Gupta (2008), Zhang, Platten, and Shen (2011)
Implement a licensed water abstraction system (surface water/ tube well)	Bribián, Capilla, and Usón (2011), McNab et al. (2011)
Increase the unit rate for water	Horne (2012) ; Joyce (2012) ; Juan et al. (2010);Savenije & Van der Zaag (2002)
Integrate water efficient techniques during pre-design and tender stages	Australian industry group (2006); McNab et al. (2011); Waylen et al. (2011)
Introduce a water action plan at the inception	Australian industry group (2006) ;McNab et al. (2011); Waylen et al. (2011)
Implement rainwater collection and reuse	Juan et al. (2010); Bourg (2010); Azhar, Carlton, Olsen, and Ahmad (2011); McNab et al. (2011)
Introduce sub-metering systems	McNab et al. (2011); Waylen et al. (2011)
Implement water auditing	McNab et al. (2011); Waylen et al. (2011)
Introduce water leak detection monitoring systems	Environmental Agency (2007); Juan et al. (2010); McNab et al. (2011); Tam & Lee (2007)

According to the Strategic Forum for Construction Water Subgroup, changing the attitude and the behaviour of workers is the key to better efficient water use (Waylen et al. 2011). As mentioned above, Russel and Fielding (2010), Carragher et al. (2012) and Fielding et al. (2012) also identify that the behavioural change of users has an impact on water conservation practices. Monitoring and targeting of water use are probably the first steps in implementing a water efficiency program in a construction project. The four (04) soft measures related to encouraging the pro-environmental behaviour in construction workers obtained through the review of literature have been included in Table 3.2. No changes were done to the existing measures during the preliminary survey. All measures were accepted as soft measures.

Table 3.2 - WEMs related to Attitudes and Behaviours

Measures for Attitudes and Behaviours	Sources of Reference
Assign responsibility and targets to site staff	Liu and Ping (2012); McNab et al. (2011); Shen et al. (2007); Tam & Lee (2007)
Introduce a penalty for unsustainable practices of site staff	McNab et al. (2011); Waylen et al. (2011)
Improve monitoring and supervision	Liu and Ping (2012); McNab et al. (2011); Waylen et al. (2011);
Increase water awareness among workers	Australian industry group (2006); McNab et al. (2011)

As discussed above, under hard measures, the selection of less water intensive construction technologies is an effective way to conserve water during construction. The seven (07) measures considered under alternative construction methods mainly refer to the substitution of construction work with less water-intensive technologies combining the findings of literature review and preliminary interviews. These measures are presented in Table 3.3. While accepting all measures, a new measure, i.e., pre-mixed concrete and pre-mixed mortar, was revealed from preliminary findings and it is indicated in bold in Table 3.3.

Table 3.3: WEMs Related to Alternative Construction Methods

Measures for Alternative Construction Methods	Sources of Reference
Introduce curing agents	Utraja (2010)
Introduce dry wall partitions instead of brick and block walls	Ramachandran (2014)
Implement closed loop systems	Australian industry group (2006); Bourg (2010); Juan et al. (2010); Tam & Lee (2007); Waylen et al. (2011); Zhang et al. (2011)
Use admixtures /chemical additives	Utraja (2010)
Use pre-cast or prefabricated construction methods	Ramachandran (2014); Utraja (2010)
Use pre-mixed concrete and pre-mixed mortar	**Preliminary interviews**
Use steel intensive construction methods	Ilgar (2011); Ramachandran (2014)

The final group ‘efficient technologies’ covers potential operational level measures that could be used to reduce water use in construction activities as well as by workers for general use and sanitation. Based on some of the comments received during the preliminary survey, several factors were grouped together and finally ten (10) measures as shown in Table 3.4 were identified, which are hard in nature and related to efficient technologies identified through the literature review.

Table 3.4: WEMs Related to Efficient Technologies

Measures for Efficient Technologies	Sources of Reference
Dust suppression vehicles with sprinklers	McNab et al. (2011); Waylen et al. (2011)
Efficient showers : Low-flow showerheads	Bourg (2010); Liu and Ping (2012); McNab et al. (2011); Waylen et al. (2011)
Fan misting systems for dust suppression	McNab et al. (2011)
High pressure trigger operated spray gun hoses	Australian industry group (2006); McNab et al. (2011); Waylen et al. (20110
Low flush cisterns/urinals/waterless urinals	Bourg (2010); Juan et al. (2010); Liu and Ping (2012); Lockwood (2006); Singapore's National Water Agency (2008)
Pressure reducing valves	Bourg (2010); McNab et al. (2011); Waylen et al. (2011)
Sprinkler systems for curing concrete	McNab et al. (2011)
Vacuum toilets	Bourg (2010); McNab et al. (2011)
Washing bays for wheel washing	McNab et al. (2011)
Water efficient taps	Arab Forum for Environment and Development (2010); Azhar, et al. (2011); Bourg (2010); Environmental Agency (2007); Juan et al. (2010); Liu and Ping (2012)

While there are many technologies available, their cost is a main concern (Tam & Lee 2007; Zhang et al. 2011). If the introduction of WEMs is to be successful, their rationale and processes need to be well understood and accepted by all workers of a construction site. The research method adopted for the study was validated through preliminary interviews. Therefore, the application and the applicability of all these measures to the construction industry in Sri Lanka were tested in this study through a case study and a questionnaire survey (refer Chapters 5 and 6 respectively).

3.3.3 Drivers for Efficient Use of Water during the Construction Stage

The fourth objective of the study was to determine relevant drivers, barriers and other attributes of sustainable water use practices in construction projects. This section discusses the key areas identified through literature review and preliminary interviews on the drivers that impact on efficient water use on construction sites.

As stated by the preliminary interviewees, the experience and commitment to sustainable use of water through appropriate policies and investments, and research and development conducted on the subject will lead to a more water secure world. Table 3.5 shows drivers that were identified through the literature review and validated through preliminary interviews as having an impact on water efficiency practices during construction stages.

Table 3.5: Drivers that Impact on Water Efficiency

Drivers	Sources of Reference
Attitudes and behaviour of site staff	Brown, Blofeld, Hadi,and Hamilton, (2014); McNab et al. (2011); Robinson, Adeyeye, Madgwick, and Church (2014)
Cost of water	Goodrum (2008); Horne (2012) ; Joyce (2012)
Experience and commitment	**Preliminary interviews**
Policies and regulations	Bourg (2010) ; Chen and Wong, (2000); Devaraja, (2013); Houser and Pruess, (2009); Loowood (2006); Luan (2010); Rosegrant et al.(2002)
Project specific documents	Road and Traffic Authority in Australia (2007)
Quality of water	Ramachandran (2014); Utraja (2010); Zbigniew and Kundzewicz (1997);
Responsibility	Bourg (2010)
Research and development	Houser and Pruess (2009); Sala et al. (2013)
Sustainability rating systems	Ali and Nsairat Al (2009) ; Fawcett (2012); Fowler and Rauch (2006); Shen et al. (2007);Walton et al. (2005); Xing et al. (2007)
Water quantity	Goodrum (2008); McComack et al. (2007); Zbigniew and Kundzewicz (1997)
Water source	Robert et al. (2006); Waylen et al. (2011)

3.3.4 Barriers for Implementing Water Efficient Practices

Section 2.11 of Chapter 2 also discussed certain barriers identified by many scholars for implementing water efficient practices. Table 3.6 illustrates common barriers or hindrances in implementing water efficient practices in construction sites as extracted from the literature review.

Table 3.6: Barriers for Implementing Water Efficiency in Construction Sites

Barriers	Source of References
Absence of water efficiency techniques and strategies during pre-design and construction stages	Australian Industry Group (2006); McNab et al. (2011)
Cost	Goodrum (2008); Tam & Lee, (2007); Savenjije and Van der Zaag (2002); Zhang et al. (2011)
Water management receiving low project priority	Houser and Pruess (2009); Sala et al. (2013)
Value of water not apparent	Eroksuz and Rahman, (2010); Guggemos and Horvath (2006)
Lack of awareness of new techniques	Guggemos and Horvath (2006)
Resistance to change from conventional methods	Ilgar (2011); Kibert (1994) ;Waylen et al. (2011)

3.3.5 Water Hierarchy and 'R' Principle

Water hierarchy is another area that supports efficient water use. This study is based on the well accepted water hierarchy of the Strategic Forum for Construction (SFfC) which consists of six (06) steps, namely the elimination of potable water, use of alternative sources, reducing , reusing, recycling and disposal (refer to Section 2.6). As discussed in Section 2.6 of Chapter 2, 3R (Reduce, Reuse, Recycle), 5R (Reduce Consumption, Reduce Loss and Waste, Re-use Water, Recycle Water and Resort to alternative sources), and another 5R (Rectify Leaks, Review, Reduce, Re-use, Recycle) and 7R (Reduce, Reuse, Recycle, Renewable, Rectify, Rules and Regulations, Reward) were introduced for water conservation during building operations.

Based on literature review and preliminary interview findings, this study proposes R principles for the water hierarchy steps that has been already identified for the construction industry by SFfC. Definitions adopted in this study for each step of the hierarchy applicable for the construction industry are presented in Table 3.7 with the proposed R concept.

Table 3.7: Steps of Water Hierarchy with the Proposed 'R' Principle

No	Existing Term	Proposed Term with the R	Definitions Adopted for the Purpose of the Study
01	Eliminate use	**R**eview	Check whether the process or activity really requires potable water.
02	Alternative non-potable water source	**R**eplace	Find cost effective alternatives to potable water.
03	Reduce	**R**educe	Explore options to improve water efficiency, basically, applying water efficient technologies, techniques, and strategies
04	Reuse	**R**euse	Water reused elsewhere without being treated (as it is)
05	Recycle	**R**ecycle	Water recycled for reuse elsewhere during construction
06	Disposal	**R**emoval	Disposal of used or excess water legally and responsibly to ensure that there is no flooding, pollution or inconvenience to others.

Cole (2005), Holmes and Hudson (2000) and Pahwa (2007) identify the necessity for conditions or regulations that will protect natural resources from environmental impacts of construction. As Byrne (2011) explains, in water consumption the 'fit for purpose" approach should be adopted using potable water for all purposes. As discussed in the background study and the findings of literature, many researchers identify the need for formulating new policies and reviewing the existing policies (Houser and Pruess, 2009; McComack, et al. 2007; Rosegrant, et al. 2002). The study conducted by Houser and Pruess (2009) justifies that if construction projects utilize appropriate best management practices, there will be a minimal impact on the overall water quality of the surrounding water bodies. Tam and Lee (2007) suggest that it is necessary to encourage and educate staff on monitoring water usage, water reusing and recycling systems, and the use of wastewater treatment during construction. This is the responsibility of the top management. Inappropriate incentives and reform of institutions often hinder the effective use of water during construction (Houser & Pruess, 2009; Sala, et al. 2013). This simply explains the importance of rewards and incentives for water efficiency practices and this was discussed by preliminary interviewees as well. Similarly, Cooley, Christian-Smith, and Gleick (2008) identify incentives as a mechanism to promote water conservation and efficiency.

Therefore, in addition to the steps of 6R (refer Table 3.7) of the water hierarchy, literature and the preliminary interviews support to identify 3 new R principles, which will impact on the sustainable use of water during the construction phase. These are Regulation, Responsibility and Reward. Table 3.8 presents the new 3R and definitions adopted in this study.

Table 3.8: New Three (03) R Sustainability Principles for Water Efficiency

New 3 Rs	Definition Adopted
Regulation	Adhere to project and environmental specific rules and norms during water consumption
Reward	Remuneration for positive attempts at reducing water consumption and innovative ideas
Responsibility	Actions towards environmental & social conservation and preservation of natural resources

As stated by Waylen et al. (2011), all these sustainability concepts depend on user behaviours and attitudes. Furthermore, Sala et al. (2013) mention that human consumption and their behaviour greatly impact on sustainable consumption styles and environmental consequences. The application and applicability of each R will be investigated through case studies and a questionnaire survey (refer Chapters 5 and 6).

3.4 Development of the Conceptual Framework

3.4.1 Process Adopted for the Development of the Conceptual Framework

As discussed in Section 3.2, a conceptual framework helps to summarize the existing knowledge into coherent systems and stimulate new research by providing both direction and impetus. It is clear that in order to create a conceptual framework, imagination and congruence with reality and existing knowledge are required. Furthermore, Vaughan (2008) mentions that the identification of key words or concepts used in the area of study would be the first step when developing a conceptual framework (Section 3.2). Concepts are placed within a logical and sequential design (Jabbareen, 2009). Then the content and the inter-relationships of each within the study boundary will be focused on.

Therefore, the development of the conceptual framework comprises of the following three (03) main components:

- Identification of key concepts,
- Identification of the relationship among concepts, and
- Identification of the study scope or boundary.

3.4.2 Key Concepts

The study mainly focused on efficient water use during construction stages. It is evident in Chapter 2 that water management in the construction industry is significant but that however it is perceived in the construction industry as a low priority area which does not require much incentives. Therefore, there is a need to implement water efficiency practices during construction stages as discussed in detail in Section 1.3.2 of Chapter 1. Thus, by conducting a thorough literature review, the study identified significant water usage activities and wasteful activities in construction stages. Furthermore, the literature presented a well accepted water hierarchy and water efficiency measures available for the efficient management of construction water, drivers that impact on water efficiency during construction stages and barriers that hinder efficient water use. Findings of the preliminary interviews further validated the key findings of the literature review and the survey guidelines that were used for the study towards achieving the research aim and objectives (refer to Section 4.3.3).

3.4.3 Relationship Among the Concepts

Having identified the key concepts from the literature review, the next step of the development of the conceptual framework is to identify the relationships among the concepts. These key concepts are drivers, barriers, water efficiency measures (WEMs), the six (06) steps of water hierarchy, i.e. 6R and new 3R principles that impact on efficient water use in the construction industry. Thus, this research examines how the above concepts can help to reduce water wastage activities and enhance sustainable use of water during the construction phase.

3.4.4 Scope of the Study

This section explains the scope of the study or boundary of the concepts and their interrelationships. Many studies are available on efficient use of water during the operational stages of a building. McComack, et al. (2007) state that while an enormous amount of water is used to operate buildings, a considerable amount is also used for extraction, production, manufacturing and delivery of materials to the site and for the actual on-site construction process. However, the Strategic Forum for Construction (SFfC) in the United Kingdom states that relatively little research has been carried out on water sustainability in construction sites (Waylen, et al. 2011). Therefore, water is one of the less acknowledged resources in construction projects although it is used in almost all of their activities.

This study is limited to the efficient use of water during construction life cycles of building projects which include pre-work, execution, and demobilization. As stated by Matar et al. (2008), pre-work covers site mobilization, mobilization of facilities, provision of construction utilities, submission of project documents, obtaining of permits/licenses, establishment of safety and quality programs, establishment of security and the development of materials management plan and execution strategy. By incorporating the main concepts as discussed in Section 3.4.2, their interrelationships as discussed in Section 3.4.3 and the scope of the study (refer to Section 3.4.4), the conceptual framework pertaining to this study was developed.

3.4.5 Conceptual Framework

Figure 3.1 shows the conceptual framework developed, which indicate the theoretical background of the research required to test empirical data. The core of the framework represents water usage and water wastage activities/processes. The framework indicates how the drivers, WEMs and Nine (09) R principles will help to reduce water wastage activities and enhance sustainable use of water in construction projects by removing barriers.

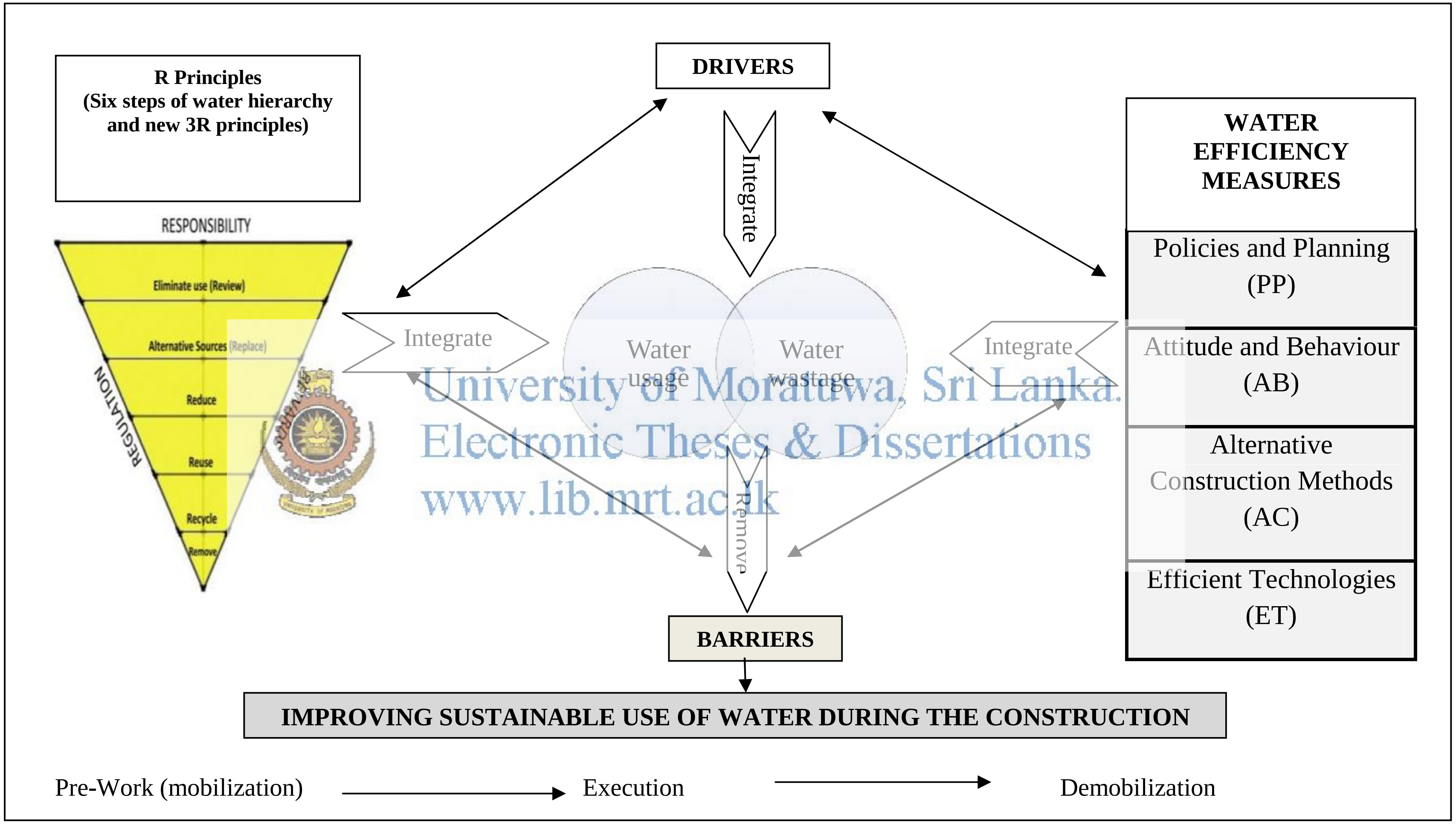


Figure 3.1: Conceptual Framework

3.5 Chapter Summary

The chapter discussed the process of developing a conceptual framework analysing research gaps of the study in order to collect empirical data. The process of forming basic ideas, designs, plans or strategies was based on available facts, and situations. Components of the conceptual framework were taken from the literature review and preliminary interviews. The conceptual framework developed illustrates the relationships among different concepts and how sustainable actions could be formulated to enhance an efficient water use culture within the construction industry. Having devised the conceptual framework, the next step of the study would be to present the research design.

CHAPTER FOUR

4 RESEARCH METHODOLOGY

4.1 Introduction

A research methodology in essence, describes the processes followed to answer research questions towards achieving the aim of a research. Therefore, this chapter describes the research methodological framework used to achieve the research objectives of this study. Firstly, the chapter rationalises the research problem through the initial impetus of the researcher, a literature review and preliminary interviews. The key elements of the research process such as research philosophy, research approach, research strategies, data collection methods, analysis techniques and the validation of research findings are then presented. Finally, the chapter discusses each element in general, followed by the adopted research methodology for the current study based on the researcher's understanding of the research questions and research position.

4.2 Formulating the Research Problem Leading to the Research

As Uyangoda (2010) expounds, the research problem is the centre of gravity of a research. According to Cresswell (2009), a research problem can originate from many potential sources. It might be a personal experience at home or at workplaces, an extensive debate in the literature or policy debates of the government or those among top executives. The research problem of this study was derived from the researcher's interest, findings of a literature review and preliminary interviews with experienced professionals in the construction industry, which highlighted the lack of empirical evidence in the study area (refer to Table 2.5) confirming the need for a research in the area of water use efficiency. Following sub-sections discuss how the above aspects contributed to the establishment of the research problem leading to the research study.

4.2.1 Initial Impetus of the Researcher

The researcher's interest is one of the important inputs to be considered when initiating a research study (Gill & Johnson, 2002; Remenyi, Williams, Money, &

Swartz, 1998; Saunders, et al., 2009). In addition to the researcher's interest, accessibility (e.g., literature, research data), time availability, importance of the potential outcome, financial support and the value and scope of the research area are other important aspects to be considered in deciding on a research topic (Gill & Johnson, 2002). As Uyangoda (2010) explains, research is not 'neutral' but reflects a range of the researcher's personal interests, values, abilities, assumptions, aims and ambitions.

The initial input to this research study came from the researcher's interest in the sustainability area, which appears to be one of the dominant research trends in the construction industry. Although water resource is a sustainable parameter, in comparison with other sustainable parameters such as energy, materials and construction waste, there is not much past research work available on this particular aspect of sustainability especially in the construction sector. However, many researchers have predicted that water will be a critical global resource during the period 2025-2030 and that therefore there is a requirement for sustainable arrangements (Economist, 2008; Samad, 2005). Being a limited resource, fresh water is a valuable resource and it is vital to seek sustainable practices towards ensuring efficient water use in the construction industry which requires water for all its activities

4.2.2 Input from the Literature Review

According to Tranfield, Denyer, and Smart (2003), there are at least two (02) major steps and purposes for reviewing a literature. The first step is the preliminary literature search that helps the researcher to generate broad research ideas. The second step is often referred to as the critical literature review, which helps to narrow down and refine broad research ideas to a workable research problem and attainable research objectives. As Uyangoda (2010, p. 63) mentions, literature review is a critical assessment by the researcher of the existing body of knowledge on the theme or problem under investigation. Moreover, Uyangoda (2010) explains following four (04) reasons as the benefits that a researcher can gain from a comprehensive literature review:

- It enables the researcher to identify important gaps in the existing body of knowledge;
- It enables the researcher to make sure that the proposed research is a fresh contribution to the existing body of knowledge;
- Researcher can demonstrate the most contemporary scholarly literature relevant to the theme of the research project; and
- Researcher can refine his/her own research problem, research questions, and methods from insights gathered from existing scholarly literature.

According to Figure 4.1, a literature review process contains three (03) important activities, viz., searching, reading and writing (Ridley, 2008). It is necessary to carry out these three (03) activities throughout a research study (Saunders, et al., 2009).

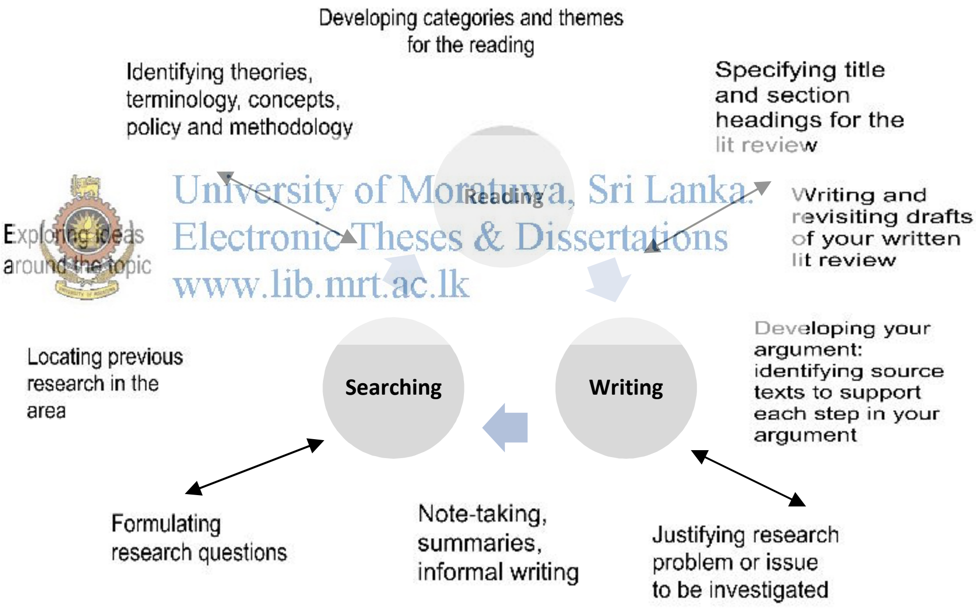


Figure 4.1: Literature Review Process

Source: Adapted from Ridley (2008, p.81)

Furthermore, Ridley (2008) states that reviewing is more than just reading. Figure 4.2 demonstrates that the process of literature review involves aspects such as appraisal, analysis, evaluation, comparison and selection.

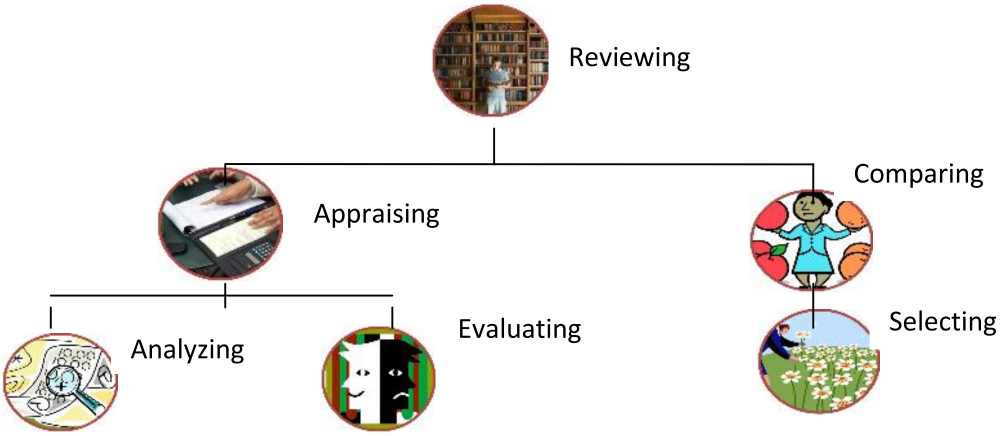


Figure 4.2: Reviewing Process of Literature Resources

Source: Adapted from Ridley (2008)

The preliminary literature review of journal articles, books, web sites, conference publications, newspapers and institutional reports was of immense use in refining and narrowing down the study area while identifying certain important research gaps on water management in the construction industry (refer to Table 2.5). The next step of the researcher was to carry out a more specific literature review on water efficiency and conservation strategies and techniques, sustainability practices, drivers, and barriers in relation to water management practices during the construction stage (refer Chapter 2). Having carried out a critical literature review on the above mentioned aspects, the researcher was able to establish the research problem, the aim and the objectives of the study and develop the initial conceptual framework (refer to Figure 3.1).The next section describes the input of preliminary interviews that contributed to achieving the refined research aim and objectives.

4.2.3 Input from Preliminary Interviews

The findings of the literature review show that there is little research with empirical evidence on water management practices in the construction industry and that the real value of same at present are the key shortcomings of the water sector in Sri Lanka. Thus, the researcher conducted four preliminary interviews to obtain opinions from experienced professionals in the construction industry in Sri Lanka. The selected persons had more than 20 years of working experience in building construction and were responsible in their respective organizations for the environmental management and sustainable construction aspects of their respective sites. The preliminary interviews primarily aimed at refining the initially established research problem and thereafter the research aim and the objectives (refer to Section 4.2.4). Furthermore, the preliminary interviews were aimed at getting critical views on the key research areas identified through the literature and a review of the key area findings in the survey instrument guides developed integrating the conceptual framework (refer to Figure 3.1).

Research gaps identified through the literature review that were not sufficiently articulated in the literature were further confirmed by the findings of the preliminary interviews (refer to Chapter 3). All of the interviewees agreed that the value of water is sufficiently considered and acknowledged by most of the stakeholders in the construction sector. The interviewees also highlighted that negative environmental impacts on water resources caused by construction activities are currently ignored. One of the interviewees explained ground water contamination and catchment area disturbances as two such impacts that are caused by the use of pressure grouting in sub-structures and piling in mega scale vertical developments that have limited land space. Moreover, interviewees collectively emphasised on the importance and necessity of having a set of clear organisational policies, rules and regulations, not only to control or minimise these issues to a certain extent but also to implement mandatory water management practices. In addition to this, suggestions were made on the survey instrument guides developed during preliminary interviews and these are discussed in Section 4.8 .2.1.

4.2.4 Research Problem

Having identified the importance of sustainable aspects of efficient water use in construction projects in Sri Lanka, the researcher finally formulated the research problem to be “How to improve sustainable use of water in construction projects?”

The aim of the study will therefore be to develop a framework for improving sustainable use of water in construction projects.

Research questions are organising elements for the topic under study. It directs the investigation into narrow topic areas and guides every aspect of the research project. Miles and Huberman (1994) state that formulating research questions are iterative processes that need to be initiated with general questions that a researcher is in touch with either through experience or literature. To achieve a greater focus for the study, the researcher established several research questions as shown below:

- How is water used and managed during construction?
- What are the water efficiency measures applicable to construction sites?
- What are the potential drivers and barriers that impact on the sustainable use of water during the construction phase of a project?
- What are the sustainable practices that can be adopted for water efficiency?
- What are the measures that can be recommended to improve sustainable water use during the construction stage of a project?

Research questions generate a base to develop a set of research objectives in order to find a solution for the research aim mentioned above. The following objectives are formulated from the above mentioned research questions to support preliminary findings:

- Review of principles and practices of sustainable use of water in construction projects
- Evaluate water use practices of construction projects in Sri Lanka
- Investigate the most applicable Water Efficiency Measures (WEMs) for construction projects
- Determine relevant drivers, barriers and other attributes for efficient water use practices in construction projects
- Develop a framework for improving sustainable use of water in construction projects

The next section describes how the research methodology was designed to cater to the established research aim. Chaudhry (1991) states that the methodology of research can be used as the basis for making knowledgeable decisions in a systematic manner to achieve the research aim and objectives. As Fellow and Liu (2003) state, the methodology of research is governed by principles and procedures of logical thought processes that can be applied to a scientific investigation. According to Kumar (2011), the basic logic of scientific methodology is same in all fields although its specific techniques and approaches will vary depending upon the subject matter. The following section discusses the research methodological design of this study.

4.3 Research Design

Tan (2002) explains that in a systematic research it is necessary to follow a research process containing a series of steps such as the formulation of research problem, determination of research design, selection of the data collection method, data analysis and conclusions. The research design guides the investigator in collecting, analyzing, and interpreting observations. Apart from that, the checking of the validity of findings is also an important step in a research process. There are hierarchical models that discuss philosophical aspects of a research project (Kagioglu, et al. 2000; Saunders, et al. 2009). The research "onion" presented by Saunders et al. (2009) shown in Figure 4.3 provides guidelines to select the most suitable research methodology for this research.

As can be seen in Figure 4.3, the 'Research Onion' consists of different layers that indicate the key aspects needed to be investigated into when deciding on an appropriate methodology. To select the most appropriate research methodological design, it is important to understand the philosophical underpinning of the research. This is the outer layer of the research onion. Other layers constitute of research approaches, research strategies, choices, time horizons and data collection, and data analysis in the order given.

The sections that follow describe in detail the research philosophy, research approaches, research strategies, choice of methods, time horizons and techniques and procedures adopted in the study for achieving the aim and objectives.

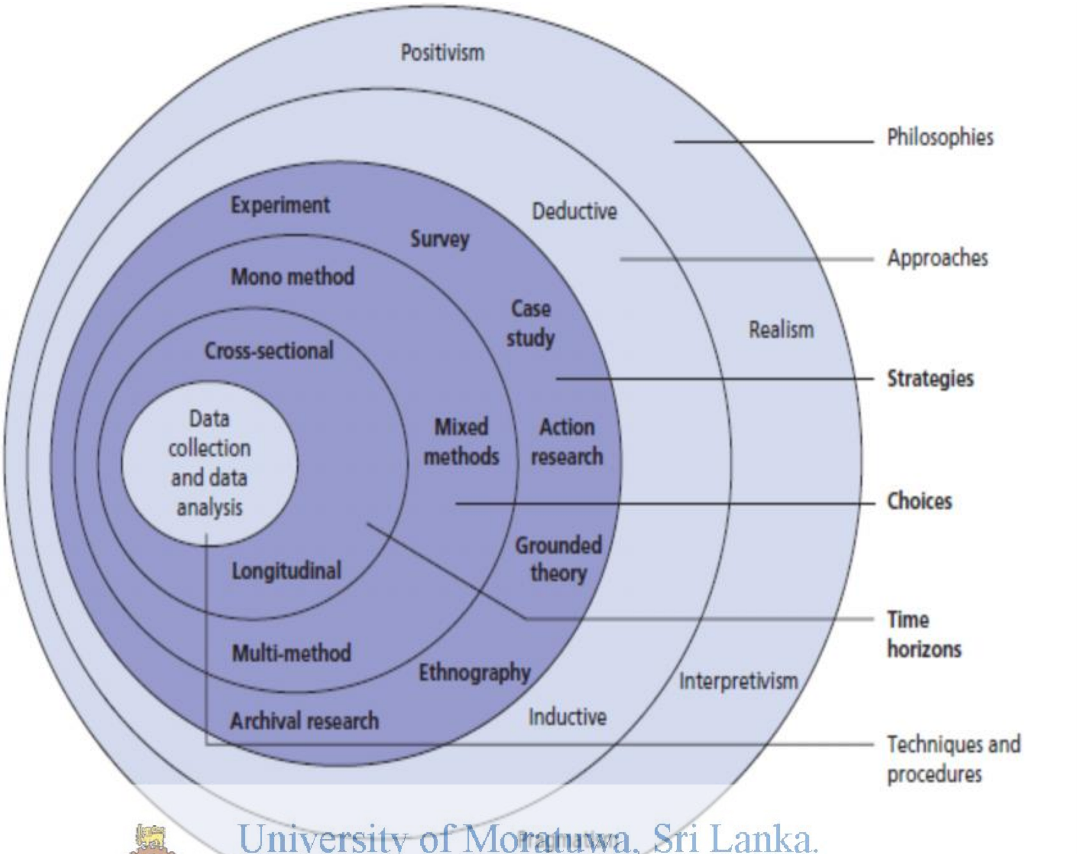


Figure 4.3: Research Onion

Source: Saunders et al. (2009)

4.4 Research Philosophy

4.4.1 Understanding Research Philosophical Positions

A good research will reflect qualities that are systematic, organised, critical, and analytical and will have the ability to communicate findings effectively (Sekaran, 2003). According to Esterby-Smith (2002), research philosophies help a researcher to clarify the research design, identify a suitable research design and create a research design outside past experience. A research philosophy will contain assumptions about how the researcher views the world and reality (Saunders, et al. 2009).These assumptions underpin research strategy and methods that are chosen as part of that strategy. As Johnson and Duberley (2006) state, management researchers need to be aware of philosophical commitments when choosing the research strategy since it can significantly impact on what is being really investigated into.

Williams and May (1996, p55) state that research philosophy is concerned about the kind of things that exist in the world and our beliefs towards them. According to Holden and Lynch (2000), the two extreme ends of philosophical positions are labelled variously in the literature. For example, Esterby-Smith et al. (1991) mention positivism and phenomenology as the two extreme ends of philosophical positions. Amaratunga, Baldry, Sarshar and Newton (2002) explain positivity as a quantitative paradigm and phenomenology as a qualitative paradigm. Hughes and Sharrock (1997) describe them as positivism and interpretivism. Levin (cited Kura 2012) states positivists believe that the reality is steady and that it can be observed and described from an objective viewpoint whereas interpretivists argue that only through subjective interpretation of and intervention in reality that reality can be understood. The author is of the view that the study of phenomena in their natural environment is the key to the interpretivist philosophy. Hussey and Hussey (1997) define the extreme two ends as objectivism and subjectivism. Saunders et al. (2009, p.129) state that objectivism holds the position that social entities exist in reality external to social actors whereas the subjectivist view is that social phenomena are created from perceptions and consequent actions of social actors.

Saunders et al. (2009) in their review on research paradigms note that many researchers identify between the two extreme end paradigms, while considering other philosophies as pragmatism and realism. Several other authors also agree that both pragmatism and realism do not belong to either the positivist or the interpretivist philosophical positions (Creswell, 2009; Teddlie & Tashakkori, 2009; Mackenzie & Knipe, 2006). Saunders, et al. (2009, p. 598) argue that in pragmatism, the most important determinant of the research philosophy adopted is the research question, arguing that it is possible to work within both positivist and interpretive positions. As many researchers state, pragmatism places greater emphasis on methods and attitudes than on a systematic philosophical doctrine (Creswell, 2009; Saunders, et al. 2009; Teddlie & Tashakkori, 2009). According to basic beliefs in the realism paradigm, the world is socially constructed and subjective (Amaratunga, et al. 2000). Saunders et al. (2009, p.129) mention that the essence of realism is what the senses show us as reality or the truth and that objects have an existence independent of the human mind.

Differences between philosophical positions are mainly based on the characteristics of ontological, epistemological and axiology assumptions (Saunders, et al. 2009). As stated by Holden and Lynch (2000), these assumptions are logical and consequential to each other. Table 4.1 provides concise notes on ontology, epistemology and axiology assumptions.

Table 4.1: Summary of Philosophical Assumptions

Philosophical Assumptions	**What Expects (Question)**	**Keyword**
Ontology	What is the nature of reality?	Reality
Epistemology	What is the relationship between the researcher and that being researched?	Knowledge
Axiology	What researcher values go in to? What is the role of value?	Value

Source: Adapted from Creswell (2009); Suanders et al. (2009)

Table 4.2 summarises the characteristics of the main research philosophical positions (i.e. positivism, realism, pragmatism, and interpretivism) according to philosophical assumptions (i.e., ontology, epistemology and axiology) as discussed by Saunders et al. (2009).

Having outlined the commonly noted research philosophies available in the literature, the next section presents the philosophical positions that have been adopted for this particular research study.

Table 4.2: Characteristics of the Main Philosophical Positions According to Philosophical Assumptions

		Philosophical Positions			
		Positivism	**Realism**	**Pragmatism**	**Interpretivism**
Philosophical Assumptions	**Ontology** (the researcher's view of the nature of reality)	External, objective, independent of social actors.	Objective, exists independently of human thoughts and beliefs or knowledge of their existence (realist), but is interpreted through social conditioning.	External, multiple, view chosen to best enable answering of research question(s).	Socially constructed, may change, multiple.
	Epistemology (the researcher's view regarding what constitutes acceptable knowledge)	Only observable phenomena can provide credible data, facts. Focus on causality and law like generalizations, reducing phenomena to simplest elements.	Observable phenomena provide credible data, facts, insufficient data means inaccuracies in sensation (direct realism).	Either or both observable phenomena and subjective meanings can provide acceptable knowledge dependent upon the research question. Focus on practical applied research. Integrating different perspectives to help interpret the data.	Subjective meaning and social phenomena. Focus upon the details of a situation, a reality behind these details, motivating actions.
	Axiology (the researcher's view of the nature of reality or the role of values in research)	Research is undertaken in a value- free way. The researcher is independent of the data and maintains an objective stance.	Research is value laden. The researcher is biased by world views, cultural experiences and upbringing. These will impact on the research.	Values play a large role in interpreting results. The researcher adopting both objective and subjective points of views.	Research is value bound. The researcher is part of what is being researched, cannot be separated and so will be. subjective.

Source: Saunders et al. (2009, p.119)

4.4.2 Philosophical Positions Specific to the Research

As discussed in Section 4.4.1, research philosophies have different beliefs, values, and concepts and they view the social world differently based on their philosophical assumptions. Holden and Lynch (2000) state that the question, 'What to research?' may have a major impact on the methodological choice.

The research problem of this study is how to improve the sustainable use of water in construction projects. Therefore, the aim of this study is to develop a framework for improving sustainable water use practices in construction projects from a Sri Lankan perspective.

The researcher therefore intends to explore how water can be used as a sustainable resource during construction phases and thereby explore means of enhancing the efficient use of water during the construction phases of building projects in Sri Lanka. Therefore, the researcher believes that it is necessary to conduct an in-depth review to identify the current status of efficient water use as highlighted in the literature (including the limited empirical studies done in Sri Lanka on the water efficiency during construction phases). The researcher also believes that in order to obtain stakeholders' perceptions for identifying recommendations for good on-site water efficient practices, it is necessary to be a part of the environment and have the co-operation of experienced professionals and workers who are actually involved in the process. Thus, the researcher perceives that the both objective and subjective points of views are required in order to carry out this research.

As Saunders et al. (2009) identify, pragmatism enables the answering of research questions in terms of epistemology, ontology and axiology positions. Pragmatism allows the researcher to use multiple methods of data collection and analysis techniques and individual researchers have a freedom to choose methods, techniques and procedures of research that best meet their needs and purposes (Creswell, 2009, Saunders, et al. 2009; Teddlie & Tashakkori, 2009).

According to the nature of research questions formulated in the study, multiple approaches which allow to collect both quantitative and qualitative data are required for this research. Therefore, for the current study, the researcher aims at considering research questions without preconditioned views, liberally selecting research methods to find answers to research questions. Thus, pragmatism becomes the most appropriate philosophical paradigm when compared to the two extreme ends (i.e., positivism and interpretivism) when the philosophical assumptions of ontology, epistemology and axiology relevant to pragmatism are considered. Pragmatism applies to mixed method research approach (Creswell, 2009; Saunders, et al. 2009). Having identified the philosophical position of the study, the next section presents a suitable research approach that could be used for the current study.

4.5 Research Approach

4.5.1 Research Approaches in General

The next step of the research methodology process is to understand the research approach. Saunders, et al. (2009) identify two main research approaches as deduction (theory testing) and induction (theory building). Although a clear demarcation could be seen between deduction and induction, Saunders, et al. (2009) argue that it is possible to combine deduction and induction within the same research. Moreover, the authors state that deduction owes more to positivism and induction more to interpretivism. Differences between the two (02) approaches are listed in Table 4.3.

Table 4.3: Differences between Deductive and Inductive Approaches

Deduction emphasizes	Induction emphasizes
Scientific principles	Gaining an understanding of the meanings humans attach to events
Moving from theory to data	A close understanding of the research context
The need to explain causal relationships between variables	The collection of qualitative data
The collection of quantitative data	A more flexible structure to permit changes of research emphasis as the research progresses
The application of control to ensure validity of data	A realization that the researcher is part of the research process
The operationalisation of concepts to ensure clarity of definition	Less concern with the need to generalise
A highly structured approach	
Researcher independence of what is being researched	
The necessity to select samples of sufficient size in order to generalise conclusions	

Source: Saunders et al. (2009)

As depicted in the literature, many scholars categorise research approaches as quantitative, qualitative and a combination of both (Amaratunga, et al. 2002; Creswell, 2009; Mack, Woodsong, Macqueen, Guest, & Namey, 2005; Newman &

Benz, 1998). Below Sections 4.5.1.1, 4.5.1.2 and 4.5.1.3 describe in detail each of the approaches.

4.5.1.1 Qualitative Approach

Qualitative research methods focus on discovering and understanding the experience, perspectives, and thoughts of participants (Creswell, 2009; Wood & Welch, 2010). As stated by Denzin and Lincin (2005), qualitative researchers study things in their natural settings, attempting to make sense of or interpret phenomena in terms of the meanings people attach to them. Qualitative research is usually described as allowing a detailed exploration of a topic of interest in which information is collected by a researcher through research methods such as case studies, ethnographic work and interviews (Creswell, 2009; Lincoln & Guba, 1985). Mack, Woodsong, Macqueen, Guest, and Namey (2005) state that qualitative research involves formulating and building new theories using highly flexible ways of collecting people's perceptions through in-depth interviews, focus groups, and participant observations. Therefore, the qualitative approach is subjective in nature (Amaratunga, et al. 2002) and adopts the philosophical position of interpretivists (Saunders, et al. 2009). Many scholars identify that qualitative research findings contribute to the development of theories (Leedy & Ormrod, 2005; Saunders, et al. 2009). Thus, qualitative research employs a clear inductive approach.

4.5.1.2 Quantitative Approach

Quantitative approach involves collecting numerical data that can be subjected to statistical analysis. The key features of many quantitative studies are the use of instruments such as experiments or surveys to collect data, and reliance on the probability theory to test statistical hypotheses that help to research questions of interest (Bryman, 2007; Creswell, 2009). Quantitative research decides what to study, asks specific and narrow questions, collects quantifiable data from participants (a large number of participants), analyzes these numbers using statistics, and conducts the inquiry in an unbiased and objective manner (Creswell, 2009). Thus, quantitative research employs a clear deductive approach and adopts the philosophical position of positivists (Creswell, 2009; Saunders, et al. 2009).

4.5.1.3 Mixed Method Approach

Although, research approaches are mainly categorised as quantitative and qualitative, many researchers are of the view that there is more insight to be gained from a combination of both qualitative and quantitative research than from either one of them alone (Creswell, 2009).

Table 4.4: Dimensions of Contrast among the Three (03) Methodical Traditions

Dimension of Contrast	Qualitative Position	Mixed Method Position	Quantitative Position
Methods	Qualitative	Mixed method	Quantitative
Researchers	QUALs	Mixed methodologists	QUANs
Paradigms (philosophical stance)	Constructivism (and variants)	Pragmatism; transformative perspective	Post positivism Positivism
Research questions	Qualitative research questions	Mixed method research questions	Quantitative research questions; research hypotheses
Form of data	Typically narrative	Narrative + Numeric	Typically numeric
Purpose of research	(often exploratory) + confirmatory	Confirmatory + exploratory	(Often confirmatory + exploratory)
Role of theory:logic	Grounded theory; inductive logic	Both inductive and deductive logic; Inductive-deductive research cycle	Rooted in conceptual framework or theory, hypothetic – deductive model
Typical studies or designs	Ethnographic research designs or others (case study)	Mixed method designs such as parallel and sequential	Correlation; survey; experimental; quasi experimental
Sampling	Mostly purposive	Probability, purposive and mixed	Mostly probability
Data analysis	Thematic strategies: categorical and contextualizing	Integration of thematic and statistical data conversion	Statistical analysis; descriptive and inferential
Validity/trust worthiness issues	Trustworthiness; credibility; transferability	Inference quality; inference; transferability	Internal validity; external validity

Source: Tashakkori and Teddlie (2009, p.22)

According to Creswell (2009) and Johnson and Onwuegbuzie (2004), the mixed method research is formally defined as the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study to understand the research problem.

As stated by Greene (2007), the mixed method research allows the opportunity to compensate for inherent method weaknesses, capitalise on inherent method strengths, and offset inevitable method biases. Table 4.4 illustrates the key characteristics of each approach based on eleven dimensions identified by Tashakkori and Teddlie (2009, p.22).

4.5.2 Research Approach Used in the Research

As discussed in Section 4.4.2, this study adopted pragmatism philosophical paradigm which allows for the use of a combined approach of qualitative and quantitative methods. Literature shows evidence that little research has been carried out on water use efficiency in construction projects and a few studies have used the qualitative approach to examine water management practices in construction sites. Furthermore, in relation to the dimensions discussed in Table 4.4, the current study employs the qualitative approach to further explore current practices relevant to on-site water usage for construction activities and adopts the quantitative approach (i.e., structured opinion survey) in order to answer established research questions (Refer Section 4.2.4). The study involves the use of both open and close-ended questions and the interaction between direct and indirect industry stakeholders and workers in a real life context. Therefore, according to philosophical assumptions along with the nature of the research questions, the study adopted the mixed method approach and the rationale for selecting a particular research method to form the mixed method approach, which is further discussed in Section 4.6.2.

4.6 Research Strategies

4.6.1 Research Strategies in General

Saunders et al. (2009) explain that the choice of research strategies is determined by research questions and research objectives. In addition, the extent of the existing knowledge, time and resources available and philosophical underpinnings also guide the research strategies suitable for a study. As indicated in the literature, experiments, surveys, case studies, action research, grounded theories, ethnography, and archival research are the main research strategies that have been identified by different scholars (Creswell, 2009; Suanders, et al. 2009; Yin, 2009). Tan (2002) and Bryman (2004) identify these strategies as the types of the research design. Although these terms are interchangeably used, this research has adopted the term 'Research Strategy'.

As Yin (2009) explains, each research strategy can be used for exploratory, explanatory and descriptive research. Some of these belong to the deductive approach and still others to inductive approach (Saunders et al. 2009). Each research strategy has its own specific approach to collect and analyse empirical data, and therefore each strategy has its own advantages and disadvantages (Amaratunaga, et al. 2002). Table 4.5 provides relevant situations for different research strategies which facilitate the selection of a research strategy for the study.

Table 4.5: Relevant Situations for Different Research Strategies

Strategy	Form of Research Question	Requires Control of Behavioural Events?	Focuses on Contemporary Events
Experiments	How, why?	Yes	Yes
Surveys	Who, what, where, how many, how much	No	Yes
Archival analysis	Who, what, where, how many, how much	No	Yes/No
History	How, why?	No	No
Case studies	How, why?	No	Yes
Action research	How, why?	Yes	Yes
Grounded theory	How, why?	No	Yes/No
Ethnography	How, why?	Yes/ No	No

Source: Adapted from Yin (2009); Saunders et al. (2009)

Yin (2009) identifies the following three conditions that have to be considered when selecting appropriate research strategies:

- Type of research questions posed;
- Extent of control an investigator has over the actual behavioural events; and
- Degree of focus on contemporary events.

Research strategies in the research onion of Saunders et al. (2009) identify seven strategies, viz., experiment, survey, case study, action research, grounded theory, ethnography and archival analysis. Following sub-sections give a concise description about the characteristics of each strategy.

4.6.1.1 Experiments as a Research Strategy

Experiments are used only for causal research when the number of variables is small and controllable (Tan, 2002). As Hakim (2000) states, the purpose of an experiment is to study causal links. Experiments therefore tend to use exploratory and explanatory research to answer ‘how’ and ‘why’ questions (Saunders et al. 2009). An experimental strategy will not be feasible for many business and management research questions as stated by Saunders et al. (2009). Hakim (2000) is of the view that an experimental strategy may be both costly and complex. It is undertaken within a highly controlled context (Saunders, et al. 2009).

4.6.1.2 Surveys as a Research Strategy

A survey is a popular and common strategy in business and management research and is most frequently used to answer “who”, “what”, “where”, “how much” and “how many” type of research questions (Saunders, et al. 2009; Yin, 2009). Tan (2002) mentions that surveys provide a relatively quick and efficient method of assessing information which may be a quantitative or qualitative data collection through questionnaires, structured observations, and structured interviews. Survey research is identified as a systematic method of collecting primary data based on a sample. As stated by Tan (2002), the purpose of a survey is not to consider a specific case in depth but to capture the main characteristics of the population at any instance, or to monitor changes that occur over time. Saunders, et al. (2009) mention that a survey strategy should provide more control over the research process and that when sampling is used, it should be possible to generate findings that are representative of the entire population at a lower cost than done when collecting data for an entire population. One of the biggest drawbacks identified in a survey strategy using a questionnaire survey was the limited number of questions that will receive a good response rate.

4.6.1.3 Case Study as a Research Strategy

A case study is a research strategy involving an empirical strategy and an empirical investigation of a particular phenomenon (Tan, 2002). Yin (2009) further defines a case study as an empirical inquiry that investigates a contemporary phenomenon in its real-life context, especially when boundaries between the phenomenon and the context are not clearly evident. Case studies are appropriate where the objective is to study the contemporary phenomenon and where it is not necessary to control behavioural events or variables (Yin, 2009). They can be used to explore and challenge the existing theories (Yin, 2009; Saunders, et al. 2009). As Morris and Wood (1991) suggest, a case study approach is suitable in situations where a rich understanding of the research context and process is required. Interviews, participant observations, archival documents or records, and audio visual material are the main sources of evidence in a case study strategy for data collection (Yin, 2009). Thus, the use of multiple sources of evidence is one distinctive feature of the case study strategy as compared to other research strategies. Yin (2009) claims that triangulation is also possible in case studies and that it allows to find answers to "why", "how" and "what" types of research questions.

4.6.1.4 Action Research as a Research Strategy

Action research takes place in real world situations, and aims at solving real problems (Eden and Huxham, 1996). Saunders et al. (2009) explain that action research places greater emphasis on research-in-action than on research-about action. A research consists of a spiral process which includes four steps, viz., diagnosing, planning, taking action and evaluating. Schein (1999) claims that in an action research strategy, practitioners' involvement throughout the research process is important. Saunders, et al. (2009) emphasize that action research combines both data gathering and facilitation of change and that it contributes to the development of theory.

4.6.1.5 Grounded Theory as a Research Strategy

Grounded theory is an approach for the discovery of emerging theory grounded in data where the research problem emerges from the first level of primary data analysis (Glaser and Strauss, 1967). Martin and Turner (1986) claim that grounded theory is an inductive approach which allows the researcher to develop a theoretical account of the general features of a topic while simultaneously grounding the account in empirical observations or data. Therefore, it starts with a field study to find out a research problem. In the grounded theory, data collection starts without the formation of an initial theoretical framework. Theory is developed from data generated from a series of observations (Saunders, et al. 2009).

4.6.1.6 Ethnography

This is similar to the grounded theory. In ethnography, the researcher is a participant as well as an observer in the context that is being studied (Wolcott, 1999). Saunders et al. (2009) mention that ethnography is rooted firmly in the inductive approach. This is obviously a research strategy that is very time consuming, which takes place over an extended time period as the researcher needs to immerse as completely as possible in the social world being researched. The research process needs to be flexible and responsive to change since the researcher will constantly be developing new patterns of thought about what is being observed (Saunders, et al. 2009).

4.6.1.7 Archival Research

The use of archival strategy involves the collection of data from administrative records and documents both recent and historical (Tan, 2002). An archival research strategy allows research questions which focus upon the past and change with time to be answered, whether they are exploratory, descriptive or explanatory. However, the ability to answer such questions will inevitably be constrained by the nature of the administrative records and documents (Saunders, et al. 2009).

4.6.2 Research Strategies Relevant to the Research

Sections 4.4.2 and 4.5.2 justify the suitability of the pragmatism philosophical paradigm for this study and the use of a combined approach consisting of both qualitative and quantitative methods. Furthermore, as discussed in Section 4.6.1, research questions of this study are primarily in the nature of 'what', and 'how'. As explained by Yin (2009), it is vital to gain some in depth understanding of the prevailing practices of efficient water use in the construction industry in Sri Lanka. Similarly, broad views of a large sample of experienced construction professionals is essential to identify applicable and significant factors relating to water efficiency measures and potential drivers, barriers and other sustainable attributes that impact on efficient use of water in construction projects. As far as characteristics of available research strategies are concerned, both case studies and survey strategies are quite appropriate to answer research questions with a pragmatism philosophical position. The proposed research is not intended to be conducted in a controlled environment. This research is not suited for research strategies such as experiments, actions research, grounded theory, ethnography and archival research.

4.7 Research Choice adopted in the Research

The choice of the method may depend upon the purpose of the study, resources available and the skills of the researcher (Kumar, 1999). As discussed in Sections 4.4.2 and 4.5.2, the mixed method was selected according to the theoretical perspective underlying the methodology. Mixed method design and research methods used in the current study are explained in the sections that follow.

4.7.1 Mixed Method Design Adopted in the Research

Mixed methods have been used in this research for the purposes of triangulation, facilitation, complementarities and generality and to study different aspects (Creswell, 2009). Although different types of mixed method designs are available in the literature, Creswell and Plano Clark (2007) identify four major types of mixed method designs, namely triangulation design, embedded design, explanatory design and exploratory design. Table 4.6 lists out the characteristics of each type of mixed method design (variants, timing, weighting, mixing and notation of each type of design).

Table 4.6: Major Mixed Method Design Types

Design Type	Variants	Timing	Weighting	Mixing	Notation
Triangulation	*Convergence *Data Transformation *Validating quantitative data *Multilevel	Concurrent : quantitative and qualitative at same time	Usually equal	Merge the data during the interpretation or analysis	QUAN+QUAL
Embedded	*Embedded experimental *Embedded correlation	Concurrent or sequential	Unequal	Embed one type of data within a larger design using the other type of data	QUAN (qual) or QUAL (quan)
Explanatory	*Follow-up explanations *Participant selection	Sequential :Quantitative followed by qualitative	Usually quantitative	Connect the data between the two phases	QUAN→qual
Exploratory	*Instrument development *Taxonomy development	Sequential :Qualitative followed by quantitative	Usually qualitative	Connect the data between the two phases	QUAL →quan

Source : Creswell & Plano Clark (2007, p. 85)

The common and well known approach to mixed methods is the triangulation design (Creswell & Plano Clark, 2007). The purpose of this design is to obtain different but complementary data on the same topic (Morse, 1991, p.122) to best understand the research problem. As Creswell and Plano Clark (2007, p.62) mention, triangulation design is used when a researcher wants to directly compare and contrast quantitative statistical results with qualitative findings or to validate or expand quantitative results with qualitative data.

According to its research purpose, research problem and the pragmatism philosophical stance, this study adopted the triangulation based mixed method convergence design during data collection (refer Table 4.6) considering other research requirements such as practicality, multiple view points, biased and unbiased views, and the extent of the subjective and objective perception inputs. A convergence model collects quantitative and qualitative data concurrently to understand the research problem, then analyzes the two data sets separately subsequently mixing the two (02) databases by merging the results during interpretation (Creswell and Plano Clark 2007). Figure 4.4 illustrates data collection and analysis process of the convergence mixed method.

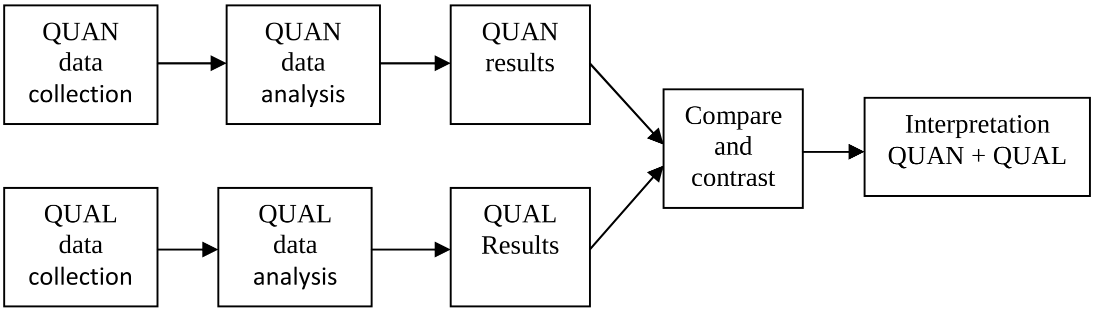


Figure 4.4: Triangulation Design: Convergence Model

Source: adapted from Creswell & Plano Clark (2007, P.63)

As stated by Creswell and Plano Clark (2007), the convergence model compares results to validate, confirm, or corroborate quantitative results with qualitative findings for a better understanding. One challenge of this method could be when the quantitative and qualitative findings do not agree with each other. In such instances, the collection of additional data or the re-examination of the existing data is suggested to address this challenge if the researcher is facing this challenge during data analysis stage (Creswell & Plano Clark, 2007).

As discussed in Sections 4.4.2, and 4.5.2, this research is intended to explore water usage practices to investigate applicable water efficiency measures and relevant drivers, barriers and other sustainable attributes that impact on the sustainable use of water during the construction phase of a building project and to come up with recommendations to improve efficient water use in construction projects. Thus, a case study (in order to further explore current practices of water usage in construction activities) and a questionnaire survey among experienced construction professionals (to identify relevant and highly applicable drivers and barriers of water use efficiency during the construction phases of building projects) will have equal importance in exploring and answering the research problem.

Time is an important parameter in determining the approach to the research. Saunders et al. (2007) mention cross sectional studies and longitudinal studies as two types of research that focus on the time line. Sunders et al. (2009, p.155) explain cross sectional studies as those that aim at a particular phenomenon at a particular time. In longitudinal studies, the aim is at a particular phenomenon that changes in depth with time with these changes forming part of the investigation. This is an investigation of a phenomenon at a given point of time rather than over a period of time. Therefore, the current research very much favours a cross-sectional study rather than a longitudinal study.

4.8 Techniques and Procedures for Data Collection

4.8.1 Case Study Design: Qualitative Data Collection

4.8.1.1 Selection of Cases

The main objective of the screening procedure is to ensure that a researcher has selected the most suitable cases prior to formal data collection (Yin, 2009). The unit of analysis is the heart of a study as it is related to the fundamental problem statement of the research (Miles & Huberman, 1994; Yin , 2009).

Based on the primary research questions, the unit of analysis for this study is defined as “Water efficiency practices in building construction projects in Sri Lanka”. Having established the unit of analysis, the next step will be to define the boundary of the study. Deciding on the boundary helps the researcher to identify the scope of the study, for example, to determine the limits of data collection (Yin, 2009). Literature review bears evidence that the access to freshwater or potable water is a main threat to people and this has been identified as a future global issue, which will take place during 2025-2030. Accordingly, the boundary of the research is defined as ‘On-going building construction projects which use pipe-borne water as a main water source for construction activities”. Pipe-borne water means the water that is supplied by the National Water Supply and Drainage Board (NWS&DB). Figure 4.5 illustrates the unit of analysis and the study boundary of the study.

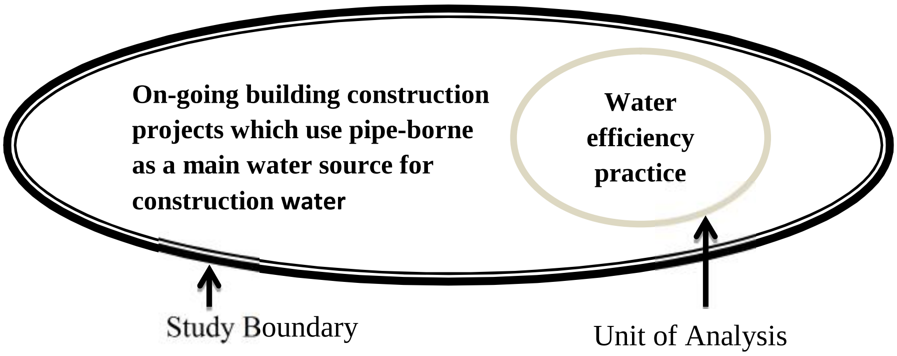


Figure 4.5: Unit of Analysis and Study Boundary

Yin (2009) suggests four (04) major types of case study designs based on a 2 x 2 matrix, which in turn is based on the unit of analysis shown in Figure 4.6.

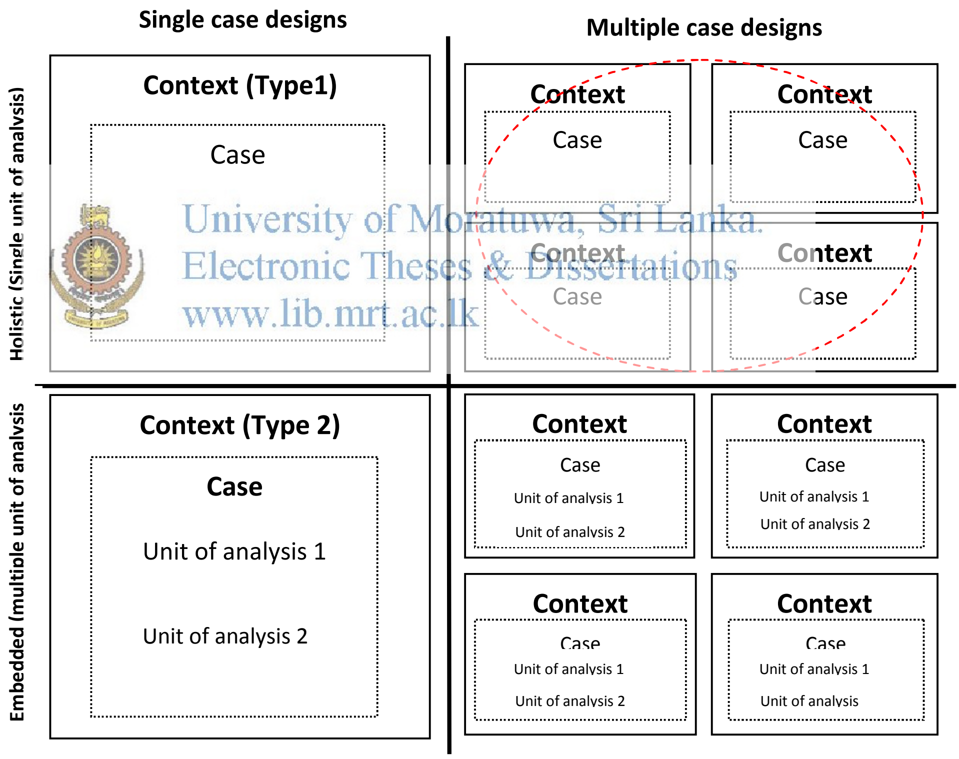


Figure 4.6: Basic Types of Designs for Case Studies

(Source: Yin 2009, p.46)

If there is one (01) unit of analysis, it is called 'holistic', whereas if there are more than two (02) units of analysis it is called 'embedded' (Yin, 2009). Accordingly, the major types of case study designs are Type 1 - single-case (holistic) designs, Type 2 - single-case (embedded) designs, Type 3 - multiple-case (holistic) designs and Type 4 - multiple-case (embedded) designs (Yin, 2009). The rationale for these four (04) types of designs depends on the unit of analysis, which is a vital factor to be considered in the research design.

The use of single case studies is preferred when the study represents a critical case, extreme or a unique case, representative or typical case, revelatory case or a longitudinal case (Yin, 2009). Multiple-case designs are likely to be stronger than single-case designs (Yin, 2009). Considering the nature of research questions of this research, multiple case studies have been selected instead of a single case study. Therefore, the collection of data is from more than one on-going building project although there is only one unit of analysis (Water Management Practice). Thus, this study has used Type 3, i.e., multiple-case (holistic) design as highlighted in Figure 4.6.

Herriot and Firestone (cited in Yin, 2009) state that evidence in multiple case studies is more convincing and that therefore in such a case, the overall study can be regarded as more robust. A multiple case study design may require more resources and time than a single case study design (Yin, 2009). The rationale for the multiple case study design is based on replication logic, with each case predicting similar (literal replication) or contrasting (theoretical replication) results, although case selection should not be based on sampling logic (Yin, 2009). Therefore, this study included as case studies, four on-going construction projects at different stages of construction project life cycle (refer to Chapter 5). During case selection in this study, the convenience sample method was adopted. According to Smith (1991), if the case selection is not typical, theoretical conclusions of the case studies are considered to be valid. In this study, the validity of the data collection was improved by using triangulation.

4.8.1.2 Data Collection Techniques

Yin (2009) states that multiple sources of evidence such as documentation, archival records, interviews, direct observations, participant observations and physical artefacts are commonly used in case studies. Strengths and weaknesses of each source of evidence are illustrated in Table 4.7.

Table 4.7: Six Sources of Evidence - Strengths and Weaknesses

Source of Evidences	Strengths	Weaknesses
Documentation	• Stable- can be reviewed repeatedly • Unobtrusive- not created as a result of the case study • Exact-contains exact names, references, and many settings	• Retrievability- can be low • Biased selectivity, if collection is incomplete • Reporting bias-reflects (unknown) bias of the author • Access-may be deliberately blocked
Archival records	• Same as above for documentation • Precise and quantitative	• Same as above for documentation • Accessibility due to privacy reasons
Interviews	• Targeted – focuses directly on the case study topic • Insightful-provide perceived causal inferences	• Bias due to poorly constructed questions • Response bias • Inaccuracies due to poor recall • Reflectivity- interviewee gives what interviewer wants to hear
Direct observation	• Reality-covers events in real time • Contextual-covers context of event	• Time consuming • Selectivity-unless broad coverage • Reflectivity-event may proceed differently because it is being observed • Cost-hours needed by human observers
Participants observation	• Same as above for direct observations • Insightful into interpersonal behavior and motives	• Same as above for direct observations • Bias due to investigator's manipulation of events
Physical artifacts	• Insightful into cultural features • Insightful into technical operations	• Selectivity • Availability

Source: Yin (2009, p.102)

This study adopted multiple sources of evidence: interviews, direct observations, and documentation during data collection (as highlighted in Table 4.7) and discusses each method briefly in the sections given below.

Interviews

Saunders, et al. (2009) state that interviews are used to collect in-depth information about a social phenomenon of concern and that interviews help to gather valid and reliable data that are relevant to research questions and objectives. Mack, et al. (2005) identify interviews as an effective way of collecting people's personal feelings, opinions, and experiences. Common typology is used to divide interviews as structured, semi-structured, and unstructured (Saunders, et al. 2009). Another typology is standardized and non-standardized (Healey, 1991). There is an overlap between these different typologies.

Structured interviews use questionnaires based on a predetermined and 'standardized' or an identical set of questions. In semi-structured interviews, the researcher will have a list of themes and questions to be covered although these may vary from one interview to another. The order of questions may also vary depending on the flow of the conversation. On the other hand, additional questions may be required to explore the research question and objectives (Saunders, et al. 2009). In unstructured interviews, there is no predetermined list of questions. The interviewee is given the opportunity to talk freely about events, behaviours and beliefs relating to the topic area (Robson, 2002; Saunders, et al. 2009). Moreover, this gives the researcher flexibility to cover certain questions and to incorporate and change questions according to the interviewee as used frequently in exploratory research (Saunders et al. 2009). Within a case study, a wide range of different people and activities are invariably examined (Baryman, 1988). Saunders, et al. (2009) state that non-standardised interviews may also be conducted group-wise where the interviewer asks questions from a group of participants.

The study envisages multiple views of project managers, project engineers, quantity surveyors, safety officers, supervisory level staff officers, administrative officers, and labourers during the data collection process. Therefore, the study adopted semi-structured and non-standardized interviews for data collection. An audio recorder was used to capture data through semi-structured and unstructured interviews. Appendix A shows the case study interview guide that was used during data collection. Table 4.8 provides key advantages and disadvantages of audio recording of the interviews. Permission should always be sought to audio-record an interview (Saunders, et al. 2009).

Table 4.8: Advantages and Disadvantages of Audio Recording of Interviews

Advantages	Disadvantages
Allows interviewer to concentrate on questioning and listening	May adversely affect the relationship between the interviewee and interviewer (possibility of focusing' on the audio-recorder)
Allows questions formulated at an interview to be accurately recorded to be used in later interviews where appropriate	May inhibit some interviewee responses and reduce reliability
Can re-listen to the interview	Possibility of technical problems
An accurate and unbiased record is provided	Time required to transcribe the audio-recording
Allows direct quotes to be used	
A permanent record is available for use by others	

Source: Saunders et al. (2009, p. 341)

Observations

Saunders, et al. (2009) state that observation is a somewhat neglected aspect of research but that however it adds considerably to the richness of research data. Noor (2008) is of the view that observation generates insight and a better understanding of the phenomenon under study. The researcher engaged in direct observations when visiting four selected construction sites to identify what is actually happening on-site with regard to the research questions. By adopting direct observations, the researcher expected a high degree of richness in research data for addressing the research questions under investigation.

Documentary Sources

Documentary evidence helps to cross validate information gathered from interviews and observations (Noor, 2008). In addition to the strengths of documentary sources identified by Yin (2009), documents provide guidelines for interviews. In order to examine details of water efficiency strategies, cost of water and water quality, the researcher gained access to available documentary sources on-site such as the Environmental Management System (EMS), Bill of Quantities (BOQ), monthly water bills, and specifications stated in the contract documents. These documents offered both qualitative and quantitative data.

4.8.2 Questionnaire Survey Design: Quantitative Data Collection Techniques

A survey is a systematic method of collecting primary data based on a sample (Tan 2002). Furthermore, Tan (2002) states that the purpose of a survey is not to consider a specific case in depth but to capture the main characteristics of the population at any given instance. A questionnaire is one of the most commonly used data collection techniques in survey research. Saunders et al. (2009) suggest that a questionnaire is best suited to a situation where most of the questions are standardized. As stated by Saunders, et al. (2009), the nature of the research questions and data needed could also influence the selection of a questionnaire survey for a research study. Moreover, Saunders et al. (2009) mention that questionnaires can be linked with other methods in a multiple method research design and that it can be complemented by in-depth interviews to explore and understand participants' attitudes. Questionnaires if worded correctly would require normally less skill and sensitivity to administer than semi-structured or in-depth interviews (Jankowicz, 2005).

Some research questions in this research were to be investigated in the form of 'what' (refer to Section 4.2.4). The study employed a survey research design to capture a broad view on the research issues identified. Therefore, a structured questionnaire survey was conducted as a data collection technique in this study. Following sub-sections discuss the questionnaire development and sample selection adopted in this study.

4.8.2.1 Questionnaire Design and Development

The questionnaire for the study was developed targeting experienced construction professionals with the aim of eliciting their opinions. In preparing questions, attention was paid to literature review findings. Questions were prepared to be in line with data needed to answer the research questions and research objectives. Google form technique was used during the questionnaire development (refer Figure 4.7).

://docs.google.com/forms/d/1BD8Yd-bSgVrDhtBn4baDTdxNm7U_ZtILp3BusPeFLGg/viewform

QUESTIONNAIRE SURVEY: SUSTAINABLE USE OF WATER IN CONSTRUCTION PROJECTS: CASE OF SRI LANKA

Dear Participants

I would like to invite you to participate in this research which I am doing for my doctoral degree at University of Moratuwa.

The aim of this research is to investigate sustainable use of water during the construction phase of building projects in Sri Lanka

The purpose this questionnaire survey is to get your valuable inputs and insights on water management in construction industry in terms of current practice and recommendations to establish good practices.

This questionnaire survey is being distributed among civil engineers, project managers, architects and quantity surveyors who are experience and knowledgeable in the subject area and working in the construction industry in Sri Lanka. You are identified as one that could provide valuable input into this research. This survey will take Maximum 40 minutes to complete. If you agree to participate, your privacy and confidentially will be strictly maintained.

If you need any further clarification or information please feel free to contact the researcher via the contact details given below. The findings of this research will be disclosed to you upon your request. The outcomes of this research/survey would be used for my thesis and research publications in journals and conferences.
Your participation in this survey is highly appreciated.
Thank you

Researcher:

Anuradha Waidyasekara
Email : anulk15@yahoo.com / anuradha@uom.lk

Phone: 0773640989/ 0718570781

SECTION I: GENERAL INFORMATION

Please provide the following Information

Name (Optional) ……………………………………

Profession……………………………………

Current Designation……………………………………

Experience in Construction Industry (Years):……………………

Contact Details (Optional) :Mobile …………… Office…………… Email……………

SECTION II: RESPONDENTS' EXPERIENCES OF WATER MANAGEMENT PRACTICES IN THE CONSTRUCTION INDUSTRY

01. What you can say about the current water management practice during the construction phase in Sri Lanka?

	Very Good	Good	Moderate	Low	Very Low
Current water management practice in Sri Lanka	○	○	○	○	○

02. How would you agree with the following statements in terms of "Water Efficiency (WE)' and 'Water conservation (WC)' in the construction industry?

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Water efficiency and conservation are two different meanings	○	○	○	○	○
Conservation means doing less by sacrificing needs	○	○	○	○	○
WE focuses on achieving					

Figure 4.7: Online Questionnaire Developed through Google Form

The questionnaire was divided into four (04) sections. Section I addressed the general demographics of the respondents. Section II was designed to obtain respondents' experience of water management practices in the construction industry, common factors that impact on efficient water use and views on current water management practices in sites. Section III considered respondents' views on the applicability of WEMs in construction sites, applicability of water hierarchy and R concepts and relevant drivers and barriers that impact on the implementation of water management in construction sites. Rating type close-ended questions were used in Sections II and III.

Literature presents the Likert scale with three, five, seven, nine and ten point levels that are used in questionnaires in construction management research. However, there is no rule regarding the use of each scale because the aim is to target the sensitivity of responses (Sarantacos, 1998; Tan, 2002). The study employed the five-point Likert scale with following definitions to be in accordance with the purpose of the questionnaire as shown in Figure 4.7. On the other hand, the five-point scale is very popular and it enables respondents to be neutral. Participants were given the five-point Likert scale to indicate the level of applicability/relevance of each factor based on their professional judgment. In this study, a Likert scale ranging from "Not applicable-1" to " Highly applicable-5" was used to measure highly applicable water efficiency measures, a Likert scale ranging from "Not relevant-1" to "Highly relavent-5" to identify most relevant drivers and barriers, and a 1 to 5 scale ranging from "Strongly disagree-1" to "Strongly agree-5" to measure agreement levels (refer Chapter 6).

Section IV of the questionnaire contains three (03) open-ended questions and participants were free to make additional comments on the research study. In addition, at the end of each closed question, an option of 'other' was also provided which the respondents could make use of to make additional comments.

As a part of the four (04) preliminary interviews, the questionnaire, which was prepared based on literature findings (discussed in Chapters 2 and 3), was presented for review and comments were obtained for improvements. The questionnaire was also presented to academics and some selected professionals for obtaining comments for improvements. Based on the comments obtained from preliminary interviews, selected academics and professionals, the questionnaire was refined prior to being used in the survey.

Following suggestions were made on the developed questionnaire. Layouts of the survey guides were accepted in general. It was recommended to analyse current ongoing projects to justify results and to find what factors impact on implementing water management and also the existing issues with the current system. In addition to validating literature findings and data instruments, certain other factors were added to the existing list of survey and suggestions were made to combine similar factors (refer to Sections 3.3.2, 3.3.3, and 3.3.4) to avoid a lengthy questionnaire. It was suggested to change the question on 'significant water usage and water wasting activities', from 'scale type' to 'list type' in the questionnaire since the answers are more subjective. A few suggestions were made on the data arrangement of the conceptual framework adjusted in the final framework (refer to Figure 3.1 of Chapter 3). The refined questionnaire, which was used in the survey to collect data, is given in Appendix B.

4.8.2.2 Sample Selection and Data Collection

Sampling techniques available were mainly divided into two (02) groups, namely probability or representative sampling and non-probability or judgmental sampling (Saunders, et al. 2009). All probability sampling techniques necessitate some form of sampling frame, so they are often more time consuming than non-probability techniques (Saunders, et al. 2009). In probability sampling techniques, the sample used is based on assumptions and will be chosen statistically at random. According to Saunders, et al. (2009), in market surveys and case study research, finding a sample frame is difficult and non-probability sampling provides a range of alternative techniques to select samples based on subjective judgment. For non-probability samples, the probability of each case being selected from the total population is not known. The choice of sampling technique or techniques is dependent on research question(s) and objectives (Tan, 2002; Saunders, et al. 2009). Patton (2003) suggests that sampling selection criteria should be identified prior to selecting a sample. Saunders, et al. (2009) emphasise that other than for quota samples in all non-probability sampling techniques, sample size is ambiguous and that unlike in probability sampling there are no rules. Furthermore, the authors state that such samples cannot be considered to be statistically representative of the total population. The logic for selecting cases for a purposive sample should be dependent on research question(s) and objectives (Saunders, et al. 2009). Purposive sampling was considered in this study. A total of 160 participants took part in the online questionnaire survey. The survey was conducted among four (04) categories of professionals who have been working in the construction industry as project managers, civil engineers, quantity surveyors and architects. The main selection criterion was the construction industry work experience of more than ten (10) years. In addition to work experience, the chartered qualifications were also considered when selecting the sample. Grade C1 contractor organisations and consultancy organisations who have been in operation for more than 20 years in the industry were considered for the sample. Table 4.9 shows the breakdown of the 160 participants sample selected for the online questionnaire survey.

Table 4.9: Questionnaire Survey Sample Distribution

Survey Participants' Organization	Project Managers	Civil Engineers	Quantity Surveyors	Architects	Total
Contractor	40	35	20	-	100
Consultant	-	05	20	40	60
Total	40	40	40	40	160

The choice of the questionnaire will be influenced by a variety of factors related to research question(s) and objectives (Saunders, et al. 2009). Characteristics of the respondents, size of samples, reliability of responses, and importance of reaching and resources (i.e., time, cost, availability) are some factors identified by Saunders, et al. (2009) and Figure 4.8 illustrates the type of questionnaires.

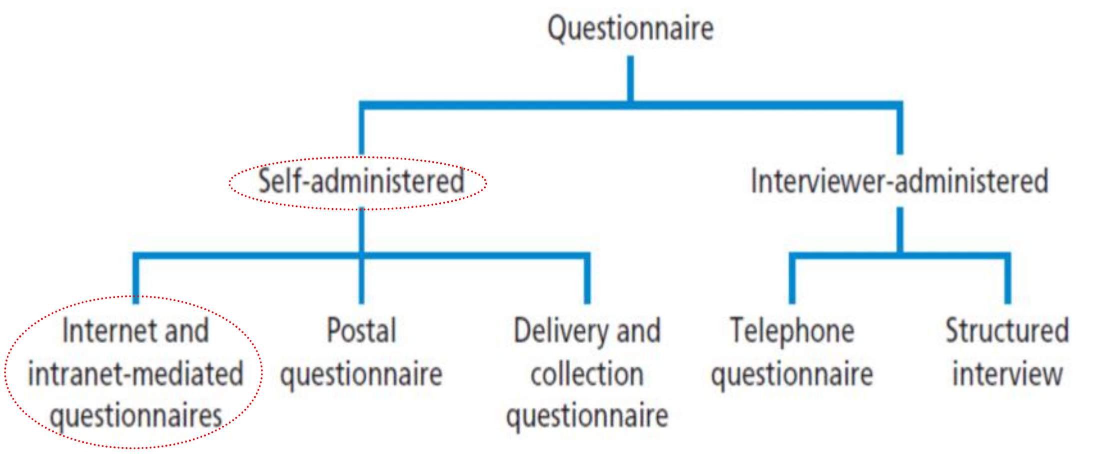


Figure 4.8: Types of Questionnaires

Source: Saunders et al. (2009, p.363)

Considering the importance of aspects such as time, cost, reliability of responses, and minimum dispersion, this study adopted self-administered internet questionnaires.

The formula developed by Czaja and Blair (2005) was used to calculate the appropriate sample size for this research (Refer Eq. 1).

$$ss = \frac{z^2 x\, \rho(1-\rho)}{d^2} \text{……………………………….(Eq. 1)}$$

where ss = sample size
z = standardised variable
p = percentage of the population
d = confidence interval, expressed as a decimal

In this research, a 95% confidence level (*z* = 1.96) and a ±10% confidence interval (*d*) were assumed (Akadiri 2011; Czaja & Blair 2005). Czaja and Blair (2005) assumed the worst case scenario for the percentage of the population (ρ) when calculating the sample size. Therefore, the study assumed ρ as 0.5 (50%). Based on the above-mentioned assumptions, sample size was computed using Eq 2.

$$ss = \frac{1.96^2 \times 0.5(1-0.5)}{0.1^2} = 96.04 \text{……………….(Eq. 2)}$$

Accordingly, at least 96 responses had to be collected from the questionnaire survey. A total of 160 questionnaires were distributed among project managers, civil engineers, quantity surveyors and architects who worked in consultant and contractor organisations. Section 6.2.1 of Chapter 6 presents the questionnaire administration and response rate.

4.9 Mapping Study Objectives with Data Collection Techniques

Table 4.10 summarises the way the study objectives were addressed through the selected data collection techniques of the study.

Table 4.10: Mapping of Study Objectives with Data Collection Techniques

Study Objectives	**Data collection technique**							
			Case study			**Web based survey**		
	Literature Review	**Preliminary interviews**	**Semi structured interviews**	**Documentary Reviews**	**Direct Observations**	**Structured Questions - Closed Type**	**Open Type Questions**	**Expert Interviews**
Objective 1- Review of principles and practices of sustainable use of water in construction projects	X	X						
Objective 2–Evaluate water use practices of construction projects in Sri Lanka	X	X	X	X	X		X	
Objective 3 - Investigate the most applicable Water Efficiency Measures (WEMs) for construction projects	X	X	X			X	X	
Objective 4 - Determine relevant drivers, barriers and other attributes for efficient water use practices in construction projects	X	X	X			X	X	
Objective 5- Develop a framework for improving sustainable use of water in construction projects	X	X	X	X	X	X	X	X

4.10 Data Analysis

The study adopted a triangulated design convergence mixed-method approach, where both quantitative and qualitative data were collected and analyzed concurrently with an equal weight (refer to Section 4.7.1). Data analysis consists of examining, categorizing, tabulating, testing or otherwise recombining evidence to draw empirically based conclusions (Yin, 2009, p.126). The next section presents the data analysis process and techniques used in the study.

4.10.1 Qualitative Data Analysis

This research study collected qualitative data through four (04) case studies where semi-structured and unstructured interviews were used with management level professionals and on-site workers. Furthermore, another set of qualitative data was collected from open-ended questions in the questionnaire survey. Yin (2009) describes five (05) specific analytical techniques that can be used for case studies such as pattern matching, explanation of buildings, time series analysis, logic models and cross case synthesis. Pattern matching compares an empirically based pattern with a predicted pattern and strengthens the internal validity of a case study when the patterns coincide. Explanation building is a special type of pattern matching but the procedure is more difficult. Glaser and Strauss (1967) state that its goal is not to conclude a study but to develop ideas for further studies. Time series analysis deals with analysis of data in specific time frames in an iterative manner when conducting experiments. A logic model intentionally stipulates a complex chain of events over time. The events are staged in repeated cause - effect - cause - effect patterns. Cross - case synthesis applies specifically to the analysis of multiple cases. The four (04) previous techniques can be used with either single or multiple case studies (Yin, 2009). Findings are likely to be more robust in cross-case analysis. This enables the comparison of multiple cases in many divergent ways. According to Marshall and Rossman (1999), case comparison in cross-case synthesis can be made against predefined categories in search of similarities and differences or by classifying data according to sources.

The study adopted analytic techniques of within-case analysis and cross case analysis. Within case analysis was generally carried out to produce a detailed write-up for each case being studied (Eisenhardt & Graebner, 2007). There is no standard way of presenting data within case analysis. Thus, the aim is to increase the familiarity of the case data until unique patterns are obtained in each case prior to generalizing these patterns across the cases. Cross case analysis is the step that comes after the within-case analysis. Content analysis was used to code textual data gathered from semi-structured interviews during the case analysis. Cognitive mapping was used to identify the relationships with concepts. Computer software, "NVivo (version 10)" was used to analyze content analysis with the aid of a coding structure and cognitive mapping as discussed in Chapter 5. Same techniques were used to analyse open ended questions received from the questionnaire survey and presented in Section 6.7.5 of Chapter 6.

4.10.2 Quantitative Data Analysis

This section presents data techniques that were used to analyse data collected from the questionnaire survey. Quantitative analysis techniques such as graphs, charts and statistics allow exploring, presenting, describing and examining relationships and trends within a data set (Saunders, et al. 2009). Descriptive and inferential statistics tests were involved during the quantitative analysis (Tan, 2002; Fink, 2009). Tan (2002) states that most common descriptive statistics are mean and standard deviations and those less popular measures include the mean, median, mode and range. Measures of central tendency and dispersion are often used in descriptive statistics (Tan, 2002; Saunders, et al. 2009). Inferential statistics are defined as sample statistics to make inferences about population in the form of a statistical hypothesis (Tan, 2002). The study adopted both descriptive and inferential statistics to analyze the questionnaire response.

As discussed in Section 4.7.3.1, the study employed the five-point Likert scale to be in line with the purpose of the questionnaire where 1 represented 'low' and 5 represented 'high'. The Mean Score (MS) of each factor was calculated using Eq 3 as performed by Ekanayake and Ofori (2004).

$$MS = \frac{1\ n1\ +2\ n2\ +3\ n3\ +4\ n4\ +5(n5)}{(n1+n2+n3+n4+n5)}\ (1 \leq MS \leq 5) \text{……………………….Eq. 3}$$

where, n1, n2, n3, n4 and n5 represent the number of respondents who rated the attributes as 1, 2, 3, 4 and 5 respectively.

Kazaz and Ulubeyi (2007) in a study aimed at investigating the significant drivers of productivity employed a ranking analysis to identify the highly applicable WEMs and the relevant drivers and barriers. Accordingly, a ratio from a difference of 1-5 (i.e., 4) and at intervals of 0.8 was used to discuss the degree of central tendency based on the following categorization:

- 1.00 ≤ 'Not Applicable/ Not Relevant' (NA/NR) ≤ 1.80
- 1.80 < ' Less Applicable/ Less Relevant' (LA/LR) ≤ 2.60
- 2.60 < 'Moderately Applicable/ Moderately Relevant' (MA/MR)≤ 3.40
- 3.40 < ' Applicable/ Relevant' (A/R) ≤ 4.20
- 4.20<' Highly Applicable/Highly Relevant' (HA/HR) ≤ 5.00

A rank differentiation where two or more variables had the same mean values was achieved through examination and selection of the variable with the lowest standard deviation (Doloi, Sawhney, Iyer, & Renata 2012; Kumaraswamy and Chan 1998).

Based on the central tendency, a benchmark-mean score of 3.40 was used to filter 'applicable/relevant' factors while a benchmark of 4.2 was used for 'highly applicable/highly relevant' factors (Kazaz & Ulubeyi 2007). It should however be noted that different approaches exist in the literature for ascertaining cut-off points when the 5-Point Likert scale is used to measure levels of agreement. For example, Yuan, Shen, and Wang (2011) adopt a cut-off mean value of 3.00.

In addition to the central tendency, the percentages of respondents in certain broader segments of the scale were calculated for each factor (Those scoring 2 or fewer, those scoring 3, and those scoring 4 or more). These were used to rank factors in which mean scores were the same (Kazaz & Ulubeyi, 2007). Cronbach's alpha coefficient was applied to check the reliability and internal consistency of survey instruments (refer to Section 4.11).

The study used one-way ANOVA (an analysis of variance) to test statistical differences in the mean score of different professional groups of respondents: project managers, civil engineers, quantity surveyors and architects. Performing ANOVA involved testing the following hypothesis at a confidence interval of 95% to reject the null hypothesis.

H_0: $\mu_1=\mu_2= \mu_3$…………………..μ_k; all population means are equal.

An alternative hypothesis is that at least one of the means is different

ANOVA requires an additional test to be performed, if there are differences of means between main groups. Rejection of the null hypothesis means all population means are not equal, and it does not show which group means are different. Therefore a 'Post-Hoc' is performed to find the different group(s) if any. This study employed the commonly used test of Tukey' 'Post-Hoc'. The results are discussed in Chapter 6.

The SPSS is one of the most widely used statistical software for statistical analysis in research. The statistical software of SPSS version 22.0 was used for data analysis. The study adopted most common descriptive statistics of mean and standard deviation, and frequency distribution, to analyze responses to rating questions.

4.11 Validity and Reliability of Data Collected

Neuman (2011) mentions reliability and validity as ideas that help to establish the 'credibility' of findings. Reliability aims towards the consistency or replication of research findings in similar conditions, while validity evaluates the truthfulness of findings. Qualitative data was validated through construct validity, internal validity, external validity and reliability (Refer to Section 5.9). Cronbach's alpha coefficient was used to check the reliability and internal consistency of survey instruments. This is one of the most popular reliability statistics aimed at determining the internal consistency or average correlation of items in a survey instrument to gauge its reliability. The value of this measure varies from 0 to 1 (Bryman, 2008). A large alpha indicates that identified variables correlate well with true scores and vice versa (Gilbert and Churchill, 1979). Nunnally and Bernstein (1978) and Tan (2002) indicate 0.7 and above to be an acceptable reliability coefficient (Refer to Section 6.9). Furthermore, the study adopted methodological triangulation which involves the use of multiple methods and makes a comparison to see if similar results are being found (Guion, Deihl & McDonald, 2011).

4.12 Research Ethics

Cooper and Schindler (2008, p.84) define ethics as the norms or standards of behaviour that guide moral choices about our behaviour and relationships with others. Research ethics therefore relate to questions about how we formulate and clarify our research topic, design our research and gain access, collect data, process and store our data, analyse data and write our research findings in a moral and responsible way (Cooper & Schindler, 2008). Ethical norms help to ensure that researchers can be held accountable to the public (McNeill & Chapman, 2005). In this research, during data collection, information obtained from interviewees and respondents was kept in strict confidentiality. Personal information about participants was not revealed in the final thesis.

4.13 Chapter Summary

Firstly, the chapter discussed the research problem through the initial impetus of the researcher, integrating literature review and preliminary interviews. Then the chapter explained the key elements of the research process such as research philosophy, research approach, research strategies, and research methods adopted for the current study based on the researcher's understanding of the research questions and research position. Then data collection and data analysis techniques were discussed. Finally the chapter discussed the measures taken to measure the validity and reliability of data followed by ethical principles considered during the study. The next chapter presents the results of case study findings carried out to explore water usage during construction phases of building projects in Sri Lanka.

CHAPTER FIVE

5 DATA ANALYSIS: CASE STUDY RESULTS

5.1 Introduction

This chapter presents the analysis of four (04) case studies selected to explore water usage during construction phase of building projects. Accordingly, this chapter is structured as follows:

First, the chapter presents the procedure adopted in analysing case study data. Second, it discusses findings of each case study in terms of water source and storage, water usage on construction site, on site water wastage, water efficiency measures, drivers and barriers, and cognitive maps to summarise case study findings. Thirdly, by implementing cross-case analysis, the chapter presents water resources arrangement on construction sites, water usage practices, drivers, barriers, sustainability attributes, positive actions, and recommendations towards sustainable use of water during construction phase of the building projects. Finally, the chapter discusses validity of case study findings.

5.2 Procedure Adopted in Analysing Case Study Data

Case study strategy facilitated the exploration and analysis of water usage during the construction phase of on-going building projects. Section 4.8.1.1 of Chapter 4 discuss selection criteria of four cases based on different types of water sources used on the site [e.g. main water supply, truck water (bowser water), well water, and rain water], contractors' grade (C1 building), type of the project (multi-storey building projects), status of the project (on-going and different stages of the lifecycle of construction project), accessibility (location-Colombo), and availability of data on the site (e.g. project documents).

Multiple sources of evidence were considered during data collection: semi-structured interviews, site observations, site documents reviews, and unstructured interviews. Data gathered from the semi structured interviews were coded using the NVivo (version 10) software (refer to Section 4.10.1) and cognitive maps were prepared using the modelling facility in NVivo software for analysing data collected from four cases.

Figure 5.1 depicts the adopted tree node coding structure to present the case study data obtained from semi-structured interviews and un-structured interviews.

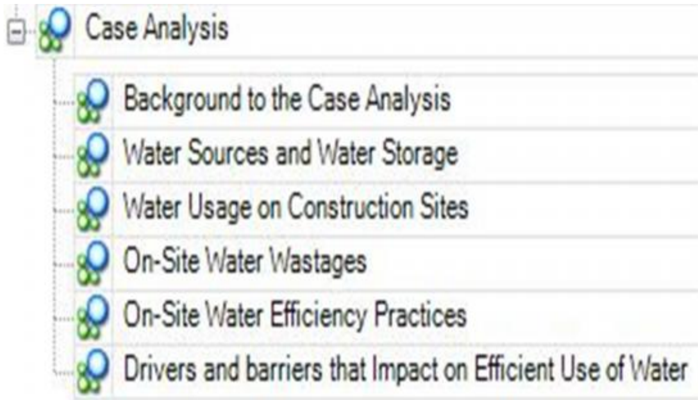


Figure 5.1: Tree Node Coding Structure for Case Study Data Analysis and Presentation

Interviews were conducted based on four (04) case studies. Semi-structured interviews were held with the site-based staff; project manager, project engineer, quality control engineer, quantity surveyor, and supervisory level site staff officers (depending on the availability). Unstructured interviews were conducted with few labourers from each case study. Following pseudonyms are used within the texts (Table 5.1) to maintain confidentiality of the case study informants, their organizations, and the data obtained from case studies.

Table 5.1: Pseudonyms Used for the Respondents

Case Study Interviews	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Project Manager (PM)	PM-C1	PM-C2	PM-C3	PM-C4
Project Engineer (PE)	PE-C1	PE-C2	PE-C3	PE-C4
Quantity Surveyor (QS)	QS-C1	QS-C2	QS-C3	QS-4
Quality Control Engineer (QCE)	QCE -C1			
Project Supervisor (SS)	PS-C1	PS-C2	SS-C3	PS-C4
Safety Officer (SO)	SO-C1			SO-4

In addition, multiple sources of evidences, i.e. project documents (Bill of Quantities, specifications, labour records, Environmental Management System, water meter bills, and Building Schedule of Rates-BSR) and site observations aided collecting additional data needed for the case analysis. Results obtained from each sources are presented in subsequent sections of this chapter.

5.3 Analysis of CASE STUDY 1

5.3.1 Background to the Case Analysis

The selected project is an on-going office complex and the current phase of construction is at the finishing stage. The project progress is 65% completed as per the construction programme. The project scope consists of constructing a twenty-storeyed office building associated with two ancillary buildings: a three-storeyed service building and a five-storeyed car park building that provide 350 parking facilities. The office building and two ancillary buildings include concrete framed structures, block walls, cement plaster and painting, and timber doors and aluminium windows. Table 5.2 provides other important project details of case study 1.

Table 5.2: Project Details of Case Study 1

Project Classification	Commercial Building
Project Cost	Rs. 7.55 billion
Building Area	61,000 m^2
Project Duration	36 months
Commencement Date	August 2012
Client type	Government
Contractor Grade	C1 Building
Contractual Agreement	Design and Build, Lump sum
Amount allocated for water in Preliminary bill	Rs. 12.0 million, ~ 3% from preliminary bill
Typical site working hours	7.30a.m. to 5.30 p.m. (work until 10.00 p.m. as overtime)
Average number of management staff	50
Average number of people on site	450

5.3.2 Water Sources and Water Storage

5.3.2.1 Water Sources

The main water source for construction activities was the water supplied through city water supply. In addition, water was provided to the site through water trucks (bowsers) from two suppliers due to high water demand for construction activities, and main water supply was unable to supply the daily water requirement during construction peak level. During the data collection period, the site fully dependent on the city water supply. Project manager [PM-C1] stated, "*initially, the site seek out tube well water as an alternative water source for the potable water supplied by the National Water Supply and Drainage Board (NWS&DB). Since ground water consists of high salinity and ferrous iron issues, the site could not depend on the alternative water sources in addition to potable water*".

5.3.2.2 Water Storage Methods

According to interviews and site observations, it revealed that the site used two overhead tanks ground sump and two plastic shell tanks to store water. As mentioned by PM-C1, "*two overhead tanks with a capacity of 10,000 litres were used to store truck water for the construction work. In addition, there is a non-site ground sump with a capacity of 50,000 litres.*" The sump comprised two compartments; one compartment designed to fulfil fire regulation requirements during work execution while the other compartment of the sump to collect and store rainwater. Two plastic shell tanks of 5000 litre capacity each, accomplished site cabin and sanitation purposes of management staff and site labourers.

It was noted that the site lacks a detailed water schematic plan; i.e. layout for temporary water distribution, which indicate locations of water outlets and distribution of pipes network.

5.3.2.3 Quality Control of Water

Interviewees were questioned about the manner in which they control quality of water used in the site. As stated by the project manager [PM-C1], "*water quality is checked daily through smell and visual observations, and water quality technical tests are performed in six month duration*". The National Building Research Organization (NBRO) prepares all relevant test reports on water quality. When questioned about the quality of water needed for ready mix concrete, the quality control engineer [QCE-C1] stated, "W*ater with a pH value between 6 and 8 is acceptable for concrete work*".

5.3.3 Water Usage on Construction Sites

Based on site experience, the project manager [PM-C1] and project engineer [PE-1] stated that water is required for wet-trades such as concreting, plastering, rendering, and during the curing process, groundwork, and for testing and commissioning. In addition, workers use significant volumes of water for bathing, cleaning, cooking, and sanitary facilities. Vehicle washing and site cleaning are other indirect activities using water on construction sites, as stated by PE-C1. According to PM-C1, rainwater and recycled water are used during the construction, in addition to main water supply and water trucks. However, project manager indicated that no proper record is available on quantity of water received to the site from alternative water sources [PM-C1].

PM-C1 stated, "*water trucks are mainly used for on-site ready-mixed plant*". No sub-meters are provided on the site in addition to the main water meter connected to the city water supply, provided by the NWS&DB. As disclosed by PM-C1, during construction peak level, an average of 450-500 workers are employed and accommodated on site. The project engineer stated, "*concrete batching plant installed on the site consumes a considerable water volume from the site's total water supply*" [PE-C1].

5.3.3.1 Records of On-site Water Consumption

Reviewing site documents and discussions with site staff revealed that the main records pertaining to the levels of site water consumption are the monthly water bills for water supply from city water line, and invoices for water supply to the site through bowsers. As stated by PM-C1, the site accountant is responsible for maintaining records on the city water line bills and bowser water supply invoices. Based on the available data provided by the accountant, Figure 5.2 demonstrate the amount of water volume supplied to the site through main water supply and water trucks (bowsers) from August 2012 to February 2015. It is apparent from Figure 5.2 that the highest water quantity was supplied through water trucks to fulfil the construction site water demand over the period of December 2013 to November 2014.

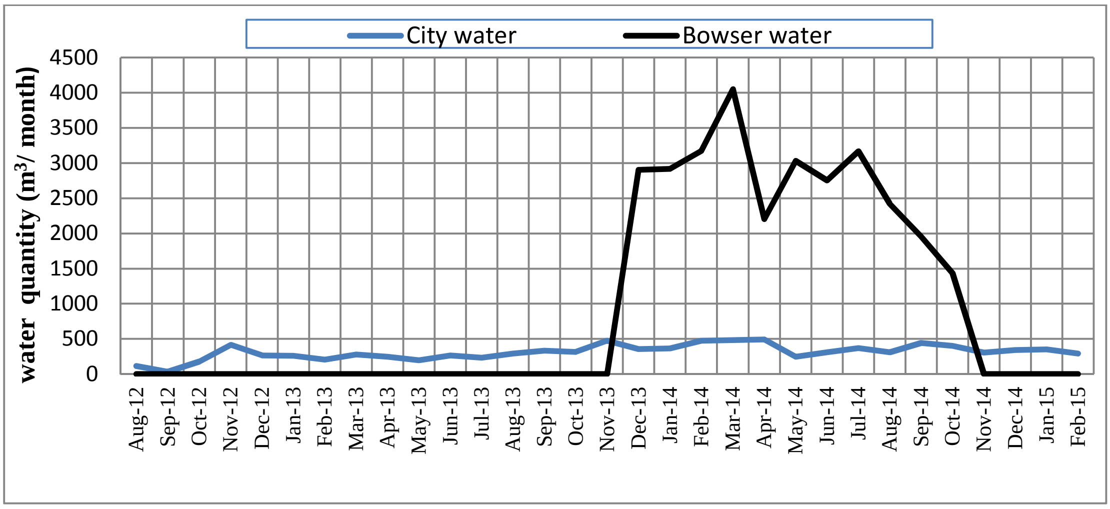


Figure 5.2: Volume of Water Supplied to the Site (m^3) - Case Study 1

As of on-site records shown in Table 5.3, the average truck water supply to the site (from December 2013 to November 2014) was 90.95m^3/day (~91,000litres/day), whereas city water consumption for the same period was 12.87m^3/day (~13,000 litres/day). This reveals that the average total daily water supply to the site consumption was 103.82 m^3/day (~104,000 litres/day) during the period from December 2013 to November 2014.

Table 5.3: Total Water Supplied to the Construction Site by Water Source

Water Source	**Purpose**	**Period**	**Total Water Supply for Consumption (Litres)**	**Average Monthly Water Supply for Consumption (m^3/month)**	**Amount (Rs.)**
City (main) water supply	• Construction • Site staff & labourer usage	Aug 2012to Feb2015 (30 months)	9,645,000	305.40	899,476.60
Water Trucks supply	• Construction	Dec2013 to Oct2014 (10 months)	30,014,550	3001.14	8,670,870.00
Total Water Supplied to the Construction site		Aug 2012 to Feb 2015	**39,176,550**		**9,570,346.60**

According to the construction programme, main wet trades such as concrete work, plaster work, and their associated activities (indirect water consuming activities) such as curing and pond testing were undertaken from December 2013 to November 2014. As stated by the on-site quality control engineer, the required water quantity for concrete production process varies according to the grade of concrete. QCE-C1 described, "*Higher the grade of concrete, higher the water consumption,*" and he provided details of water quantity used in their batching plant according to the concrete grade. Based on these data, water quantity required to produce 1m^3 of ready mixed concrete is presented in Table 5.4.

Table 5.4: Water Quantity Required to Produce Ready Mixed Concrete (by Concrete Grade)

Grade of Concrete	**Required Water Quantity (Litres per 1m^3)**
Grade 15	171.6
Grade 20	181.5
Grade 25	190.8
Grade 30	200.0
Grade 40	216.0

In addition, according to the construction programme, other trades such as aluminium work, painting, tiling, and Mechanical and Electrical (M&E) work were performed on the site from December 2013 to November 2014. Thus, the average labour involvement of labourers was as high as 450-500.

5.3.3.2 Computing Water Requirements

Table 5.3 denotes a high price difference between city water supply and water supplied through trucks. It is apparent in Figure 5.2, the site records of water consumption were initiated in August 2012. It shows that 9645m^3 of city water supply was consumed on the site over a period of 31 months, giving an average of 311.1m^3/month. This figure includes mainly indirect construction activities and certain direct construction activities. Assuming the average main water consumption continues until project completion, the site will consume approximately 11,199.6m^3 of water from city water supply. This excludes water consumed for concreting trade and some direct and indirect construction activities.

Therefore, according to the available data, the average water usage for the construction period (36 months) will approximate to 41,213m^3 from main water supply and from water trucks. This predicted amount includes water consumed for ready mix concrete and for providing on-site labour accommodations for an average of 450 labour force. However, the building maintenance period was not considered during calculation. Accordingly, water consumption of the building is equal to 0.75m^3 per square meter, excluding variables such as variations to work, time extensions, and water received from alternative water sources.

As discussed in Section 2.9 of Chapter 2, norms for water quantity were available for limited direct activities. Based on project BOQ and choosing available norms from BSR, Table 5.5 illustrates water requirements for certain direct construction trades of Case Study 1.

Table 5.5: Water Requirement for Wet Trade Activities - Case Study 1

Direct activity	Type of water source	Quantity based on BOQ	Unit	Water per unit based on norms* (litres)	Total water quantity required (m^3)	% from the predicted water qty. 41,213 m3**	Remarks
Concrete	Water trucks/ City water					~ 17%	Ready mix
Grade 15		450.0	m^3	171.00	76.95		
Grade 20		1205.0	m^3	181.00	218.11		
Grade 30		33345.0	m^3	200.00	6669.00		
Plaster work	Water trucks/ City water	65,452.0	m^2	4.90	320.57	~1%	1:5 mix
Floor rendering	Water trucks/ City water	41,560.0	m^2	4.90	203.77	~ 1%	1:4 mix
Painting	Water trucks/ City water	93,000.0	m^2	0.05	4.65	< 1%	One primer and two coats

* Obtained from BSR (refer Table 2.10); **this figure was derived through the monthly water bills and invoices of water that supplied through water trucks

It is apparent from Table 5.5 that among direct construction activities, concrete is the main wet trade that needs significant quantity of water than other wet trades such as plastering and rendering in this building. However, as stated by PM-C1 and QS-C1, water requirement for particular trades may vary significantly according to type of design (e.g. walls were designed with block works and dry partition, thus less quantity of water is required compared to brick walls), conditions of material, type of techniques, weather conditions, and persons who handle the work during site operation. Table 5.5 signifies the requirement of water for painting is less than for plasterwork and floor rendering. Meanwhile, as stated above, curing is an indirect activity associated with concrete work, which needs considerable volume of water. It revealed that water requirement for curing work is highly subjective and constantly deviate from the standard norms, making it difficult to quantify.*"...during the rainy season, less quantity of water is needed for curing. On the other hand, in dry seasons, number of times of curing may increase per day"* [PE-C1]. Moreover, Table 5.5 bears evidence that approximately over 75%- 80% water is utilised for indirect construction activities such as site cabins and sanitary purpose, curing, testing and commissioning, site cleaning, and wheel washing.

During data collection, permission was sought to conduct a water audit for the site to identify daily water consumption pattern and how it varies from the average monthly water bill. However, due to practical difficulties of accessing the water meter, water audit for the site could not accomplished. Section 5.9.3 discusses the relationship between the available standard norms and the norms that are developed based on site practice, according to work studies performed on the site.

5.3.4 On-Site Water Wastages

With respect to water wastage during construction, PM-C1 and PE-C1 stated that water wastage due to direct construction activities is minimal, but indirect construction activities such as washing, bathing, and sanitation were identified as the most potential waste water actions on the site. Moreover, *"activities such as curing and washing tools demand more water than the required, if we couldn't monitor such on-site activities properly"* [PM-C1] and this totally depends on due care by the workers. Conversely, as stated by PE-C1, according to the type of construction method adopted, water quantity requirement may vary for curing.

Quality control engineer stated, "*water wastage is minimal during the concreting process because all the processes are controlled through a computerized system*" [QCE-C1]. The project manager stated, *"although quantity of water is controlled* *during the concrete production process, a considerable quantity of water is needed for washing concrete trucks, and approximately 200 litres of water is used for washing and cleaning a truck"*[PM-C1].

Project supervisor indicated that, labour behaviour greatly impact on water wastages on the site [PS-C1]. He further explained some ways of on-site water wastages due to labour behaviour: "E*very day, an average of 400-450 labourers work on the site. We have observed that some labourers forget to close taps, or do not close taps fully, and occasionally, they remove showerheads and valves. Using buckets for washing clothes by labourers is rare"* [PS-C1]. The project supervisor elaborated further, *"a significant cost incurs to replace broken and damaged taps, every month*" [PS-C1].

It was observed that labourers use hose or buckets to obtain water during mortar mixing. When asked from three (03) number of labourers how they measure quantity of water for mortar mixing, they replied, "*there are no standard methods followed to measure water quantity required and we use our know-how gained from previous work experiences to determine the required water quantity*". However, as stated by the project supervisor, "*workers cannot use more than the required water for mixing mortar since it affects workability; and water needs for mortar work is automatically controlled"* [PS-C1]. Overflowing of water tanks is another method of wasting water on construction sites as observed. As stated by some labourers the volume of water needed differs according to the nature of sand. Accordingly, during rainy season, sand requires less quantity of water due to high moisture content, than the content required during dry condition.

As commented by some labourers, no immediate actions were taken to rectify the leakages, and a couple of site labourers revealed they experience low pressure of showers during bathing. Compared to the number of on-site labourers, the number of pipe outlets provided in the site is not sufficient to meet the requirement.

5.3.5 On –Site Water Efficiency Practices

5.3.5.1 Water Management Plans

It was revealed from the interviews and review of documentation that this project does not have either water action plan or water management plan in place. The project manager stated, *"there is no separate water action or management plan for the site"* [PM-C1]. However, the project manager stated that this project has environmental management system (EMS). The project manager explained the EMS benefits to the project, *"EMS addresses how to protect and conserve water sources, maintaining water quality, reduction of water contamination due to construction waste and disposal of waste water"* [PM-C1]. Project manager further stated that EMS engineer and quality control engineer were assigned to the site to check the environmental impacts and quality controlling of construction work, which aims to minimize unnecessary damages to the environment due to construction operation. On the other hand, project manager recognised that it helps to maintain the required quality standards of project performance.

5.3.5.2 Monitoring and Supervision

The project manager explained on site water monitoring systems. *"If there is no proper water monitoring systems on site, water consumption by the workforce will increase tremendously therefore we have assigned staffs for monitoring and supervising the construction activities which includes prevention of wasting the water by site workforce when performing all direct & indirect site activities"* [PM-C1].

5.3.5.3 Raising Worker Awareness

As stated by PM-C1 and PS-C1, daily operation, awareness on consumption of water, electricity and safety aspects were discussed in regular basis at the site meetings. Safety officer and administrative officer are in-charge of conducting regular meetings and overall site monitoring. In addition, posters are pasted and displayed at necessary places (washing area, canteen, on the site) to remind good practices among workers and the staff. The notice on the photograph (Figure 5.3), which is written in local language (Sinhala) says, 'LET'S SAVE WATER'. As found from labourers, displaying notice boards are more effective, but it should be maintained throughout the construction period.

Figure 5.3: Display Posters at Bathing Area

5.3.5.4 Assign Responsibilities

The PM-C1 stated that a skilled person is assigned daily to check water storage, leakages, water collection, and to identify wastages and misuses of water. In addition, site engineer, administrative officer, safety officer, plumber, lab technician (ready-mix concrete), quality control engineer, EMS engineer, and material inspector are other responsible parties working on water management activities during construction.

5.3.5.5 Compliance with Obligations

Since the site is located in Colombo Municipal Area, the contractor is obliged to obtain permission for some construction activities, from the Central Environment Authority (CEA), Road Development Authority (RDA), Urban Development Authority (UDA), Municipal Council (MC), and the Police Station, as stated by PM-C1. For an instance, prior to the disposal of wastewater to the municipal line, it requires permission and ensuring that it is free of chemicals and contain non-toxic materials. Therefore, as stated by the project manager, *"all wastewater that is generated on construction site is subjected to a filtering process before it is disposed* *to the municipal drain*" [PM-C1]. Figure 5.4 depicts the existing filtering system used before dispose wastewater to public drain.

Figure 5.4: The Existing Filtering System Used Prior to Wastewater Disposal

5.3.5.6 Water Efficient Techniques

The case study interviewees highlighted many on-site water efficient techniques. PE-C1 and PS-C1 stated that high-pressure spray gun hoses for wheel washing and cleaning floors after chipping reduces unnecessary water usage. Workers used pressure reduction valves to reduce water pressure for some construction activities and to control water usage.

5.3.5.7 Re-Use and Recycle

The project manager [PM-C1] stated, "*During concreting, the batching plant water run-off and water used after washing trucks is sent through a sedimentation and settlement tank. After the filtering process, the filtered water is reused for curing and tools washing purposes*". This, specify the application of closed looped (recycling and reuse) system on the site.

5.3.5.8 Rain Water Collection

Another on-site water efficiency measure highlighted by PM-C1 was, "*we collect rainwater and use for some indirect construction activities such as dust controlling* *and vehicle washing*" [PM-C1]. He further stated that filtered drain water is used to fulfil fire regulation requirements.

5.3.6 Drivers and Barriers that Effect on Efficient Use of Water During Construction

This section analyses the drivers and existing barriers that affect efficient use of water during the construction stage. Absence of separate water sub-meters prevented calculation of the exact water consumption for individual items. The project manager explained about on-site record keeping on water needs, water supply, and consumption; *"at present, no record keeping is practiced on water need, on exact amount of water supply, or water used for individual activities. Even if we used rainwater and other alternative water sources for certain indirect construction activities, currently there are no record keeping either on water received from sources or water consumed for different activities on the site"*[PM-C1]. The project manager [PM-C1] further stated, *"there is no water auditing system that checks water consumption of each month. Administrative officer is responsible for any significant deviations of monthly water bill on the construction site"*.

The project manager attempted to provide a general comment, which may be applicable to the entire construction industry, and which focussed on at least two main aspects: introducing water requirements at the outset of project design stage to tender stage, and the role of the government and relevant authorities on implementing water efficiency practices in construction industry. The PM-C1 stated, *"still no sustainable solution for water management at tender stage nor any proposals or innovations introduced by the consultants/responsible parties whenever they make the designs or the practices in construction. It should be implemented by the powerful arm such as the authorized government body or the relevant institutes engaged in construction industry, as a mandatory requirement in the country"* [PM-C1].

When questioned about the reasons for the absence of integrating water efficient techniques during construction, the project engineer [PE-C1] stated, "*everything is a cost to the project*" [PE-C1]. He elaborated that, *"During the tender, everything* *should be included as tender requirements, so it automatically connects to the project cost. None of the contractors is interested on spending additional costs unless mentioned in the tender document, especially in the competitive bidding environment. Contractors always think of high profits from their jobs, and thus, use of water efficiency technologies is limited on construction sites. For example, use of curing agents is more effective but the cost is high"* [PE-C1]. In addition, the project manager highlighted that *"water is comparatively inexpensive"* and thus, to a certain extent, still a less attention is paid for water efficiency [PM-C1]. However, according to the project manager, "*our company has developed many sustainability strategies on resource efficiency during the construction; thus, currently, certain strategies have helped to minimise unnecessary water wastages on the site"* [PE-C1].

Project manager and project engineer stated that, experience and commitments of individual staff members greatly influence current water management practices. PM-C1 indicated, "*Personally I attend to them and wherever possible, implement strategies"* [PM-C1].

Figure 5.5 synthesises the water use efficiency measures, and barriers and drivers that influences efficient use of water during construction phase as presented in a cognitive map of Case Study 1. Drivers refer to positive influences on efficient use of water and barriers represent negative influences on efficient use of water during construction phase.

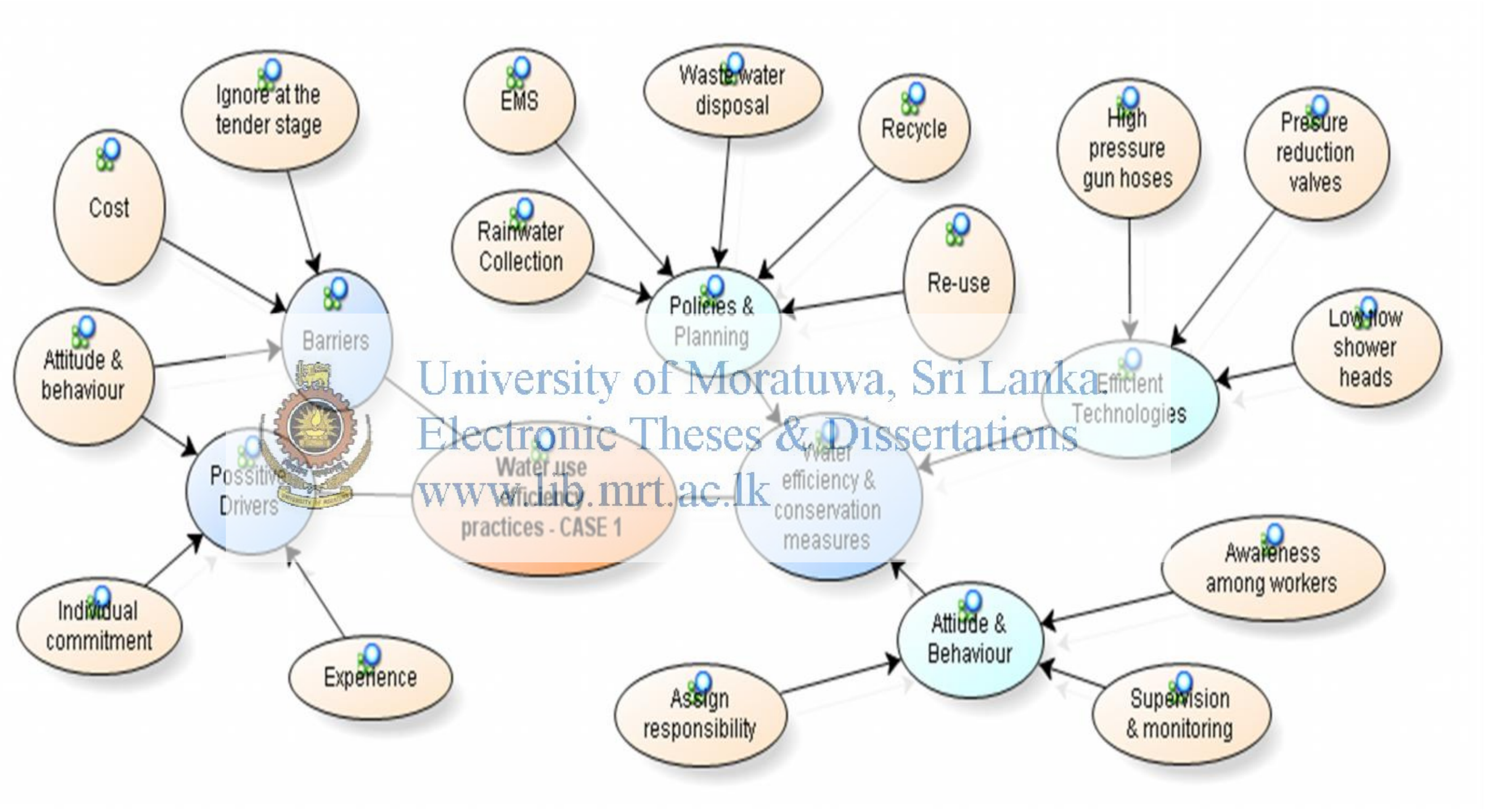


Figure 5.5: Cognitive Map for Water Usage During the Construction Stage – CASE STUDY 1

5.4 Analysis of CASE STUDY 2

5.4.1 Background to the Case Analysis

The selected project is an on-going super luxury residential apartment at construction of the superstructure stage (at the 10th floor level). Project is 15% completed according to the construction programme. The project scope comprise of constructing a fifty-storeyed building with a nine level car parking building, which provides 370 vehicle parking facility. The luxury residential apartment and the car park includes a concrete framed structure, block work for external and internal walls, cement plastering work, painting work, and timber doors and aluminium windows. Table 5.6 provides other important project details of case study 2.

Table 5.6: Project Details of Case Study 2

Project Classification	Residential Apartment
Project Cost	Rs. 5.09 Billion
Building Area	54,500 m^2
Project Duration	44 months
Commencement Date	01st August 2013
Client type	Private
Contractor Grade	C1 Building
Contractual Agreement	Design and Build , Lump sum
Amount allocated for water in Preliminary bill	Rs. 40,950.00 per month Approximately 0.75% from total preliminary bill
Typical site working hours	7.30 a.m. to 4.30 p.m.(Work until 9.30 p.m.)
Average number of management staff	45
Average number of people on site	200

5.4.2 Water Sources and Water Storage

5.4.2.1 Water Sources

The main water supply and well water were the water sources for the construction site, and the site received two (02) main water connections. According to interviews, no specific pre-determined activities or processes practised according to water source. As stated by project manager, well water is mainly used for indirect construction works such as curing, cleaning, wetting roads, and washing wheels. Main water supply fulfils drinking, bathing, washing, sanitary purposes of labourers, and certain direct activities (plastering, rendering) and indirect construction activities (curing, testing, and structural testing) [PM-C2]. As stated by PM-C2, ground water table is high around the site and the quality of well water is not up to the drinking standard.

5.4.2.2 Water Storage Methods

According to interviews and site observations, four plastic shell tanks with a capacity of 2000 litres were used to store water derived from main water lines, which is used for site cabins, welfare, and sanitary purposes of labourers, and direct construction activities. Another two tanks with a capacity of 2000 litres store water derived from the well, which was used for certain construction activities such as curing, cleaning, washing vehicles, and dust controlling. No detailed water schematic plan was available for the site to illustrate the layout for temporary water distribution indicating locations of water outlets and distribution of pipes network.

5.4.2.3 Quality Control of Water

When questioned whether the quality of well water meets the standards given in the specification document SCA/4/1 published by the ICTAD (2004) (Institute of Construction Training and Development) currently known as CIDA (Construction Industry Development Authority), the project manager replied that they have checked the water quality initially and found it does not comply to drinking standards [PM-C2]. However, the observation and discussion with labourers (05) revealed that well water was used for curing purpose as well. This is against the standard specified for water for curing, according to the specification document (SCA/4/1).

5.4.3 Water Usage on Construction Site

According to the project manager, ready mixed concrete was supplied for all concreting items on the site and block work were used for external and internal walls [PM-C2]. Thus, it has a less impact on water usage from these activities compared to indirect activities such as curing, site cleaning, and washing trucks and tools associated with them. PM-C2 further stated plastering and rendering are the key wet trades that consume more water on the site, in addition to testing and commissioning, and worker requirements, which includes washing, bathing, and sanitation.

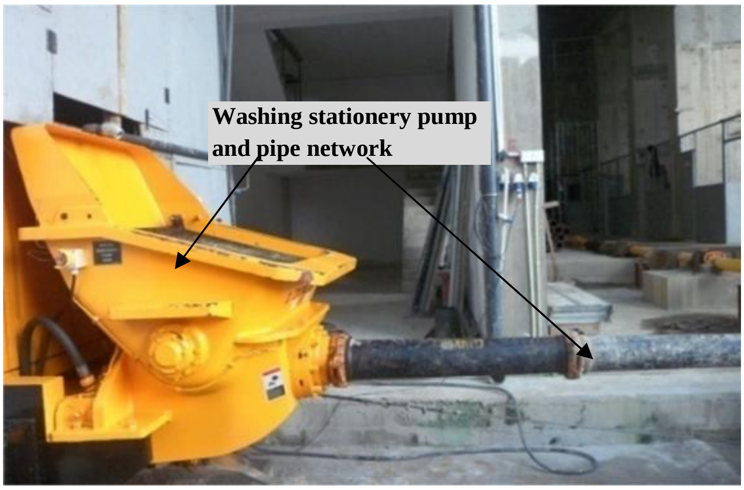


Figure 5.6: Stationary Pump to Transport Concrete for Upper Floors

Figure 5.6 illustrate the stationary pump to transport concrete for upper floors. Project supervisor mentioned that at least 4000 litres of water is needed for washing stationery pump (refer Figure 5.6) and the connected pipelines after concreting work [PS-C2].

This is another significant water consuming activity, as identified by PS-C2. Further, the required water quantity is increased for washing stationary pump, as per the number of storeys. Project engineer explained, during concreting and rainy seasons, a significant quantity of water is required for wheel washing (according to RDA regulations, it is compulsory to clean the wheels before leaving the site) [PE-C2].

Similar to Case 1, PE-C2 described that, weather, type of materials, and person who handle the work, influence on water quantity required for curing, plastering, and site cleaning. For instance, if sand gets wet, less quantity of water is needed during mortar mixing and *vice versa* [PE-C2]. Project supervisor specified that slabs and columns sizes also impacts water quantity required for curing, other than the weather condition [PS-C2].

As stated by PM-C2, well water is used for most indirect construction activities, which include curing work, dust controlling, site cleaning, and vehicle washing. The site records indicate an average number of 200 labourers working on the site. PS-C2 stated that labour accommodations are provided only for 50 labourers on the site while daily transport facilities are provided for labourers having outside accommodation.

5.4.3.1 Records of On-Site Water Consumption

Water bills comprised the main record keeping on water consumption on the site. In addition, PM-C2 mentioned that a separate person is assigned for recording reading of two meters routinely at 5.30 a.m., before starting construction work. This is maintained as an internal auditing purpose as stated by the project manager. Based on the records available on the site, Figure 5.7 depicts water consumption from June 2014 to March 2015, along with the activities according to the construction programme, labourers, and the staff. As per the figure, general water consumption is increasing.

							L 1/2	L 3/4	L 4/5	Metal work
							G.F	L 1/2	L 2/3	Toilet tiling
							G.F/L1	L 2	L 3	Floor Finishes
					Electrical/fire / plumbing					M & E work
					G.F	L 1/2	L 3/4	L 5/6	L 7/8	Int. painting
				G.F	L 1/2	L 3/4	L 5/6	L 7/8	L 9/10	waterproofing
				G.F	L 1	L 2/3	L 3/4	L 5/6	L7	Ceiling - Gypsum
			G.F	L 1/2	L 3/4	L 4/5	L 6/7	L 8	L 9/10	Plastering
		G.F	L 1	L 2	L 3/4	L 5/6	L 7/8	L 9	L 9/10	Block work
L 1	L 2	L 3	L 4	L 5	L 6	L 7	L 8	L 9/10	L 10	Concrete frame
Jun-14	**Jul-14**	**Aug-14**	**Sep-14**	**Oct-14**	**Nov-14**	**Dec-14**	**Jan-15**	**Feb-15**	**Mar-15**	Month
155	**158**	**160**	**159**	**164**	**162**	**187**	**202**	**190**	**210**	**Labour**
42	**44**	**45**	**44**	**45**	**43**	**44**	**44**	**42**	**42**	**Staff**
200	**384**	**298**	**244**	**409**	**319**	**409**	**340**	**662**	**610**	**Total Water qty. (3875m^3)**

Figure 5.7: Main Water Supply on the Site (m^3) - Case Study 2

Figure 5.7 illustrates main water supply on the site (m3), number of staff and labourers, along with construction activities based on the construction program. According to Figure 5.7, over the period of June 2014 to March 2015, 3875m3 of main water supply was used by the site, indicating the average water consumptions as 388m3 per month. As stated by the PM-C2, at the time of research, main water supply was also used for the construction works although initially it was limited for workers and management staff. Thus, it is apparent in Figure 5.7, construction trades, number of labour involvement, and main water supply used for indirect construction activities, impact on the increase of water consumption.

Based on monthly water bills, Figure 5.8 depicts the cost of city water per month on the site.

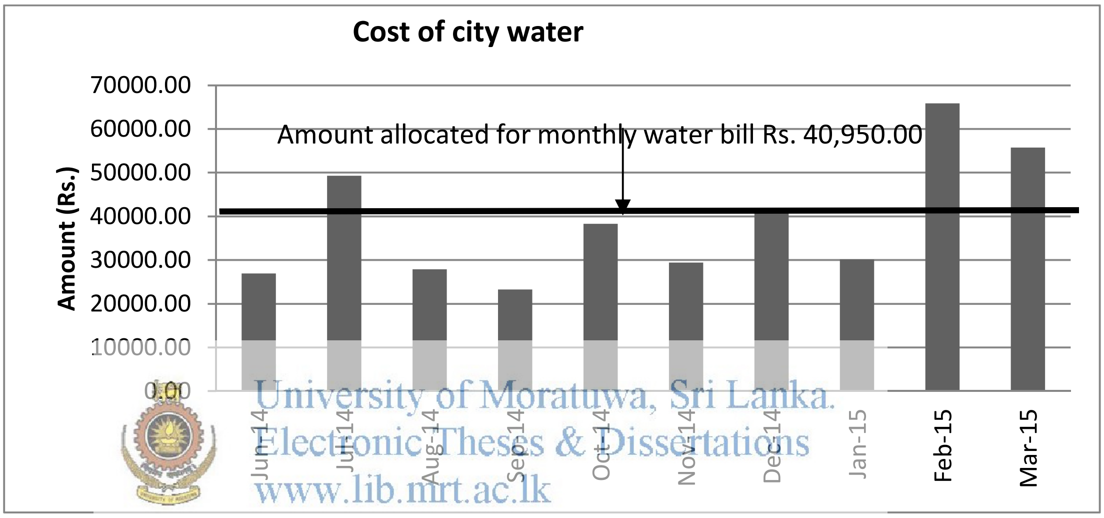


Figure 5.8: Cost of City Water per Month - Case Study 2

As illustrated in Figure 5.8, cost of water in the months of July, February, and March were above the monthly allocation of Rs.40,950 for water in the preliminary bill. When questioned about underestimating the cost of water, the quantity surveyor answered that cost of water was priced referring to previous similar projects in the same area during the tender stage [QS-C2]. Moreover, QS-C2 stated, "*even we expected well water for all construction work during the tender stage, due to poor quality standards, city water supply was used for construction activities.*" This implies that paying attention to water source and ground water condition during the pre-tender site visit is important, in addition to the volume of construction and number of people involved in the project; currently, pricing the cost of water is not considered as an important criterion.

Water Audit Conducted on the Site

In addition to available data, permission was sought from the project manager to conduct a one-day audit system for site water consumption during April. An account of this site audit is presented in Figure 5.9.

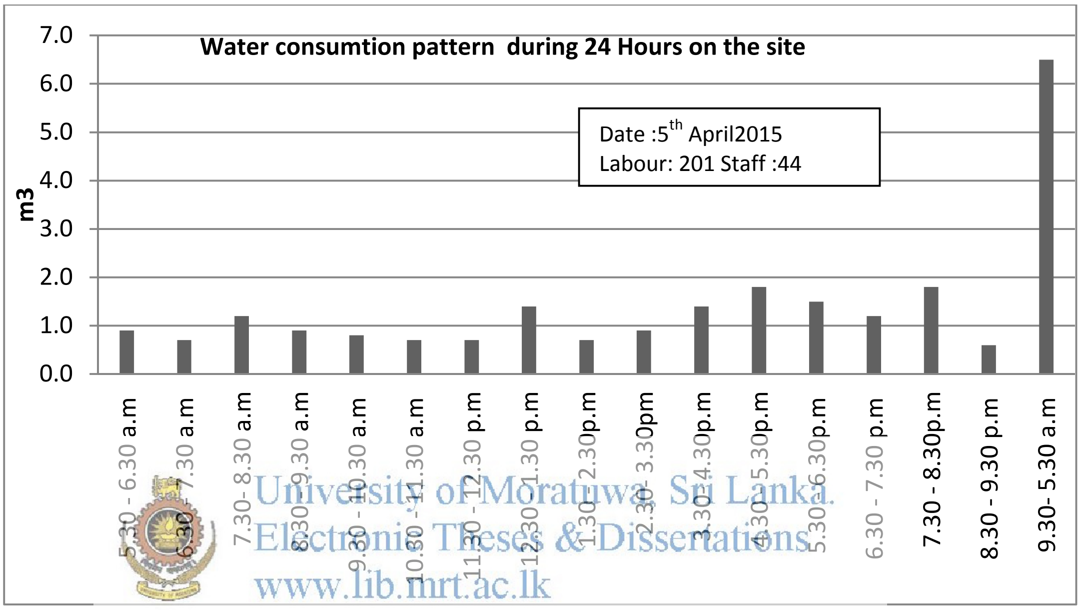


Figure 5.9: Water Consumption Pattern of a Day - Case Study 2

As per Figure 5.9, water consumption pattern indicate over 1m^3 water usage during the lunchtime (12.30 p.m. to 1.30 p.m.) and from 3.30 p.m. to until 8.30 p.m. The administrative officer informed that labourers' tea time is at 3.30 p.m. and they will be off from duty after 4.30 p.m., and time may change based on the overtime work. It could be observed that a significant quantity of water is consumed from 9.30 p.m. to 5.30 a.m. and the total water consumption during 24-hour period is given as 23.4 m^3 per day. The daily records of meter reading taken at 5.30 a.m. each day reveal that the average daily water usage is 21-24 m^3 when the average staff on the site is 42-46 and the average number of workers are around 180-200 in April. If so, the average water consumption per month is approximately 652m^3, which is similar to water consumption patterns in February and March, according to Figure 5.8. As per Figure 5.9, high consumption levels observed from 9.30 p.m. to 5.30 a.m. may be attributed to tank filling at night through pressure, overflow from tanks, or leakages in the pipe network. This indicate, conducting water audits in a regular basis on the site will help to recognize leakages, peak levels of water consumption, and to note integrate strategies to reduce unnecessary water usage.

5.4.3.2 Computing Water Requirements

Based on the above two average figures (i.e. 388m^3 per month and 652m^3 per month), the monthly average water consumption was taken as 520m^3 to produce a reasonable figure. Assuming this average main water consumption continues until the completion of the project (44 months), approximately, a 22,688m^3 of city water will be consumed by the site. This excludes water consumption for concrete trade since ready-mix concrete was used. Accordingly, water consumption is equal to 0.42m^3 per square meter of the building area under following criteria: Site use ready-mix concrete, labour force is around 200, labour accommodation provided on the site, and external walls may block work.

In addition, similar calculations as in Case 1 were used for Case 2 to identify water requirements for some wet trades and presented in Table 5.7.

Table 5.7: Water Requirement for Wet Trade Activities - Case 2

Direct activity	**Type of water source**	**Qty. based on BOQ**	**Unit**	**Water per unit based on norms* (litres)**	**Total water quantity required (m^3)**	**% from the predicted water qty. 22,688 m^3****	**Remarks**
Concrete	Beyond site	29470	m^3	200	5894.00	This does not affect site water consumption	Ready mix
Plaster work	City water supply/ well water	125,320	m^2	4.9	614.07	~ 3%	1:5 mix
Floor Finishes	City water supply / well water	54,530	m^2	4.9	267.20	~2%	1:3 mix
Painting	City water supply / well water	125,650	m^2	0.05	6.28	Negligible	One primer and two coats

*Obtained from BSR (refer Table 2.10); **this figure was derived through the monthly water bills and invoices of water that supplied through water trucks

According to Table 5.7, approximately 3% and 2% from the total water consumption is required for plastering and rendering respectively. Water requirement for painting work is negligible. However, above percentages exclude indirect water consumption associated with these activities such as cleaning and washing tools. As stated by PE-C2 and PS-C2, this quantity may vary according to the conditions of material and type of weather. It revealed that chipping and cleaning of floors need more water before laying the floor screed. This is one of the indirect activities involved with floor finishing, due to improper practices during the plasterwork.

Since there is no record on water consumption from wells, it is difficult to compute total water consumption by the site for direct and indirect construction activities. However, considering the total water consumption predicted (22,688 m^3) for main city line and the results in Table 5.7, it is apparent that the water requirement for indirect construction activities is highly significant. This results report the need for water efficient strategies for indirect activities rather than direct activities. Moreover, as stated by the project manager, excess water used in direct activities is minimal. The following subsections further discuss on site water wastages, minimisation practices, drivers, and barriers.

5.4.4 On-Ste Water Wastages

Similar to Case 1, the project manager stated, "w*ater wastage in construction activities is minimal due to continuous supervision and proper site management"* [PM-C2].Washing, bathing, and sanitation were identified as high potential activities of wastewater on the site, in addition to indirect activities such as curing, wheel washing, and site cleaning [PM-C2, PE-C2].

As stated by the project supervisor, "*most workers use running water taps directly to wash clothes. Even posters displayed at shower area, people are very careless when using water. For instance, they do not close taps properly and do not know how to operate taps, remove shower heads. And, some workers cannot read and write properly"* [PS-C2]. PS-C2 further stated, "*most workers are very arrogant and conveying messages to them is difficult."* Site observations showed dripping taps and overflowing tanks causing water wastage. Another poor practice observed was mixing mortar on the floor, as presented in Figure 5.10.

Figure 5.10 : Mixing Mortar on the Floor

PS-C2 stated, *"Water leakages is another way of wasting water on construction sites. Water may leak from damaged washers in taps, worn valves, and damaged pipe work. High frequency of operation of a tap per day also affects dripping and durability of the pipefitting."* Another point highlighted was, though showers are provided for bathing purposes, workers always remove showerheads to increase the water pressure (refer Figure 5.11).

Figure 5.11: Remove Showerheads

PS-C2 further stated, *"If not properly supervised, certain amount of water wastage may occur during curing, site cleaning, and washing tools."* Figures 5.10 and 5.11

provide evidence for such poor practices happening on the construction site due to carelessness of labourers.

When questioned whether any measurements are available on water usage and water wastage, PM-C2 answered that the site does not have a proper recording system on water use according to activities or processes other than meter reading at the main supply.

5.4.5 On –Site Water Efficiency Practices

5.4.5.1 Water Efficient Techniques

Discussions with PE-C2, PM-C, and PS-C2 revealed that following water efficient methods are practised on the site to reduce water quantity. Bowsers with sprinklers to spray water daily to control dust on roads, and high-pressure spray gun hoses for curing work, washing vehicles, cleaning machine pumps and pipe network, and for floor cleaning. Figure 5.12 depicts the use of high-pressure spray gun hoses for curing floor slabs. In addition, the site has a washing bay for vehicle washing, which helps to reduce water quantity and water wastage.

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Figure 5.12: High-Pressure Spray Gun Hoses for Curing Concrete Slabs

Vacuum system was another water efficient method used to minimise the dust generated during construction. Low flow showers were provided for workers and they were advised to use showers during bathing; further, a specific period was given for bathing and washing. It revealed that without proper monitoring and supervision, none of these systems functions effectively.

The project engineer stated that *"curbs are provided at the edges of slab perimeter to avoid water wastage during the curing other than use of gunny bags and thick polythene sheets"* [PE-C2].

Project supervisor suggested the possibility of using flexible pipe network or heavy duty pipe system for temporary distribution line to reduce pipe get damaged due to droppings and damaging equipment and tools. However, cost is identified as the main barrier when implementing such work [PS-C2].

5.4.5.2 Raising Worker Awareness

According to PM-C2, conducting awareness raising programmes and meetings among people and displaying posters at necessary places (refer Figure 5.13) are other strategies followed during construction to control water consumption by workers.

Figure 5.13: Display Posters on the Site to Save Water at Bathing Area

5.4.5.3 Assign Responsibilities

The project manager stated, *"we have assigned two persons for inspecting overall site activities. They check water-collecting places to avoid spreading diseases among workers; e.g. Dengue"* [PM-C2]. As stated by PM-C2, *"there is a high risk of spreading diseases on construction sites that can hugely impact on project progress. Thus, the amount of money we spend on these two workers is more worth, compared to the total loss"*. In addition, the management staff was made responsible on overall site management [PM-C2]. As stated by PS-C2, "*the education level, behaviour, and attitudes greatly impact on resorting correct actions, which make working as a team more productive*."

5.4.5.4 Water Auditing

It was noted that daily meter reading is a good practice conducted on the site. This is similar to an internal auditing system, and according to PM-C2, the administrative officer is responsible for this. PM-C2 further stated, "*At present, other than keeping records, none of the analysis is performed on the site to check water consumption pattern.*" PM-C2 recognized and agreed with the idea of making graphs for each month to check the daily water pattern with the number of labour force and construction activities, and include in the monthly progress report.

PM-C2 and PE-C2 identified the importance of having a water action plan and an EMS plan for a site as efficient water practices, though the site does not use such practices.

5.4.5.5 Compliance with Obligations

As stated by the project manager, all wastewater generated on construction sites is subjected to a filtering process before disposed to the municipal drain [PM-C2]. Project supervisor mentioned, "*there are two waste water drains connected to the canal and five manholes are used to collect water from construction sites. Wastewater from workers' bathing and storm water is directly discharged to one drain. Similarly, another waste drain is connected to the canal after the filtering system*" [PS-C2].

5.4.5.6 Encourage Innovative Methods/Techniques

The project manager stated, "*I have introduced one litre plastic water bottle in the cistern and saved a litre of water in each flushing by the management staff. I have already practised these in my previous projects and reduced water bills to a certain extent. We tried sensor taps, but it was not a success*" [PM-C2]. Cost on frequency repairs, replacement cost, and stealing are some hindrances highlighted by PM-C2 in terms of implementing sensor taps on construction sites.

5.4.6 Drivers and Barriers that Effect on Efficient Use of Water During Construction

As stated by the project manager, individual commitment and previous experience greatly impact on current practices adopted in the site, since there is no specific guide on water management aspect [PM-C2]. PE-C2 further stated that certain water reduction strategies have implemented during the construction period and it depends on the commitment of management staff.

Project Engineer stated, "*Use of potable water must be constantly monitored, investigated, and strictly controlled, to make consumers understand the need for conserving potable water*" [PE-C2]. Further, PE-C2 mentioned, "*Our workers' awareness on the scarcity of potable water and water availability is limited.*" PM-C2 described that workers assume they get water free of charge, and hence lacks the feeling of its real value. Conversely, PE-C2 identified that the water source directly affect saving water. He stated, "*Here, site workers get water free of charge and they have a feeling of 'don't pay don't care attitude'; the increased water bill won't affect labourers, but ultimately goes to the client or the contractor".* Quantity surveyor [QS-C2] stated that one of reasons for less attention on water resources as, "*....sustainability practices and social responsibility on natural resources are not addressed in the project specific documents.*" PE-C2 was of the same opinion that "*water efficient techniques and strategies were not identified at the tender stage*" and PM-C2 further stated, "*Significantly less cost of water compared to other preliminary commodities indulge them to pay less attention.*" Another important point stated by PE-C2 was, "*None of the contractors were interested on spending for water efficient techniques, unless they enjoy completive advantages.*"

Figure 5.14 synthesises the water efficiency measures, drivers and barriers that influences water efficient practices, and presented in a cognitive map of Case Study 2. Drivers refer to positive influences on efficient use of water and barriers represent negative influences on water efficient during construction phase.

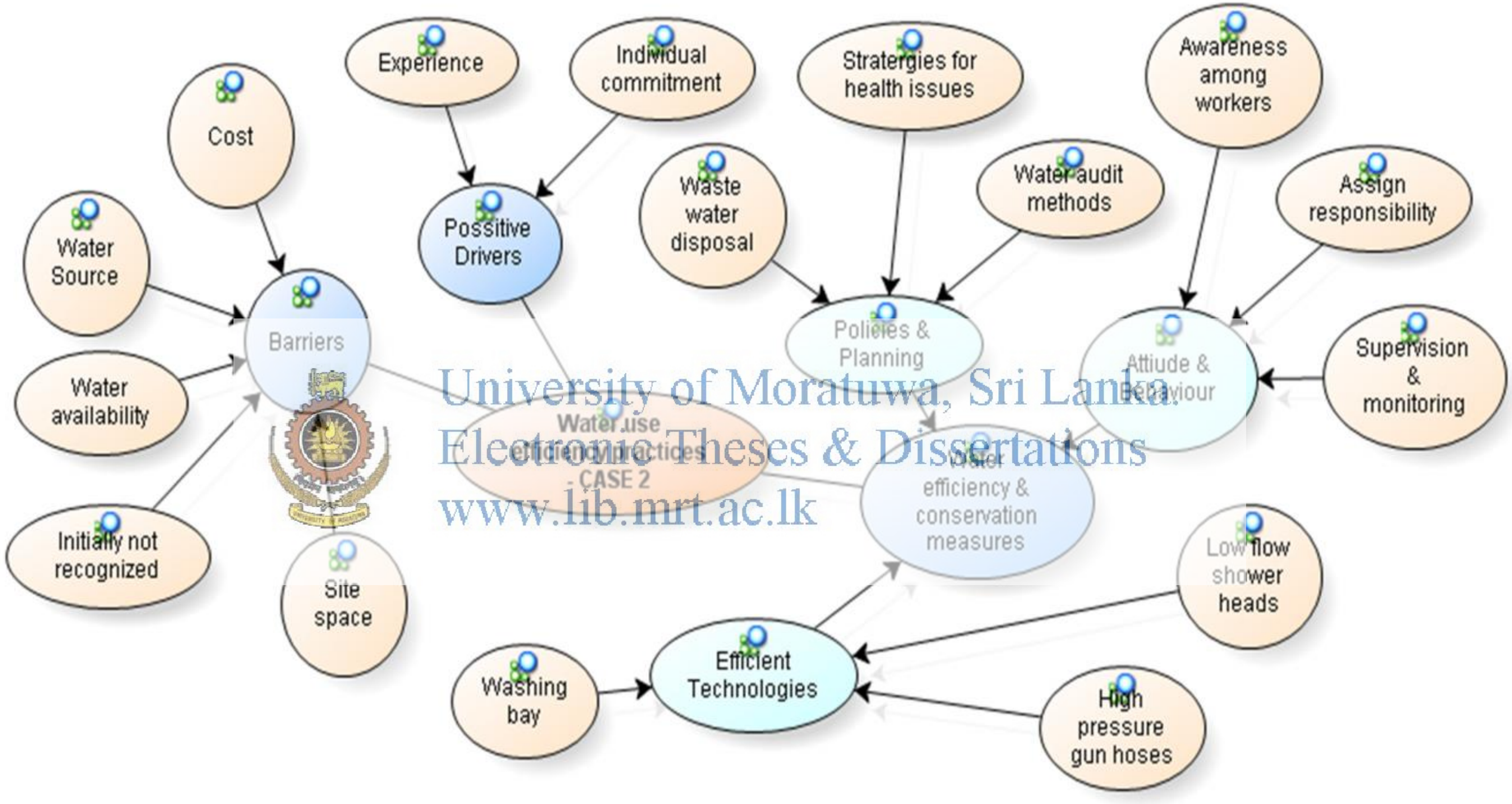


Figure 5.14: Cognitive Map for Water Usage During the Construction Stage of Case Study 2

5.5 Analysis of CASE STUDY 3

5.5.1 Background to the Case Analysis

The selected project is an on-going office complex and the project is at construction of brick walls and plastering work. The project progress is 47% completed as per the construction programme. The project scope consists of construction of thirteen storeyed building. The office complex include a concrete framed structure, block walls, cement plastering work and painting works, and aluminium doors and windows. Table 5.8 provides other important project details of the Case Study 3.

Table 5.8: Project details of Case Study 3

Project Classification	Office building
Project Cost	Rs. 1.0 billion
Project Area	8000m^2
Project Duration	21 months
Commencement Date	August 2013
Client type	Private
Contractor Grade	C1 Building
Contractual Agreement	Design and Build - Lump sum
Amount allocated for water in Preliminary bill	Rs. 685,000.00 Approximately 1% from the preliminary bill
Typical site working hours	7.30 a.m. to 4.30 p.m. (work until 9.30 p.m.)
Average number of management staff	18
Average number of people on site	56

5.5.2 Water Sources and Water Storage

5.5.2.1 Water Sources

The main water source for construction was the main water supply. As project manager stated, initially, tube well water was used for substructure construction work, but later it revealed that water quality did not satisfy the construction standards as stipulated by the specification document SCA/4/1 published by ICTAD (2004). Therefore, tube well water was utilised for site cleaning and dust controlling purposes [PM-C3]. As stated by project manager, at the time of the research, they have never used tube well water for any other purpose due to its high level of contamination. Therefore, water requirements for construction work totally depended on the main water supply during data collection. PM-C3 further stated that when water demand exceed the supply, then water is transported in bowsers (water trucks), and according to project supervisor, two main water connections are used for direct and indirect construction work [PS-C3].

5.5.2.2 Water Storage Methods

Interviews and site observations revealed that two tanks of 5000 litres capacity and two plastic shell tanks of 2000 litres capacity were used to store water for construction, site accommodation, and sanitary purposes. Labour accommodations were provided on the site. It was observed that water was stored in small barrels and flexible pipes used where necessary. As stated by project supervisor, water tanks of 1000 and 500 litre capacity were provided for necessary floors when water-consuming activities were in action (e.g. plastering, masonry, lintols) [PS-[i]S3].

Similar to Case 1 and Case 2, a detailed water schematic plan for the site does not exist here; i.e. layout for temporary water distribution, which indicates locations of water outlets and distribution of pipes network.

5.5.2.3 Quality Control of Water

Interviewees were asked about how they control quality of water used in the site. As stated by project manager, checking water quality was unnecessary since the site uses main water supply. However, PM-C3 stated, initially they have tested quality of tube well water.

5.5.3 Water Usage on Construction Sites

According to the project manager, ready-mixed concrete was supplied to all concreting items on the site [PM-C3]. Thus, less impact was noted on site water usage. Curing, site cleaning, washing trucks and tools were identified as associated indirect construction activities with concrete trade. PE-C3 stated, "m*ain key wet trades as brick work, plastering, and rendering consume more water on the site in addition to testing and commissioning, and worker requirements such as washing, bathing, and sanitation.*" As stated by project supervisor, "*at the time, 50-60 number of labourers worked at the site and labour accommodation was provided on the site"* [PS-C3]. Quantity surveyor informed that "*a considerable water quantity is required for soaking bricks. According to the test reports prepared on water absorption of* *bricks, one brick absorbs 450ml of water on average"* [QS-C3]. However, as stated by PE-C3, "*water quantity depend on site location, weather condition, and the construction method*". PE-C3 further stated that *"during rainy season, less quantity of water required for brick soaking, plastering (due to wet sand), and for any curing work*" [PE-C3]. Project engineer further described that "*in the construction process, commissioning and testing of plumbing, air conditioning (A/C), and M & E works performed at a later stage, consumes a large volume of potable water"*.

5.5.3.1 Records of On-Site Water Consumption

Reviewing site documents and speaking to site staff identified that monthly water bills are the main documents available for computing site water consumption, which is maintained by the accountant. Project manager stated that administrative officer is in-charge for monitoring site water consumption [PM-C3].

Site water consumption was calculated based on monthly water bills from January 2014 to February 2015, and presented in Figure 5.15.

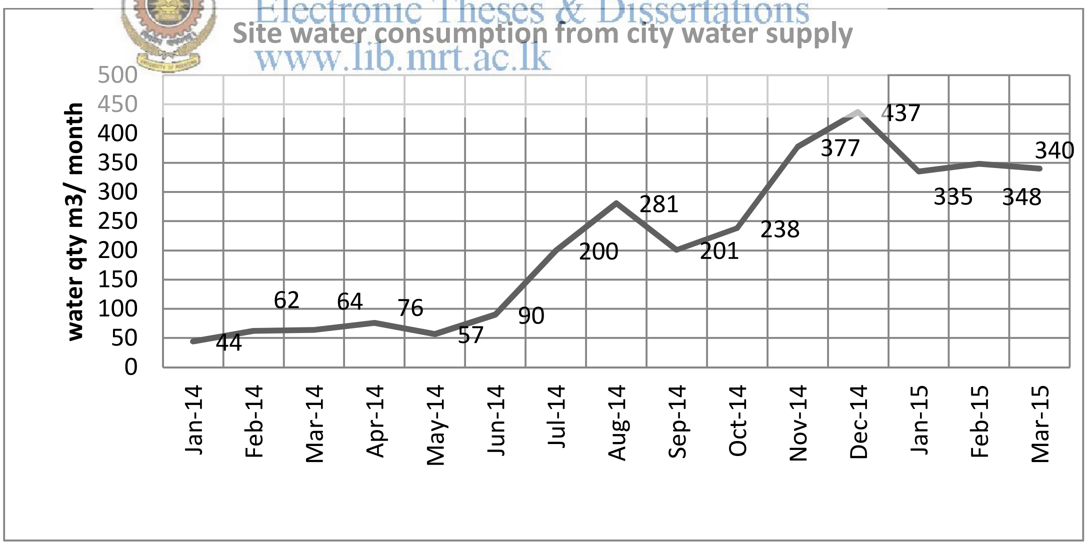


Figure 5.15: Volume of Water Supplied to the Site (m^3) - Case Study 3

It is apparent in Figure 5.15, during the initial six months period, water consumption was less and the average monthly water consumption was less than $70m^3$. The project manager explained reasons as, *using tube well water initially during* *substructure construction work, less number of labour involvement, and due to project delays* [PM-C3]. According to Figure 5.15, water consumption increased tremendously with the commencement of other construction work.

Since records were available in January 2014, it was possible to calculate the water consumed in the site was 3150m^3 over a period of 14 months, giving an average of 210m^3. This produces an average water bill of Rs.35,530.00 per month. Assuming the average water bill continues until the completion of the project (21 months) (excluding maintenance period), approximately the total cost of water is around Rs.746,500.00, which is more than the allocated sum in the preliminary bill. When questioned about under estimation of cost of water in the preliminary bill, QS-C3 answered that *less attention paid on factors such as total water volume, water source, and number of labour force during the tender period may resulted such deviations*. QS-C3 further stated that contractor organizations rarely maintain database for site water consumption, other than individual experiences.

According to the available data, Figure 5.16 further illustrates the water usage between construction and non-construction activities from June 2014 to January 2015. Non-construction refers to water consumed by workers. Considering the average workforce and their water consumption per month, benchmark for average water consumption was calculated as ~ 140 litres per day per person in this project.

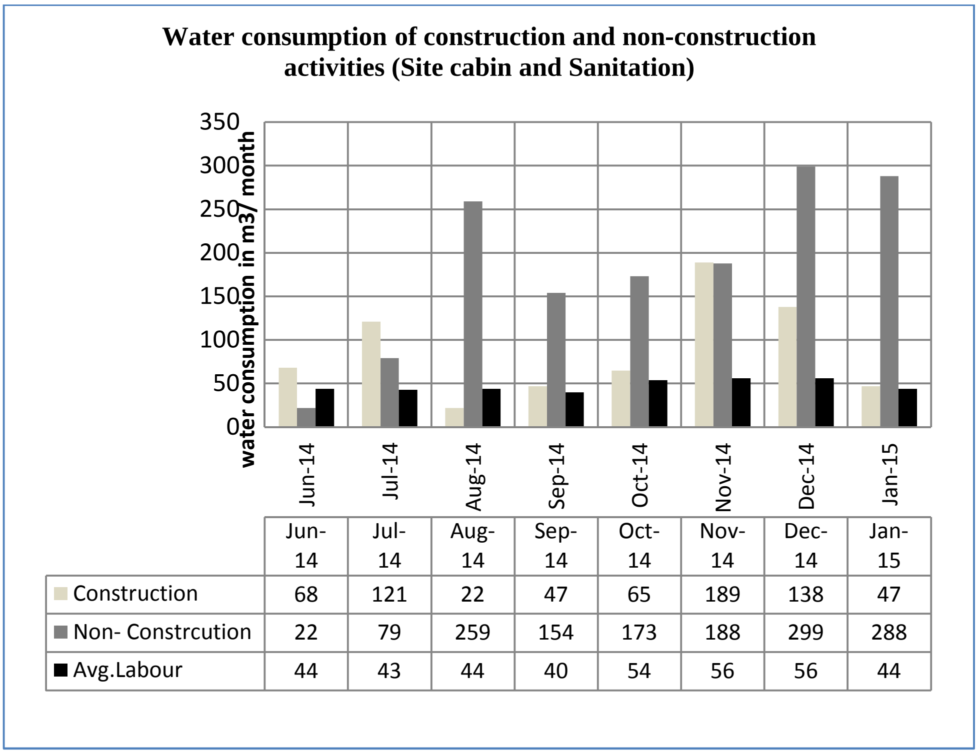


Figure 5.16: Volume of Water Consumed by Non-Construction - Case Study 3

5.5.3.2 Water Auditing on the Site

Project manager admitted that the site lacks a water action plan and a water audit system. PM-C3 further stated these terms are not familiar in the exiting project documentations. During the data collection period, permission was sought from the project manager to conduct water audit to analyse regular site water consumption pattern. Details of the water audit conducted in two days are summarised in Table 5.9.

Table 5.9: Information of Water Auditing - Case Study 3

Date on water audit	20th March 2015	21st March 2015
Time (24 Hours)	Record at one hour interval start at 6.00 a.m.	
Number of management staff	16	15
Number of labourers	50	42
Number of labourers accommodate on site	49	39
Water consuming construction activities taken place	Brick work (mortar), lintol work	

Water meter reading started from 6.00 a.m. in one-hour intervals. It was possible to record water consumption on two consecutive days as depicted in Figure 5.17 and Figure 5.18. It is apparent in Figure 5.17, water consumption pattern varied over the period. In addition, Figure 5.17 illustrates the total water consumption per day and similar pattern in both days. The average water consumption was in between 8-9 m^3 per day with 43 labourers and 15 management staff working on site. During these two days, significant water consumption in construction activities was not reported by PS-C3 as per the construction programme.

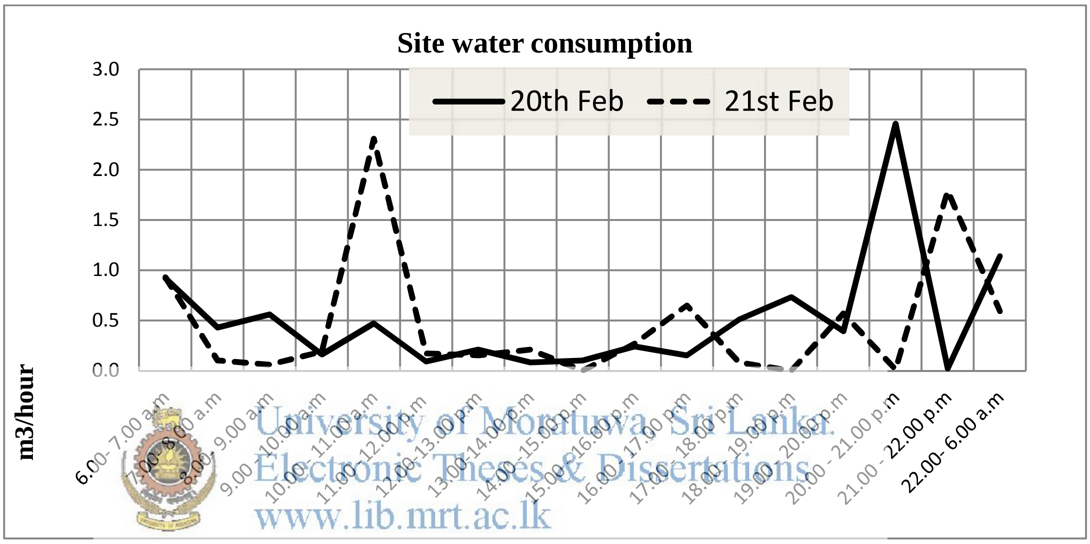


Figure 5.17: Water Consumption Pattern

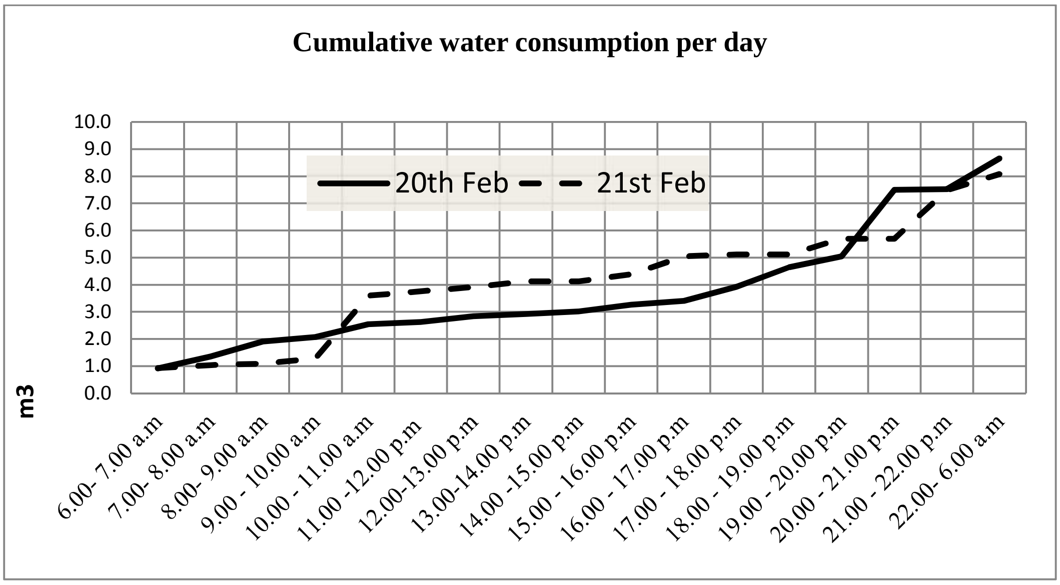


Figure 5.18: Total Water Volume per Day

However, in Figure 5.17, a noticeable rise in water consumption was observed on 21st February around 10.00-11.00 a.m. It was due to additional washing, cleaning, and curing work related to a minor concreting work performed during the morning as stated by PS-C3. It is apparent in Figure 5.17 that water consumption was considerably high before 7.00 a.m. and after 8.00 p.m. and a similar pattern could be observed in Case 2 analysis. Results in Figure 5.18 indicate that the total water volume was equal in consecutive days and was around $8.5m^3$ per day.

When results of water auditing was discussed with PM-C3 and PE-C3, they identified the benefits of conducting water audits at sites (visible to recognize leakages, peak levels of water consumption, water consuming activities, and water volume required per day) and explained that it would be beneficial to include these requirements in tender documents.

5.5.3.3 Computing Water Requirements

It is apparent in Figure 5.15, from July 2014 onwards, the average water consumption increased to $306.3m^3$ per month. Accordingly, the average main water consumption was $258.1m^3$ per month (average of $210m^3$ per month and $306.3m^3$ per month). As per the results of water audit, it proves the accuracy of average monthly water consumption ($8.5m^3$ per day = $255m^3$ per month). Assuming the average consumption continues until completion of the project (21 months), the site will consume approximately 5420.1 m^3 of main water. This can present as a water consumption rate of 0.68 m^3 per square meter of the building area. One main reason for this high figure compared to Case 1 and Case 2 is this site totally depended on main water supply for direct and indirect activities. Construction methods and type of building materials are other variables identified.

As discussed in Section 2.9 of Chapter 2, norms for water quantity were available for limited direct activities (wet trades). Based on project BOQ and obtaining available norms from BSR, Table 5.10 illustrates water requirements for some wet construction trades of Case Study 3.

Table 5.10: Water Requirement for Wet Trade Activities - Case Study 3

Direct activity	**Type of water source**	**Qty. based on BOQ**	**Unit**	**Water per unit based on norms* (litres)**	**Total water quantity required (m^3)**	**% from the predicted water qty.5,420.1 m^3****	**Remarks**
Concrete			m^3	200	This does not affect site water consumption		**Ready Mix**
Brick Wall	City Water Supply	5127.0	m^2	12.4	63.47	**~1.5 %**	**Full brick**
Brick Wall-Half Brick	City Water Supply	1085.0	m^2	5.4	5.84		**Half brick**
Plaster work	City Water Supply	16,157.0	m^2	4.9	79.17	~1.5%	1:3 mix 16mm thick
Floor Rendering	City Water Supply	6,814.0	m^2	4.9	33.39	~ 1.0 %	1:3 mix, 20 mm thick

* Obtained from BSR (refer Table 2.10); **this figure was derived through the monthly water bills and invoices of water that supplied through water trucks

The results in Table 5.10 indicate that approximately 5% of water quantity is needed for direct construction activities, excluding concrete work. Similar results could be observed in Cases 1 and 2. As found from other cases, concrete work is the main direct activity which consumes more water. The results further proved that a significant quantity of water is consumed by indirect construction activities.

Section 5.9.3 discusses the relationship between available standard norms and the norms that are developed based on site practice of some work studies conducted on the site.

5.5.4 On-Site Water Wastages

When queried on water wastage actions during construction, PM-C3 and PE-C3 stated that water wastage due to direct construction activities is minimal. They have emphasized that more water wastage may occur in labour usage like bathing and washing. Similarly, project supervisor mentioned that, *"It is very difficult to control water consumed by labourers. This totally depends on worker behaviour. Most workers on the site come from villages and their education level is very low; majority cannot write or read. Though we have provided showers for bathing, most of them* *remove showers or shower heads. Thus, water wastage is high, because they are used to draw water from wells or rivers before they came here"* [PS-C3].

Discussions with a few five (05) number of labourers revealed that the water pressure is low when using showers, and since they are tired after working hard the whole day, it is inconvenient for them when the water pressure is low. However, interviewees [PM-C3, PE-C3, and PS-C3] were of the opinion that workers rarely feel or worry about conservation of water. PS-C3 stated the impracticability of introducing a penalty system among workers on their due care.

Project engineer stated, "*Water needed for the curing purpose cannot be considered as wastage but can be minimised through proper supervision and integrating water efficiency techniques"*. PE-C3 further stated, "*A major complaint from the consultant was the inadequate water for curing work. In certain days, more than three times of curing work was performed for slabs per day due to high temperature during concreting time. However, we can reduce water quantity by replacing water curing agents, but it is expensive"* [PE-C3].

In addition, the project engineer stated, "*Water wastage may happen during site cleaning and washing vehicles. Several times, I have observed, workers open the taps and attend another work while washing and cleaning. Thus, quantity of water wastage totally depends on the person who handles and his carelessness*" [PE-C3]. Moreover, PE-C3 stated, *"We observe dripping taps and leakages from taps, but most of the time, nobody take any action."*

Project supervisor stated, *"Water used for testing, plumbing, air conditioning (A/C), and M & E almost go wasted after the testing. If there is a mechanical system to collect water, it can be reused for another purpose"* (PE-C3). Further, interviewees mentioned, "*Implementation of these practices totally depends on the responsibility of the top management*" [PS-C3]. Another possibility of re-use of water identified by project manager was, "... *it is possible to re-use water consumed for water proof testing. It can be used for mixing mortar for the tile bed in the same floor, if planned in advance"* [PM-C3].

5.5.5 On – Site Water Efficiency Practices

5.5.5.1 Raising Worker Awareness

As stated by the project manager, the site has no special water management plan, even for the environmental management system. As found from other sites, PM-C3 stated, "*During the regular site meetings, safety officer and technical officers generate awareness on water consumption among workers.*" PS-C3 stated, "*We have already educated our workers on preventive measures on health affairs, since health officers visit sites on a regular basis to prevent health issues, e.g. Dengue.*" PS-C3 further explained, *"Posters on water saving are pasted on walls to communicate the importance of saving water."*

5.5.5.2 Assign Responsibilities

The project manager specified, "*Management staff has been assigned to monitor and supervise construction work*" [PM-C3]. As stated by the project engineer, "*Certain responsibilities come under the control of management staff in terms of water consumption by construction activities*" [PE-C3].

5.5.5.3 Water Efficient Techniques

The interviews revealed, currently, some water efficient techniques are implemented on site, based on the site management experience and their commitment.

It disclosed that admixtures and chemical additives were used during concreting and plastering to reduce water quantity and increase workability. High-pressure spray gun hoses were used for wheel washers and cleaning purposes, and pressure reduction valves are used at necessary places to reduce unnecessary water wastages. As project engineer [PE-C3] stated, "*During the ground work, dewatering water was used for construction of piling work.*" During the curing of slabs and columns, gunny bags and thick polythene sheets were used to reduce water evaporation (Figure 5.19). In addition, sand or mortar makes edges around the slab to stop water overflow through slab edges to reduce water quantity.

Figure 5.19: Columns Covered with Gunny Bags to Reduce Water Evaporation

Use of metal trays (6’x4’) for mixing mortar and concreting work (lintol work) are other strategies on water efficiency, observed on the site (Figure 5.20). The two (02) labourers said that when trays are used, it is easy to change location without wasting materials and it reduces time and water for cleaning.

Figure 5.20: Trays Fofr Mixing Mortar and Concreting

Project Engineer [PE-C3] suggested, “*Using sensor taps could minimise wastage, but currently special water efficient techniques cannot be used on the site*”. Engineer explained reasons for this as “*being expensive, most workers are not familiar with the method to operate such taps, and there are chances for greater losses.*”

5.5.5.4 Compliance with Obligations

Similar to other cases, since the site was located in the Colombo municipal area, the contractor is obliged to take permission for construction activities from relevant authorities. The project manager [PM-C3] stated, *"The contractor ensure the absence of non-toxic or chemicals in waste water before it is disposed. In addition, health officers execute monthly site inspections to detect dengue."*

5.5.5.5 Site Policies

PS-C3 informed, *"Limited time was allocated for labourers for bathing and washing in the morning and evening to control water consumption."*

5.5.5.6 Worker Behaviour and Attitudes

During site visits, vegetable cultivations (e.g. Kohila, Chillies, Curry leaves, Spinach) around the site office and near labour accommodation were observed, as presented in Figure 5.21. Few labourers (3) informed that some workers were interested in planting and harvesting them for cooking. This is a good practice to implement in construction sites, since current trend of the country and the world is to move towards sustainability and green concept.

Figure 5.21: Sustainability Practices - Vegetable Cultivation

5.5.6 Drivers and Barriers that Effect on Efficient Use of Water During Construction

This section analyses the drivers and existing barriers that influence efficient use of water during the construction stage. When inquired about the barriers on efficient use of water on the site, the project manager stated that water is still easily accessible and cost of water is comparatively low; therefore, the management pays less attention [PM-C3]. Project engineer [PE-C3] stated as previously, "*This site does not use pre-determined water efficiency techniques; all practices are based on staff experience.*"

PS-C3 stated, *"The most difficult task is to convince things to labourers who have different education levels, and different attitudes and behaviours towards water usage."*

When questioned about the possibility of rainwater collection on the site, PE-C3 replied, "*This site is very congested, therefore rainwater collection is impracticable. When considering rainwater, it should be used at least for 6-7 months; otherwise, it is wastage for a project with the initial cost. If rainwater collection is compulsory for a site, it should include in the initial plan and communicated through tender documents. Everything costs for the contractor. Therefore, it is necessary to communicate initially with the contractor. For example, if curing agent or sprinklers are used, it should be mentioned in project specifications, or else, the contractor will strictly adhere to traditional methods irrespective of its efficiency"* [PE-C3].

The engineer believed that *"It is important to cultivate good practices among construction workers; unfortunately none of them are interested in it with important phenomenal with the tight schedule"* [PE-C3].

Figure 5.22 synthesises the water efficiency measures, barriers, and drivers that influences on efficient use of water during construction phase, and presented in a cognitive map of Case Study 3. Drivers refer to positive influences on efficient use of water and barriers represent negative influences on efficient use of water during construction phase.

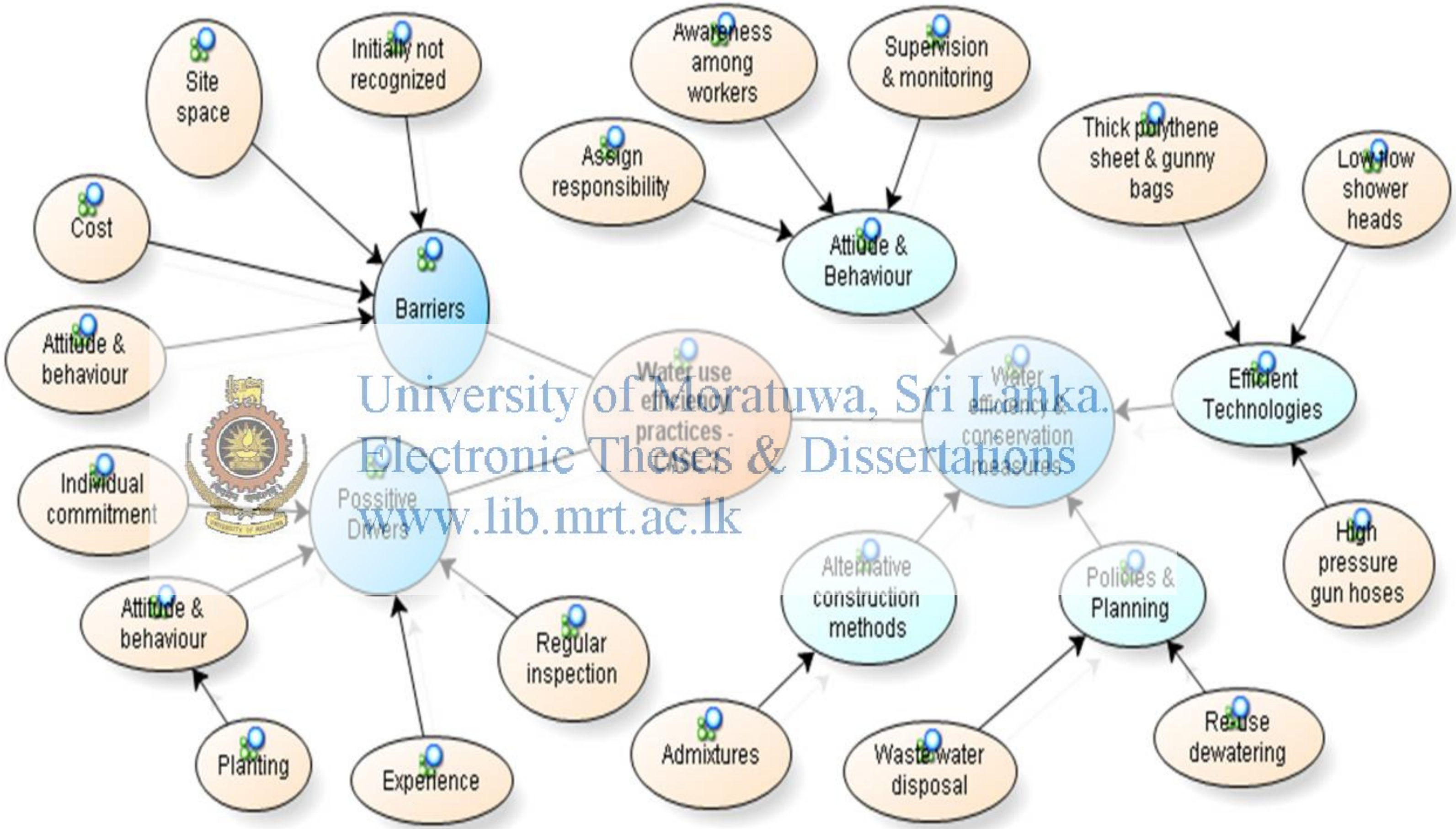


Figure 5.22: Cognitive Map for Water Usage During the Construction Stage of Case Study 3

5.6 Analysis of CASE STUDY 4

5.6.1 Background to the Case Analysis

The selected project is an on-going office complex, currently at the stage of superstructure construction (at the 5th level). The project progress is 18% completed according to the construction programme. The project scope comprise of construction of thirty-five storeyed building including two basements. The office complex include a concrete framed structure, block walls, cement plasterwork and painting work, and timber doors and aluminium windows. Table 5.11 provides other important project details of Case Study 4.

Table 5.11: Project Details of Case Study 4

Project Classification	Office building
Project Cost	Rs. 7.89 billion
Project Area	46451.5 m^2
Project Duration	36 months
Commencement Date	October 2013
Client type	Government
Contractor Grade	C1 Building - Joint venture with a foreign firm
Contractual Agreement	Design and Build , Lump sum
Amount allocated for water in Preliminary bill	Rs. 22.0 million (3% from preliminary bill)
Typical site working hours	Start at 7.30 a.m. - 4.30 p.m. over time work until 10.00p.m.
Average number of management staff	45
Average number of people on site	140

5.6.2 Water Sources and Water storage

5.6.2.1 Water Sources

City (main) water supply was the main water source for the construction site. As stated by project manager [PM-C4], "*High contamination of ground water was the main hindrance for using tube well water as an alternative water source for main water supply.*" Project engineer stated, "*During substructure construction, it was found that the site was filled with chemicals wastes, and thus, soil was highly polluted. This was one of the reasons for high contamination of ground water*" [PE-C4]. Therefore, mainly main water supply fulfilled direct and indirect construction activities. As stated by PM-C4, "*Bowser water (water trucks) was used whenever* *necessary when water demand was at the peak level. Drinking water for management staff was provided through bottled water.*"

5.6.2.1 Water Storage Methods

Interviews and site observations revealed that two plastic shell tanks of 5000 litre capacity were used to store water for construction work. In addition, two tanks of 1000 litre capacity were provided at first and third floor levels to fulfil water requirement for construction work. Water pump facilitated water supply for higher levels. Cost of electricity consumed by water pumps was an indirect cost, which is one of the hidden and ignored aspects of the cost of water, according to interviewees [PM-C4 and PS-C4].

5.6.2.2 Quality Control of Water

Similar to Case 3, project manager stated that since the site used main water supply, checking quality of water was not required [PM-C4]. PM-C4 further stated, "Still w*e check quality of ground water to decide the possibility of using tube well water as an alternative source for construction activities.*"

5.6.3 Water Usage on Construction Sites

As stated by the project engineer, city water supply satisfied the needs of direct and indirect construction activities, while management staff used bottled water for drinking purposes [PE-C4]. Similar to Cases 1, 2, and 3, ready mixed concrete was supplied for all concreting items on the site. PM-C4 further explained, "*ice is used during transportation to maintain the required temperature of ready mix concrete (above Grade 40) according to specifications*". He further stated that 10 cubes of ice are required for 5m^3 of concrete if transported at night. This quantity may increase up to 25 cubes if transported during daytime. Cost of ice per cube was calculated as Rs.183.67. Although impact on site water consumption is nil if ready mix concrete is used, cost of all indirect activities ultimately adds to the project cost. In addition, curing and washing concrete trucks are associated activities with the concrete process that consume more water on the site [PM-C4]. As found from other sites, Project supervisor also stated that "*weather condition greatly impact on water quantity required for curing work*" [PS-C4]. During hot days due to high temperature, water demand for curing slab is high as stated by PS-C4. Pond testing (curing) is performed 4 or 5 times during some days [PS-C4].

Interviews with PM-C4, PE-C4, and PS-C4 identified plastering, rendering, testing and commissioning, site cleaning, and dust controlling as other water consuming activities on the site, in addition to labourers' requirements; bathing, washing, and sanitary purposes. However, protect supervisor stated, "*Since labour accommodations are provided outside the site, it has a less impact on site water consumption*" [PS-C4].

5.6.3.1 Records On-Site Water Consumption

Quantity surveyor explained that water bills were the main record keeping in water usage and handled by the accountant [QS-C4]. In addition, bottled water was provided for drinking purposes of the management staff. As found from case studies 1, 2 and 3, no sub-meters are provided on the site, other than the water meter supplied by the NWS&DB. Based on the records available on the site, Figure 5.23 depicts the city water consumption over the period of January 2014 to March 2015.

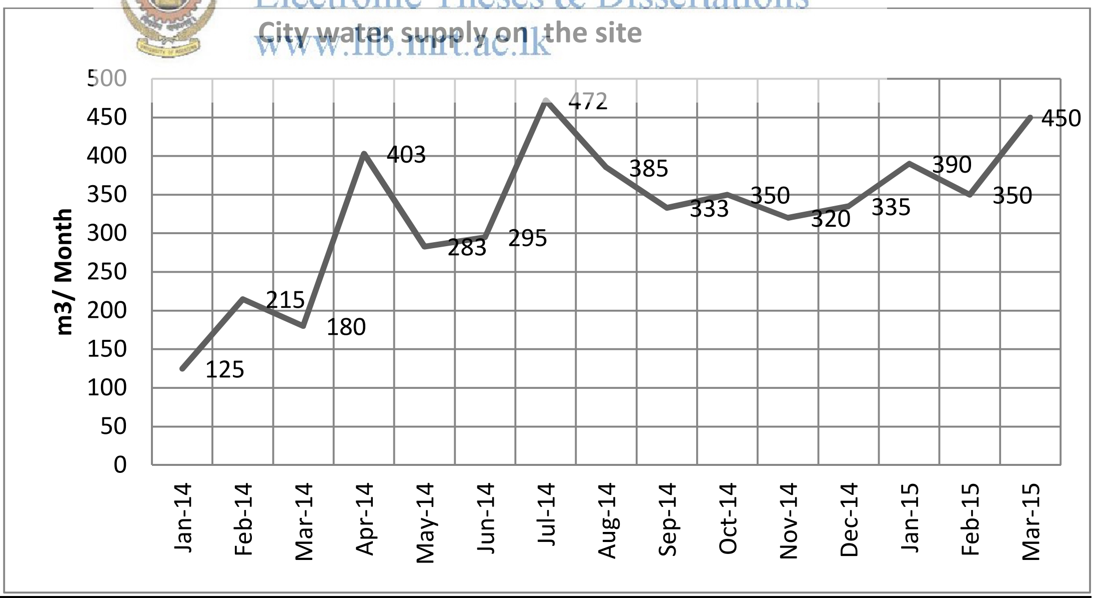


Figure 5.23: City Water Supply on the Site (m^3) - Case Study 4

It is apparent from Figure 5.23 that water consumption pattern may fluctuate over the period displaying average monthly water consumption as 326m^3. Project Manager stated, "*Number of trades and number of labourers employed at the site impact on water consumption pattern*" [PM-C4].

Figure 5.24 illustrates the bottled water used by the management staff from January 2014 to March 2015. It could observe that demand rises with the number of employees.

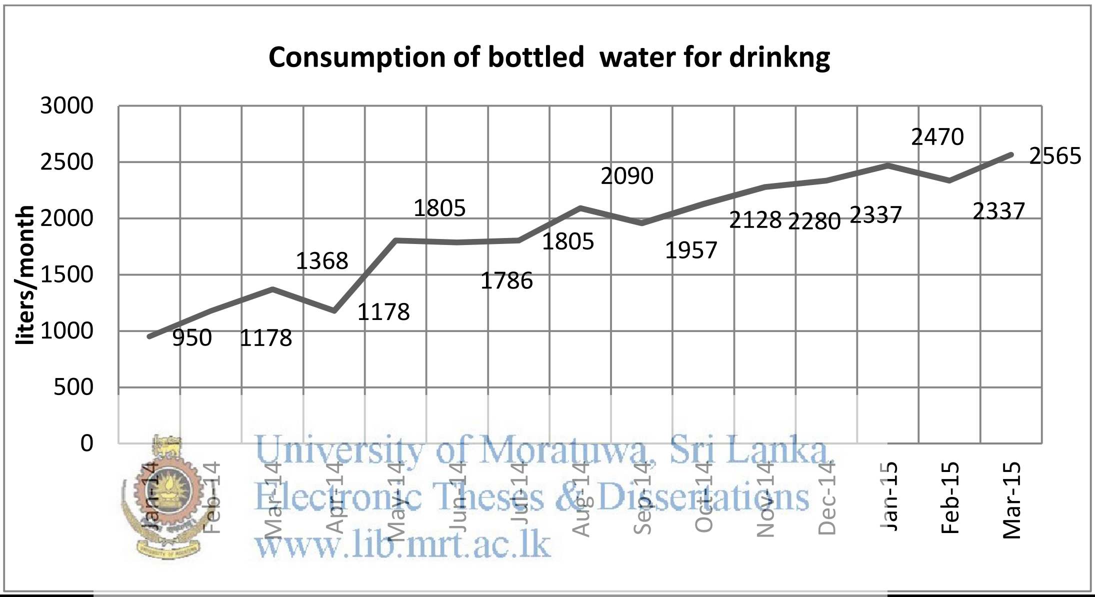


Figure 5.24: Consumption of Bottled Water

Based on the recorded data, when the average management staff is 40, water consumption was approximately 2m^3 per month and average water bill was around Rs 13,900 per month for bottled water. Site records indicated that the average water bill for the city water is around Rs. 35,200 per month. This clearly shows a huge cost deviation in per cubic meter of bottled water and city water, and prove that using city water is more economical than using bottled water.

5.6.3.2 Water Audit on the Site

During the data collection, the permission was sought from the project manager to conduct a water audit for checking of water consumption on the site. Details of the water audit done at two consecutive days are summarized in Table 5.12.

Table 5.12: Information for Water Auditing in Case 4

Date on water audit	2nd April 2015	3rd April 2015
Time (24 Hours)	Record at two hour interval start at 5.30 a.m.	
Number of management staff	35	22
Number of labourers at site	135	137
Water consuming construction activities taken place	Curing work	

Water meter reading started from 5.30 a.m. and continued at two-hour intervals. It was possible to record water consumption on two consecutive days, and cumulative water consumption for 24 hours is depicted in Figures 5.25 and 5.26.

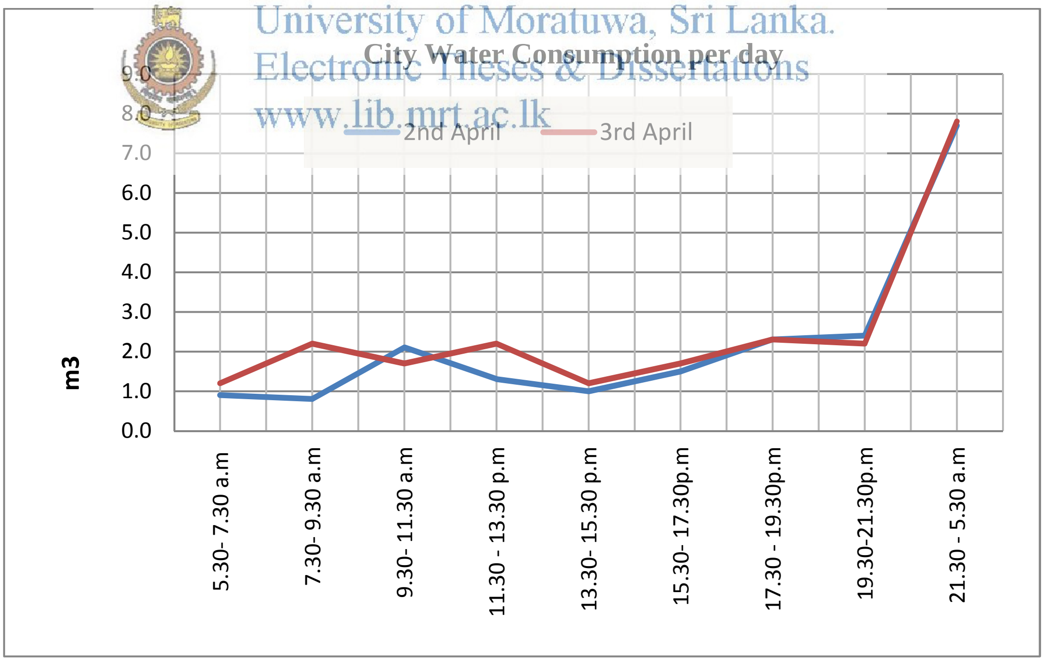


Figure 5.25: Water Consumption per Day

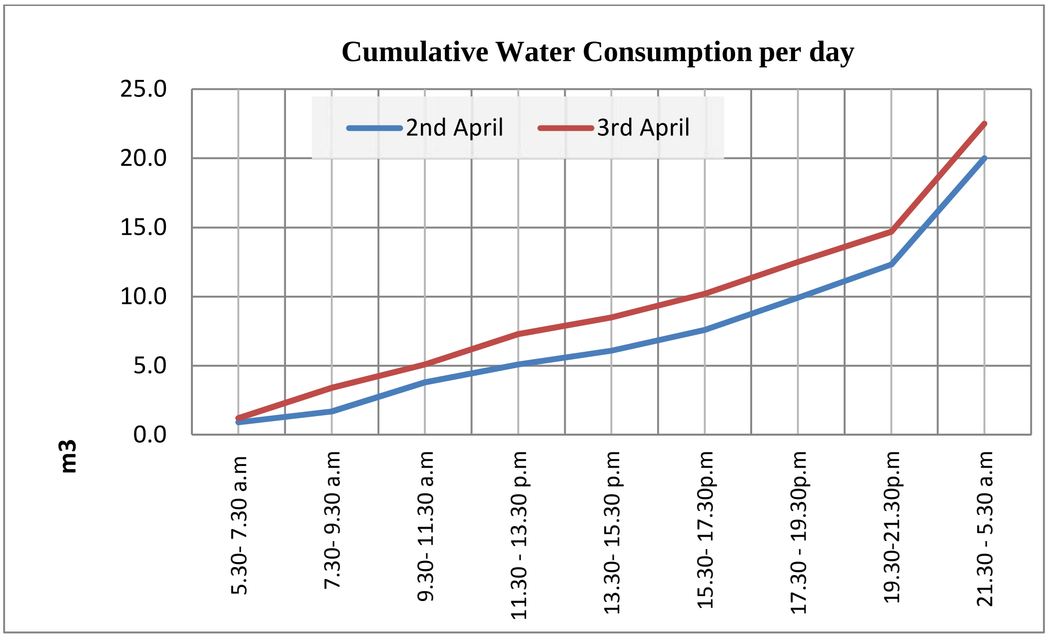


Figure 5.26: Cumulative Water Usage

It is apparent from Figures 5.25 and 5.26, that similar pattern of water consumption could be observed in two consecutive days. According to Figure 5.26, total water consumption per day (24 hours) is 20.0m^3 and 22.5m^3 respectively and a significant deviation observed from the average water consumption during previous months. Noticeable water consumption could be observed during 9.30 p.m. to 5.30a.m., which is around 7.7-7.8m^3. Since there are no sub-meters, it is difficult to measure the accurate water volume according to water consuming activities. Reasons may be leakages and errors in water meter, internal pluming arrangement, or filling water tanks via high pressure during night. Case analysis 2 and 3 provided similar information.

5.6.3.3 Computing Water Requirements

According to Figure 5.23, 4886m^{3}of city water was consumed at the site over a period of 15 months, providing an average monthly water consumption rate of 325.7m^3. However, according to water audit results, monthly water consumption shows 630m^3 (if average water consumption per day is 21m^3). Thus, average water consumption is equal to 478m^3. Assuming average water consumption per month continues until the completion of the construction period (36 months), the site will consume approximately 17,208m^3 of city water and this is equal to 0.37m^3 per square meter of building area. When compared with the results of Cases 1, 2, and 3, Case 4 shows comparatively less volume. Perhaps the main reason is labour accommodations provided outside the site.

In addition, as discussed in Section 2.8 of Chapter 2, norms for water quantity were available for limited wet trades. Based on project BOQ and norms available, Table 5.13 illustrates water requirements predicted for some direct construction trades of Case 4.

Table 5.13: Water Requirement for Wet Trade Activities - Case Study 4

Direct activity	**Type of water source**	**Qty. based on BOQ**	**Unit**	**Water per unit based on norms* (litres)**	**Total water quantity required (m^3)**	**% from the predicted water qty.17208m^3****	**Remarks**
Concrete					This does not affect site water consumption		Ready mix
Plaster work	City Water	83,243.0	m^2	4.9	407.89	~ 2.5 %	1:3 mix 16mm thick
Floor Rendering	City Water	46,800.0	m^2	4.9	229.32	~ 1.5 %	1:3 mix, 20 mm thick
Painting	City Water	115,100.0	m^2	0.45	5.78	<0.5%	Primer and 2 coats

* Taken from BSR (refer Table 2.10); **this figure was derived through the monthly water bills and invoices of water that supplied through water trucks

Results in Table 5.13 indicate, approximately 5% of water consumption (assuming total water consumption as 17,208 m^3) represents direct activities such as plastering, floor rendering, and painting, excluding concrete works. This further proved that a significant quantity of water is needed for indirect construction activities including curing, washing, testing, and commissioning other than for site workers.

As discussed under each case, data were obtained from labourers and supervisors on water requirements for some wet trades based on work-studies and through direct observations by the researcher as discussed in Section 5.9.3.

5.6.4 On-Site Water Wastages

As stated by project supervisor, "*Water wastage occur in the site due to pipe leakages, breaking pipes, and overflow from tanks due to carelessness of workers*"

[PS-C4]. PE-C4 stated, "*Worker behaviour highly influence excessive water consumption in the site*" and as PS-C4 informed, "*Wheel washing and dripping taps are other ways of water wastage.*" Speaking with site staff [PM-C4, PE-C4, and PS-C4] revealed, "*Curing, and washing wheels and tools consume more water than necessary, if nobody is present to monitor and supervise.*"

As stated by the engineer, "*Water is wasted not only in its use for construction related processes, but also in sanitation of workforce*" [PE-C4]. Project supervisor stated, "*Since labour accommodations are provided outside the site, water wastage is comparatively less.*"

According to the project manager, "*During substructure stage, all dewatering water is disposed directly to the municipal storm drain. This is wastage. In India, the excess water is always re-used to increase the ground water table without just disposing, according to established rules and regulations*" [PM-C4]. The project manager further stated, "*These aspects should consider before starting construction work. Implementing these systems in Sri Lanka will be beneficial to the country.*"

"*When water quantity is excessive than the required, it impacts on the quality of product. Therefore, during concreting and plastering work, excess water should be avoided. This is further controlled by supervisors and trainers assigned to construction supervision*" [PM-C4].

5.6.5 On –Site Water Efficiency Practices

5.6.5.1 Monitoring and Supervision

Project supervisor [PS-C4] stated, "*We try to minimise water wastage as much as possible through supervision,*" and the project manager informed, "*At this stage, there is no specific water management plans for the site. Every day we supervise construction activities, and check unnecessary water wastages. However, checking and supervising water consumption on site is difficult. The most important factor in this process is the implementation of regulatory methods or manuals, which are absent in construction industry at present*" [PM-C4].

5.6.5.2 Water Efficient Techniques

Project engineer stated, "*Recently we have introduced spray taps to control unnecessary wastage due to taps being open when it is not occupied; after a few months we can check whether it's a success or not*"[PE-C4].

PS-C4 suggested using heavy-duty fittings instead of uPVC fittings during site operation due to its durability. One limitation was the material cost, but these aspects need to be considered during the tender stage. The project supervisor stated, "*Currently pressure gun taps are used for wheel washing, showers are provided for bathing, and spray taps are fixed for certain areas to reduce unnecessary water wastage*" [PS-C4]. Four (04) number of labourers informed that during curing, either plaster band is used or sand is stored around the slab at the edge, to contain water and gunny bags to reduce water quantity.

5.6.5.3 Raising Worker Awareness

As stated by Safety officer, "*We have daily meetings to raise an awareness of construction practices for newly joined workers. In addition, posters are displayed at strategic places (washing area, canteen, on the site) to remind good practices to workers and the staff*" [SO-C4]. However, SO-C4 stated "*awareness of water conservation should come from the grass root level*".

5.6.5.4 Assign Responsibilities

The administrative officer and safety officer are the main responsible persons on the site for handling water consumption, as stated by PM-C4, "*The safety officer conducts meetings for workers every day before starting construction work and raises awareness on safety, site ethics, and resource handling, including water resource. In addition, the management staff is more responsible on site supervision.*"

5.6.6 Drivers and Barriers that Effect on Efficient Use of Water During Construction

This section analyses the drivers and existing barriers that influence on efficient use of water during the construction stage. Similar to findings of Cases 1, 2, and 3, project manager stated, "S*taff experience and management commitment greatly impact on water efficient practices on the site*" [PM-C4]. When inquired about the barriers effect on water efficient practices on construction sites, project manager said, "*Water is a serious issue in India. During construction, water efficient technologies are resorted. Here we tried to use tube well water as an alternative to potable water, but ground water contamination was the main barrier. During excavation, we couldn't use dewatering water even for site cleaning purposes due to its high contamination. Thus, directly it was disposed to the municipal storm water drain*" [PM-C4]. Project manager further explained that, due to limited space availability, it is not possible to build tanks to collect storm water on the site, and he further elaborated that in India, projects are not approved without a rainwater-harvesting pit during construction. PM-C4 further stated "*if had a proper system we can use rainwater for site cleaning and wheel washing rather than waste potable water*".

The project engineer [PE-C4] explained, "*Water is still not given a priority in the construction process compared to other resources; even water wastage is not considered.*"PM-C4 stated, "*Cost of water is not highly significant and responsibility of individual is not established within the tender. These are additional factors that negatively influence water use efficiency on the site*."

QS-C4 indicated that, "*Generally, we pay less attention to the area of water management during pre- and post-contract stages.*"

Further, QS-C4 emphasised that no one pays much attention to water management practice on the site until water becomes a serious issue.

Figure 5.27 synthesises water management practice on the site and is presented in a cognitive map. The figure elaborates that water efficient measures, drivers, and barriers impact on efficient use of water during the construction of case study 4.

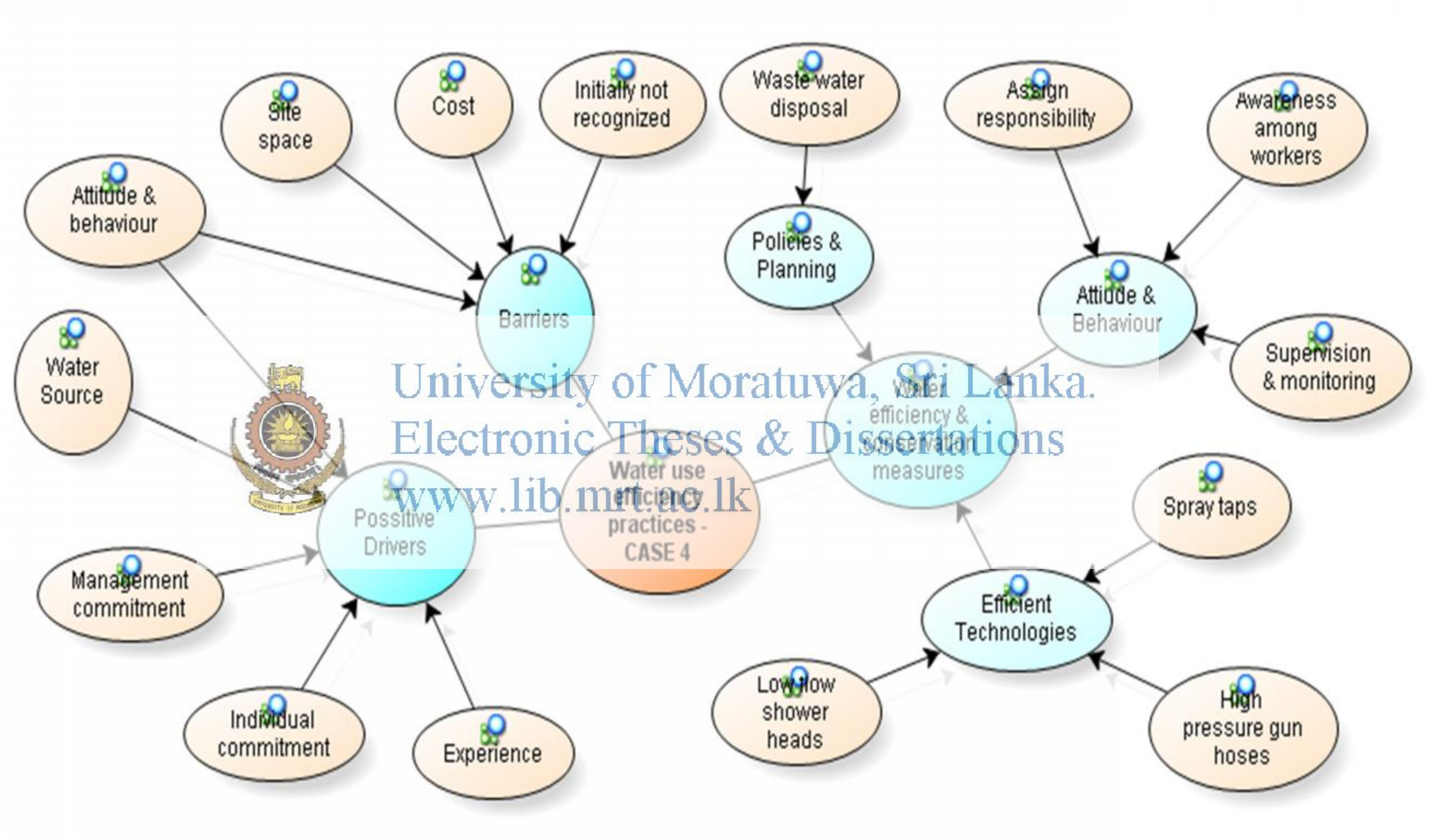


Figure 5.27: Cognitive Map for Water Use Efficiency Practice in Case Study 4

5.7 Cross -Case Analysis

This section discusses and synthesises the findings of four individual cases discussed above.

5.7.1 Water Sources for On-site Construction Activities

Based on the data analysis findings of the four (04) case studies, different types of water sources for on-site construction activities were identified, i.e. main water supply (city water supply); water supplied from trucks (bowsers); well water; tube well water; rain water; and bottled water. It was also identified from the review of documents that the type of water source to be used has not been specified in the contract documents of the four case studies and thus, the responsibility for the selection of the type of water source rested solely with the contractor. The sub-sections that follow discuss about the water sources that were identified from the four (04) case studies.

5.7.1.1 Main Water Supply

Main water supply is the source used mainly in the four (04) case studies in the construction activities. During the data collection period, Cases 1, 3 and 4 were totally dependent on the main water supply (i.e. city water line). It was found that the quantity of water from the main supply that could be used at construction sites was unlimited and the monthly payment for the quantity of water used was on volumetric basis.

5.7.1.2 Water Trucks (Bowser Water)

As stated by PM-C1, PM-C3, and PM-C4, the sites were dependent on the water supply from bowsers when the city water supply could not meet the daily water requirements. It was found that Cases 1, 3 and 4 where necessary used water trucks in construction activities in order to meet the required water demand, especially when concreting work was being carried out. Based on Case 1 data, it was evident that the cost of water from a truck was more than the cost of water taken from the main water supply.

5.7.1.3 Well Water

In addition to the main water supply and water truck supply, well water has been used in the construction activities of Case 2. However, as stated by PM-C2, the quality of well water was found to be not up to the required standard for drinking water due to the high ground water table of the site. Thus, water obtained from the well was used for some indirect construction works such as curing, cleaning, wetting of roads, and washing of wheels.

5.7.1.4 Tube Well Water

Case study interviewees stated that tube well water also is used as a water source at the construction sites. However, they stated that ground water contamination was a barrier for using tube well water as an alternative to potable water (main water supply) at their construction sites (Cases 1, 3 and 4). One project manager stated that initially they looked out for tube well water as an alternative to potable water supplied by the NWS&DB but that since ground water was of high salinity and contained ferrous iron particles, they opted to depend on water trucks in addition to the main water supply [PM-C1].

5.7.1.5 Rain Water

Empirical data of case study 1 shows that rainwater also could be used for on-site construction activities. As stated by PM-C1, Environmental Management Systems (EMS) were the main driver for using rain water at the site. Limited site space and high initial cost are identified as major hindrances against implementing rainwater collection at sites [PE-C3]. As noted by PM-C4, there is a possibility of collecting rain water after constructing the structure of the building. However, all such requirements should be decided at the initial stage of the project itself and communicated to the required parties through tender &contract documents.

5.7.1.6 Bottled Water

In Case study 4, bottled water was used for drinking by site staff. From the cost comparison done with the data available (Refer to Section 5.6.3.1), it was found that the unit cost of bottled water is high compared to that of main water supply.

5.7.2 On-site Water Storage Methods

Based on the four (04) case analyses, it was found that "plastic shell tanks" were mainly used to store water received from the main water supply and trucks. The capacity of tanks and the number of tanks are totally dependent on the required water demand, which varies according to work trades and number of labour grade employees, as highlighted by PE-C1 and PE-C3. In Case 1, in addition to plastic shell tanks, there was an on-site ground "sump" with a capacity of 50,000 litres. The sump had two compartments, of which one compartment was designed to fulfil fire regulation requirements during the execution of works and the other compartment was designed to collect and store rain water for on-site activities such as cleaning and vehicle washing [PM-C1].

5.7.3 Quality Control of Water

It was found from four (04) case studies that the assessment of the water quality is based on subjective measurements. As mentioned by PM-C1, the quality of water supplied by trucks was checked daily through aural and visual observations. Initially their management has obtained assistance from the NBRO to check the quality of water obtained from alternative water sources. In Case 2, it was found that the quality of well water is not suitable for drinking. However, Case 2 interviewees stated that they do not check the quality of well water on a regular basis even though well water was used for curing purposes. Case study interviews revealed that although specifications were provided in the contract documents, the supervision of quality of water in construction activities such as concreting, plastering and curing during construction is not considered as very important [PM-C1, PE-C2, and QS-C4].

5.7.4 Cost of Water Used for Construction Activities

This is another area to which little attention is paid during the tendering stage by construction parties and there are only a few standards are available for pricing cost of water. As stated by QS-C2 and QS-C3, during the tendering stage the cost of water was computed referring to similar projects done in the same area previously. In Case 2, Rs.40,950.00 per month was allocated in the preliminary bill for supplying water. However, it was found that there is a significant cost deviation of the average monthly water bill from the amount that was allocated during the tendering stage. This was same with Case 3 as well. Some interviewees (QS-C2, PM-C3, QS-C3 and PM-C4] attributed the reasons for such cost deviations to the little attention paid during the tendering stage to the water source, ground water condition, volume of construction and number of labour grade employees involved. This further support the reason for less percentage allocated for the water item in the preliminary bills.

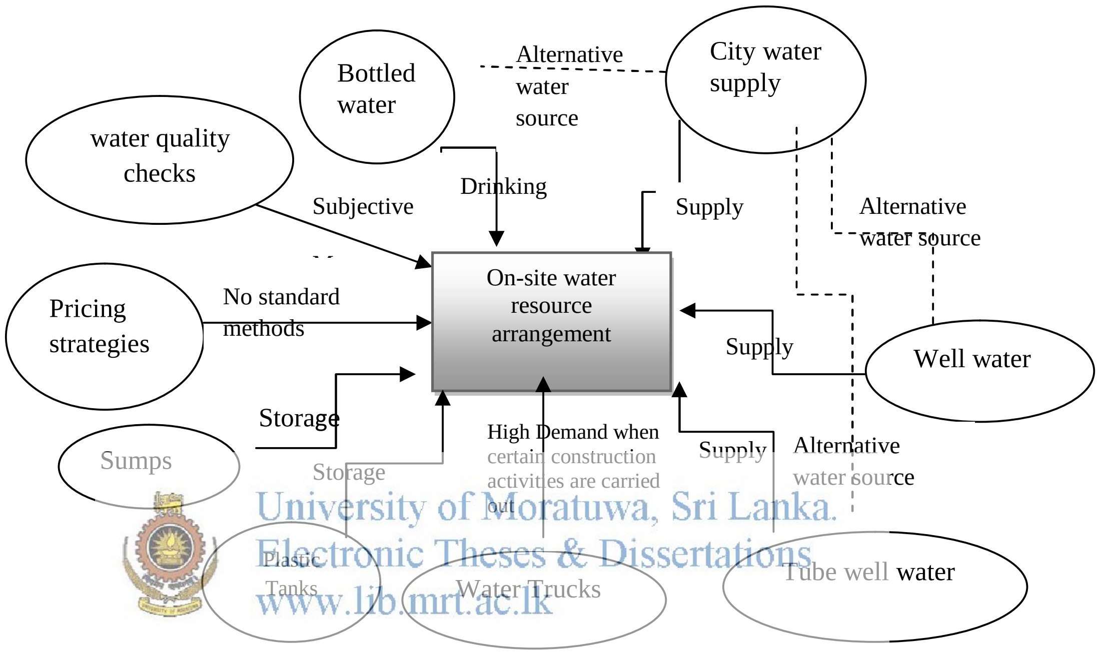


Figure 5.28: Water Resources Arrangement in Construction Sites

In Figure 5.28, the facts discussed under Sections 5.7.1, 5.7.2, 5.7.3, 5.7.4 and 5.7.5 are summarised under water resources management in construction sites in relation to water acquisition, water storage, water quality and cost of water. It was also found that none of the sites had a detailed water schematic plan, i.e., layout for temporary water distribution indicating locations of water outlets and the distribution pipe lines.

5.8 Use of Water Sources in Construction Sites

5.8.1 Water Sources for Direct and Indirect Construction Activities

Water is used for both direct and indirect construction activities. Direct activities include wet trades such as concreting, plastering, rendering etc. Indirect activities include curing, testing and commissioning, site cleaning, wheal washing, dust controlling etc. Case studies 3 and 4 were totally dependent on the city water supply for both direct and indirect construction activities and ground water contamination was a barrier for using tube well water as an alternative to water from the main supply. In case study 2 as stated by PM-C2, well water was used for indirect construction activities such as curing work, road wetting, site cleaning, dust controlling and wheal washing. In case study 1 as PM-C1 stated, water supplied from trucks was mainly used in the on-site ready-mix plant. In addition to this, rain water was also used for indirect construction activities such as site cleaning, wheel washing and water storing for fire emergency purposes. Moreover, some interviewees [PM-C1, PM-C4] stated that certain activities do not need potable water standard. Such as site cleaning, dust controlling and wheel washing.

5.8.2 Water Sources Usage by On-Site Management Staff and Labourers

In all four (04) cases, water from the city water line was mainly used by site management staff and site labourers for activities such as drinking, washing, bathing and sanitary purposes. In addition to these, bottled water was also used for drinking in Case 4. As stated by PE-C1, none of the labourers used rain water or bowser supplied water for washing and bathing purposes and were totally dependent on the main water supply.

5.9 Water Consumption During the Construction Phase

5.9.1 Water Consuming Activities

Based on the findings of the four (04) cases, it was found that direct activities, i.e. wet-trades such as concreting, plastering and rendering and indirect activities, i.e. curing, ground work, testing and commissioning, vehicle washing and site cleaning were water consuming activities. In all four (04) cases, ready-mix concrete was used for concreting. In case study 1, the concrete batching plant was mobilised at the site and the required water quantity was supplied from water trucks. Moreover, interviewees stated that use of ready-mix concrete had a lesser impact on on-site water consumption. Curing and washing of concrete trucks were identified as associated indirect activities that need more water for the concreting process. Additionally, interviewees stated that workers need a significant quantity of water for bathing, cooking, washing and sanitary purposes. This is further proved by the results obtained from case study 4 (refer to Section 5.6.3.3).

5.9.2 Record Keeping of Water Consumption at Sites

Monthly water bills were the main record keeping mechanism on the quantity of water consumed at a site. It was observed during the site documentary review that case study 1 had a system to maintain utility bills and records of amounts of water that were supplied by water trucks. The site accountant was responsible for maintaining water bills in all the cases. PM-C2 stated that in addition to maintaining monthly water bills, case study 2 had a system to record daily water meter readings for internal auditing purposes. One of interviewees of Case 1 explained that the monthly water bill was the main measure to see any significant change of water quantity since there are no quantitative records maintained related to project activities [PM-C1]. In addition, it was revealed from all four case studies that there was no proper record of the quantity of water that was consumed from alternative water sources.

5.9.3 Computing Water Requirements of Construction Activities

It was found that none of the four sites had installed sub-metering systems at the site in addition to the main meter installed by the NWS&DB. As stated in Section 5.9.2, monthly water bills and invoices for water trucks were the main data sources available on the water consumption of each site. There was no system available to compute the quantity of water that was taken from alternative sources. Therefore, due to such limitations it was difficult to compute the exact quantity of water used by some of the individual activities especially indirect construction activities.

Based on the data that was gathered from the four cases and with some sensible assumptions, the total water quantity consumed was predicted and presented as

m^3/m^2 identifying variables (project scope, labour accommodation on or off the site, number of labourers, weather, construction methods and techniques) that impact on water consumption in each individual case analysed in this chapter (refer to Sections 5.3.3.3, Section 5.4.3.3, Section 5.5.3.3 and Section 5.6.3.3). However, the results show that the process of computing the quantity of water and its important variables need to be considered at the initial stage of a project itself.

Based on water audits carried out, it was found that water consumption is unique to each case. Water audit results provide the daily quantity and peak consumption times in respect of each activity making it easy to identify any leakages and predict site water consumption.

Section 5.9.4 discusses some variables that can have an impact on the quantity of water used in construction sites. Moreover, water requirements for direct activities (concreting, brick work, plastering and rendering) are computed using published norms given in the Building Schedule of Rates (BSR). From the analysis of the four cases selected, it was found that approximately more than 75% of water used in a construction site is required for indirect construction activities. Moreover, if ready-mix concrete is supplied to a site, more than 90% of water consumed will be by indirect construction activities and processes.

During data analysis, it was revealed that although standard norms are available, industry practices on water consumption of certain activities can vary. Figures 5.29, 5.30 and 5.31 respectively present the results of site practices and available norms according to BSR (Table 2.10), which are based on site exercises conducted on each case study in relation to concreting, plastering and rendering activities,.

It is apparent from Figure 5.29 that except for Grade 20 concrete, water requirement of each of the other grades of in-situ concrete is higher than that of ready-mix concrete. As stated by QCE-C1, one advantage of ready-mix concrete was that its quality could be controlled by ensuring the standard of water used.

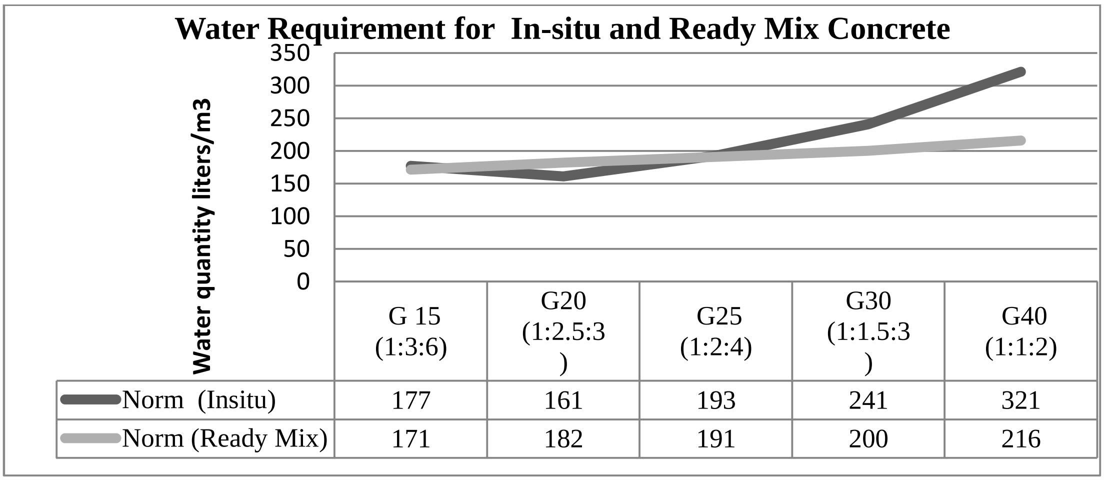


Figure 5.29: Water Requirements for In-Situ (BSR Norms) and Ready-Mix Concrete (Site Practice)

Moreover, Figure 5.30 shows the water requirement for 1:2:4 concrete mix based on site practice. All figures were taken from concreting done at sites during data collection.

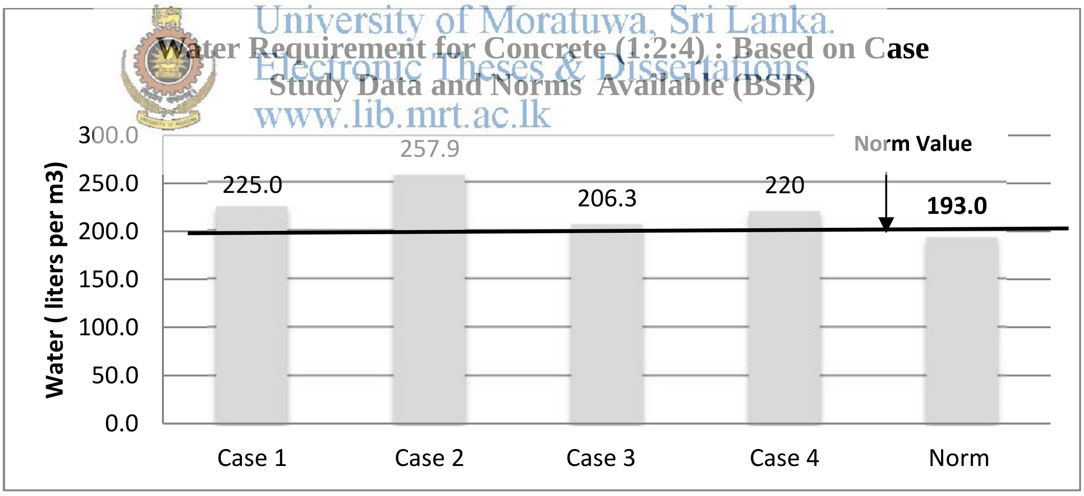


Figure 5.30: Water Requirement for 1:2:4 Concrete Mix based on Site Practice and BSR Norms

From Figure 5.33, it can be seen that only Case 2 shows a significant deviation from the standard norm and Figure 5.31 indicates the results of a similar kind of exercise done for plastering work. Here also a significant deviation could be seen in Case 2.

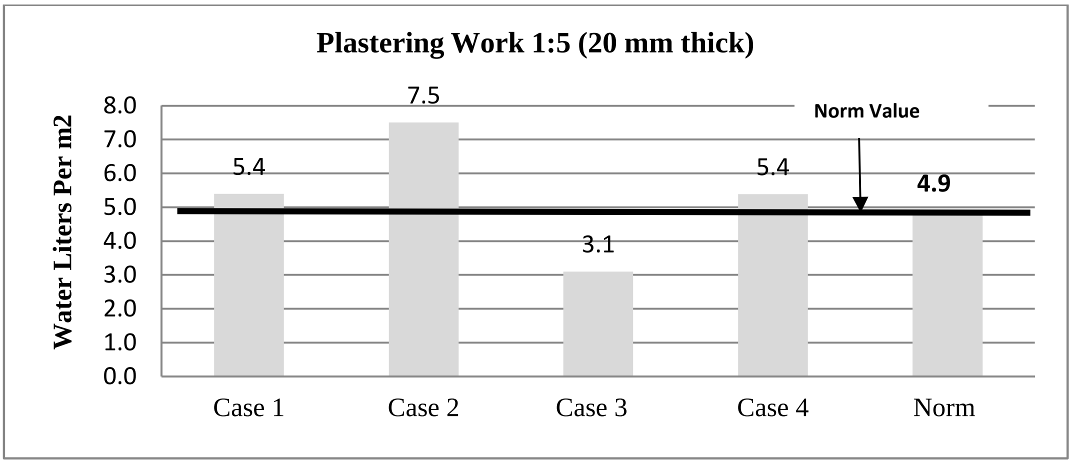


Figure 5.31: Water Requirement for 20mm Thick Plastering Work (1:5): Site Practice and Norms from BSR

Factors that were identified as affecting on-site water consumption from discussions with interviewees and observations made during data collection are presented in Section 5.9.4.

5.9.4 Factors Affecting On-site Water Consumption Levels

Condition of Materials

Case analysis findings show that the volume of water required for construction activities can vary with the nature of materials used. For instance, during the rainy season, due to the high moisture content of sand, the construction activities that require sand need a lower volume of water than that it requires during dry conditions. Similarly, the volume of water required for soaking bricks and blocks can vary depending on their wetness/dryness.

Types of Construction Methods /Techniques Adopted

In Cases 1, 2 and 4, blocks were used for external walls and some of the internal walls. Dry partitions were designed for some of the internal walls. Thus, the water consumption of such activities was minimum compared to brick work. Another technique adopted was the use of thick polythene sheets and gunny bags during curing. This was practiced in all four cases. Another practice adopted in Case 2 was, the use of thick polythene covers and vacuum systems to control the spreading of dust. In Cases 2 and 3, metal trays were used to mix mortar. According to project supervisors, the use of metal trays can reduce material wastages and can indirectly reduce water usage at the sites as a lesser amount of water would be required for the cleaning of floors.

<u>Number of Labourers that can be Accommodated at the sites</u>

Water audit results of Cases 3 and 4 clearly show that (refer to Sections 5.5.3.3 and 5.6.3.3) the number of labourers accommodated on-site can impact on the total water consumption at the site. As stated by PE-C3 and PM-C4, when accommodation for labourers is provided at sites, it can significantly raise the water consumption of the site.

<u>Weather Conditions</u>

This is one of the critical factors identified from all four cases. For example, during the rainy season, a lower quantity of water is needed for curing. On the other hand during dry seasons, the number of times that curing has to be done may increase. Another example cited was that if sand gets wet, a lesser quantity of water would be needed during mortar mixing. PS-C2 stated that during the rainy season, the wetting of roads will not be required.

<u>Quality of On-Site Supervision and Labour Behaviour</u>

The quality of on-site supervision and labour behaviour are recognised as important aspects that affect the water consumption levels at the sites. One of the interviewees from Case 3 stated that certain construction activities like curing and washing of tools would need more water than what is required if the processes are not monitored properly [PM-C3]. Water wastage totally depends on the carelessness of workers [PM-C1]. Project supervisors highlighted the fact that labour behaviour while carrying out site activities can have a significant impact on the water consumption at the site.

5.10 Water Wastage during Construction

5.10.1 Water Wasting Activities

The syntheses of the findings indicate that most of the water wastage may occur due care by workers or absence of proper supervision and monitoring. Interviews explained high or low quantity of water will impact on strength and workability of certain activities. Thus it automatically controls water quantity. Therefore, water wastage due to direct construction activities is minimal.

Indirect construction activities such as curing, cleaning, bathing, washing and sanitation were identified as activities that contribute most to the waste of water at a site when not properly monitored and supervised. QCE-C1 stated that water wastage is minimal during the concreting process because all the processes are controlled through a computerized system but that however, a considerable amount of water is required for washing and cleaning of trucks and for curing which may lead to waste of water if not monitored and supervised properly. Cleaning of floors (chipping) is identified as leading to an unnecessary water wastage. Moreover, it was observed that certain loopholes exist regarding ways and means of water wasting during the construction activities. For instance: hose is directly used for soaking bricks and mixing mortar, overflows could be seen from barrels that are used to collect water for construction activities. Pipe leaks, dripping taps, overflowing overhead tanks are identified as other common ways of water waste in construction sites.

5.10.2 Reasons for On-Site Water Wastage

Following reasons were highlighted by interviewees as reasons for on-site water wastage based on the results of four case analyses:

- Lack of education/knowledge on water wastages during the construction phase
- Absence of on-site water saving measures
- Not taking immediate actions to repair leakages
- Lack of tools and equipment on-site to measure required water levels
- Lack of appropriate supervisory advice and guidance to laborers on water usage in construction activities

- Labour attitude and behaviour and knowledge on value of the water resources

5.11 Practices for the Efficient Use of Water during the Construction Phase

5.11.1 On-Site Water Efficiency Measures

After analysing the results of the four case studies, a number of techniques and strategies that help to enhance the efficient use of water were identified. Table 5.14 summarises cross cases analysis of identified on-site water efficient measures.

Table 5.14: Cross- Case Analysis of On-site Water Efficiency Measures

On-site Water Efficiency Measures	Case 1	Case 2	Case 3	Case 4
Assign water minimisation responsibilities among site management staff and other site workers	√	√	√	√
Supervision and monitoring (assign staff)	√	√	√	√
Conduct meetings	√	√	√	√
Display posters and notices	√	√	√	√
Use low flow shower heads	√	√	√	√
Use high pressure gun hoses	√	√	√	√
Use pressure reduction valves	√			
Reuse water	√		√	
Recycle water	√			
Adopt proper wastewater disposal systems	√	√	√	√
Use thick polyethene covers for concrete slabs	√	√	√	√
Use Gunny bags to cover concrete columns/slabs	√	√	√	√
Use metal trays for mixing mortar		√	√	
Use thick polyethene for dust controlling		√		
Use rainwater collection mechanisms	√			
Implement an EMS plan	√			
Have a washing bay in place		√		
Vacuum system for dust controlling		√		
Use water auditing		√		
Adopt strategies for health issues		√	√	
Use admixtures to reduce water consumption			√	
Use spray taps			√	√
Adhere strictly to existing rules and regulations	√	√	√	√
Advice and guide labourers on efficient water usage for construction activities	√	√	√	√
Take immediate actions to repair leakages				
Provide appropriate tools and equipment on-site to measure required water levels				

It is apparent in Table 5.14, assign responsibilities, supervision and monitoring, site meeting, display posters and notices, use low flow shower heads, and high pressure gun hoses are some water efficiency measures practised by all four cases. In addition, each site had a proper wastewater disposal system. This is one of the existing regulations properly practise at the sites.

It was found that none of the sites had water action plan or management plan and most of them were not familiar with the terms 'water action plan' and 'water audit'. It could be observed that although there is no explicit ways on water conservation and efficiency methods, certain sites which had the environmental management system had implemented the options of water recycling, water reuse and rainwater harvesting during the construction phase (refer to Section 5.3.5.1). In addition, the management staff had implemented and promoted water management actions at site level depending on their previous experience and individual commitment. However, these practices varied from project to project.

5.11.2 Drivers and Barriers for Implementing On-Site Water Efficiency Practices

Case analysis results revealed that individual experience and commitment were the main drivers that have an impact on the implementation of current on-site water minimisation and management measures. Cost, water source and worker behaviour and attitudes are other drivers that impact on the efficient use of water during the construction phase as found from four cases. As revealed by the interviewees, certain drivers (cost, water source, attitude and behaviour) are identified as either positively or negatively impacting on the efficient water-use.

Following factors were identified through the analysis of the four cases as negatively impacting on the implementation of sustainable use of water during the construction phase.

- Low attention paid on water minimisation and management during a construction phase by construction stakeholders as the cost of water is considered insignificant when compared to the cost of the other preliminary items.

- Workers' attitude towards water as an unlimited resource which is available almost free of charge depending on the type of the water source and ease of access
- Non-identification of practices/strategies/techniques for the on-site efficient use of water in project specific documents of the tendering stage
- Absence of reference to social responsibilities with regard to natural resources in the project specific documents.
- Unrealistic project programmes and schedules for the construction phase.
- Limited site space available for water storage (e.g., collection of rain water at the site).
- Unavailability of a proper system to record water consumption in construction sites.
- Non- availability of set benchmarks and Key Performance Indicators (KPI) for on-site water consumption.

5.11.3 Applicability and Application of Nine (09) R Principles for the Efficient Use of Water in Construction Sites

This section presents the comments made by project managers and project engineers during the four case studies in terms of the applicability and application of nine (09) R principles for the efficient use of water in construction projects. The nine (09) Rs constitute the six (06) R principles of existing water hierarchy (i.e. Review, Replace, Reduce, Reuse, Recycle, and Removal) and the new 3R dimensions (i.e. Regulations, Reward and Responsibility) emerged from the case studies.

Existing 6R - Review, Replace, Reduce, Reuse, Recycle and Removal

5.11.3.1 Review

This is the first step of the water hierarchy which checks whether potable water is compulsory for construction activities or processes. It is revealed that none of the site documents clearly mention the water source required for a particular construction activity. As stated by some interviewees [PM-C1, PM-2, PM-C3, CE-C3, PE-C4], contractors of all four (04) cases were assigned the responsibility for obtaining the water required for their construction sites.

5.11.3.2 Replace

Replace refers to finding out cost effective alternatives to potable water initially or during the construction phase. The findings from case studies revealed that 'Replace' is practiced in the four (04) construction sites. The project manager of Case 2 was of the view that if potable water is used in construction sites, water hierarchy will provide more benefits. PM-C4 stated importance of collecting rainwater in construction sites. Cases 1 and 3 also have implemented this step (Replace). However, it was revealed that ground water contamination was a main barrier faced in construction sites when obtaining water from tube wells as an alternative to potable water. Cases 3 and 4 identified space limitation at a site as the main barrier for implementing rainwater harvesting.

5.11.3.3 Reduce

This step basically explores options or ways to improve the water use efficiency by applying water efficient techniques and strategies. In all four cases, monitoring, supervising, assigning responsibility and promoting worker awareness through meetings and posters were implemented to minimise water wastage due to construction activities. Pressure gun hoses were employed additionally during vehicle washing and cleaning of the site to reduce water usage and minimise unnecessary water wastages. PM-C3 stated that if curing components are applied on concrete walls, columns, and slabs, it will reduce water usage and that it is more expensive than the usual pond system although it will be a very good solution when there is a water scarcity. As stated by project managers of Cases 1 and 4, all these applications totally depend on the cost, which is the responsibility of the contractor and the client. Curing agents were already in-use in Case 4.

5.11.3.4 Reuse

Re-use means checking whether water can be reused in another activity or process without it being treated. It was observed that the implementation of the 'Reuse concept' had been successful in Case 1, which had a proper system to collect rainwater and use it for dust controlling, vehicle washing, and in a fire emergency. It was also revealed from Case 1 that the Environmental Management System (EMS) in place at the site was the main reason to implement these strategies at the site. From Cases 2 and 4, it was revealed that their projects did not have predetermined plans for the efficient use of water during the construction stage. However, such practices were implemented based on staff experience. Furthermore, PM-C3 stated that during construction it is possible to re-use water that is used for testing of water proofing and it can also be used for mixing mortar for the tile bed on the same floor if planned in advance [PM-C3]. However, interviewees of all four (04) cases believed that the re-use of water is rarely fully accomplished at the construction sites unless it is identified as a mandatory requirement during the project initiation stage.

5.11.3.5 Recycle

This step checks whether water can be recycled for use elsewhere in the same project. In Case 1, its EMS was greatly conducive for the implementation of 'recycle' during the construction stage. As revealed from Case 1, recycling promotes significantly the usage of potable water. This is the only site, which has adopted the 'Recycle' concept for water. From the four (04) cases, it was revealed that none of the sites practised 'Recycling' if the requirements were not identified in the contract documents. It was also revealed from case studies that in order to get more benefits from recycling in a cost effective way, such requirements should be communicated during the tendering stage.

5.11.3.6 Removal

Removal means disposing the excess or waste water legally ensuring no flooding, pollution, or inconvenience to others. The findings revealed that all four (04) cases practiced removal mechanisms. The interviewees from all four cases claimed that there were no complaints or any action taken against sites due to non-adherence to current regulations on wastewater disposal. Also, all four (04) cases claimed that up to the time of data collection, the sites were successfully implementing relevant regulatory requirements as no major complaints have been identified by the relevant authorities through their regular site inspections.

New 3R - Regulation, Reward, and Responsibility

5.11.3.7 Regulation

Most interviewees agreed that firm enforcing of certain regulations on water usage during construction is required to enhance the efficient use of water in construction sites. It was observed that regulations on wastewater disposal were well practiced in the construction sites, mainly due to regular inspections by relevant authorities and monitoring as revealed by the interviewees. PM-C4 stated that rainwater harvesting need to be implemented at the sites and that it is important to find ways to enrich ground water than just disposing waste water to the municipal waste drain. PM-C4 further stated if reuse and recycling requirements are strictly implemented as specified in the regulations, the contractor will be more responsible. A number of other points emerged from case studies which suggest to have regulations to control the unlimited usage of city water for both direct and indirect construction activities, excessive extraction of ground water and absence of regular checks on the quality of water.

5.11.3.8 Reward

This step provides for remuneration for the positive attempts made by the parties involved in a construction project. There was an agreement among the four cases that rewarding is a good policy, which encourages both the contractors (can be considered for contractor grading criteria and awarding) and the workers (incentives for innovative work) who strictly adhere to practise sustainability approaches. For instance, PM-C3 and PE-C3 stated that *if the contractor is rewarded for practising innovative and sustainable practices in the annual award ceremony and during contractor performance grading, there is a high tendency for the water use efficiency measures including maintenance of water hierarchy among contractors to become popular*. PE-C3 stated these aspects are not yet established in the construction industry. PM- C4 stated "*not only rewards but also penalties should be introduced with the system as then only people will feel the value of taking steps on water saving measures*".

5.11.3.9 Responsibility

Responsibility is another attribute identified in the literature and by preliminary interviewees as having an impact on the efficient use of water in construction projects. Some of the case study interviewees [PM-C1, PM-C2, PE-C3] acknowledged that the responsible industry stakeholders' actions towards environmental and social conservation, and preservation of natural resources in construction sites are primarily important to achieve sustainable use of water. PM-C1, PM-C2, PE-C3 stated that the responsibility in respect of different tasks has already been determined and well practiced while some interviewees [PE-C2, PE-C4] were of the view that there is a requirement for the appropriate allocation of responsibilities relevant to water efficiency and sustainability practices. Many interviewees also reported that it is important that the top management gets involved in monitoring whilst others are assigned responsibilities to implement water and sustainability related practices [PE-C2, PM-C2, PE-C2].

5.12 Recommendations for the Sustainable Use of Water during Construction

Suggestions and recommendations proposed by the interviewees of four cases for the sustainable use of water in construction projects are presented in Table 5.15. There was a similarity among the recommendations made by different interviewees. For instance, factors such as 'consideration of water efficient aspects from the early stages' and 'provisions in a contract document' have been suggested by many interviewees.

The proposed recommendations for improving efficient water-use should be implemented at project level. Some recommendations are beyond site management although as can be seen in Table 5.15 ultimately all will impact on the sustainable use of water during site operations. Thus case study findings show that in addition to direct stakeholders' involvement, the government and the relevant construction authorities and institutes will also have a big role in establishing and implementing sustainable water use practices in construction projects. Section 7.9 of Chapter 7 discusses in detail the recommendations according to this classification.

Table 5.15: Recommendations for the Sustainable Use of Water during the Construction Stage

At the Project (Site) Level	Beyond the Site Level
• Identify initially a list of 'should do' and 'should not do" items for the efficient water-use in construction projects • Introduce a water action plan for the site initially • Lay down a code of conduct which the managers and other staff including labourers have to follow • Look at alternative water sources for potable water • Check regularly the quality of water • Implement a supervision and monitoring system • Develop benchmarks and KPIs for water use activities through work studies • Display schematic water design plans and targets for water usage activities at sites for reference by site workers and staff • Set targets and respond quickly to reported leaks and repairs • Encourage innovative methods (though it may take time and effort)	• Address water management aspects clearly from the early stages • Provide for water efficient measures in contract documents • Specify alternative water sources for potable water only where necessary & allow for other options in the contract • Make compulsory, the integration of EMS /sustainability rating assessments for construction projects according to project complexity and considering available rules and regulations • Grant approval for shallow tube wells and implement regulations on water extraction • Enhance public awareness on future water dilemma • Reinforce relevant environmental protection laws • Establish central treatment plants which will become economical in the identified industrial zones or communities

5.13 Challenges Faced during Data Collection and Case Study Analysis

The managements of all the cases extended their fullest cooperation during data collection. Support was received from the middle level staff when collecting records of water consumption (water bills) during site observations. The biggest help was received from administrative and security staff during water auditing to record water consumptions at one hour or two hour intervals. This shows their responsibility and high commitment.

Case 1 had a proper computerised system on the consumption of water and electricity and on the usage of telephones during the construction phase. The system analysed water consumption in respect of the site and staff quarters separately and also the amount of water transported through bowsers. All the other sites had manual systems and copies of water bills that were referred to during data collection were systematically filed.

During the case analysis, following issues were identified as limitations for computing real water requirements according to the activities or processes.

- There was no proper recording system for measuring water consumption according to construction activities other than the monthly water bills.
- Some water significant items e.g. testing and commissioning, landscaping, are measured together.
- Incomplete past site records of the total number of labourers who had worked on a particular day
- Difficulties in finding site records on previous activities
- Non-availability of records on non-potable water consumption- rainwater collection
- Inaccuracy of quantities in the BOQs due to variations and use of lump sum basis
- Complicated systems within the internal pipe arrangement (combining meters).

The above information provides for the requirement for developing standard forms to ensure systematic data records of water consumption. Brown, Blofeld, Hadi and Hamilton, (2014) have also stated that although water efficiency is important and necessary, it is difficult to evaluate the effectiveness of a water efficiency intervention due to the type of data available. This statement is thus proved by empirical findings. Another limitation was the inability to find out the exact amount of water required for indirect water consumption activities or processes. None of the sites analysed water consumption in respect of water consuming construction activities and the number of labourers. Few attempts were made and courtesy reminders were made to collect data on the number of labourers and management staff working at the site and get the construction program. Each site was at least visited four or five (05) days to collect all necessary data. The construction industry always has tight schedules with many meetings taking place among the stakeholders. It was quite difficult to get an appointment from some of the top management staff. Construction staff changes at the sites also had an impact on data collection. This was the case with all except case study 2. It was observed that the majority of labourers never gave genuine answers to the questions posed to them. They felt as if they were being checked. Thus, their answers were always positive. This was overcome through cross checking by raising the same questions when interviewing some of the management level staff and supervisory level staff working at the site and through site observations. During water auditing, it was observed that there were certain arithmetic errors in entering data. Therefore, a few more days than expected had to be spent on water auditing. It was observed that the documentation varied from site to site and that the system totally depended on the commitment and experience of top management staff at the site.

5.14 Validity of Case Study Findings

Table 5.15 explains the validity of case study findings under the four areas, viz., construct validity, internal validity, external validity and reliability.

Table 5.16: Validity of Case Study Findings

Construct Validity	Multiple sources of evidence were used. Data was collected from each case by interviewing project managers, site engineers, quantity surveyors, technical officers, safety managers, supervisory level staff and labourers. Multiple views during data collection helped to justify answers given by individuals. Furthermore, answers were justified by direct observations.
Internal Validity	During data analysis, findings were first explained through a case analysis and then through cross-case pattern matching. Results obtained were compared with extant literature and survey findings (Data triangulation - refer to Chapter 7)
External Validity	The study adopted multiple case studies and scope and case study boundaries were well defined. Data triangulation was used during data analysis (refer to Chapter 7).
Reliability	During the research design, the same case study protocol was refined and used for data collection. In addition to this, recordings, observations and actions were used consistently as much as possible.

5.15 Chapter Summary

This chapter analysed the findings of four (04) case studies. Semi structured interviews, documentation analysis and observations were used to collect data. Each case was analyzed under the main headings of water acquisition to the site and storage, water usage in construction sites, on-site water wastage, on-site water efficient practices, drivers and barriers. Then cross case analysis was done on the overall findings and results presented accordingly. Case study results found that experience, individual commitment, cost, water source, workers' behaviour and managerial policies greatly impact on the efficient use of water in construction. Findings of case studies show that water wastage due to direct construction activities is minimal and more water consumed by indirect construction activities and processes which is more than two third of the total water consumption. Assign responsibilities, supervision and monitoring, site meeting, display posters and notices, use low flow shower heads, and high pressure gun hoses are some water efficiency measures practised by all four cases. The chapter further discusses applicability and application of existing 6R and newly introduced 3R principles in construction projects. Based on the case study findings, certain recommendations were made for enhancing the sustainable use of water during the construction stage.

Thereafter, the challenges made during data collection and case analysis were discussed. Finally, the chapter discussed the validity of case study findings in terms of construct, internal, external and reliability aspects. The next chapter presents the findings of the questionnaire survey that sought to generalise the findings in the construction industry in terms of water use efficiency.

CHAPTER SIX

6 DATA ANALYSIS: QUESTIONNIRE SURVEY RESULTS

6.1 Introduction

Results of the structured survey conducted with construction project stakeholders are presented in this chapter. Aim of the questionnaire survey was to obtain a broad view of highly applicable water efficiency measures (WEMs), drivers, barriers, and actions that influence the enhancement of efficient use of water in construction industry as expected in the research objectives stated in Chapter 1. The first section present results of the questionnaire survey administration, response rate, and background information about the sample selected for the survey. The second section discusses the water management practices in construction industry, while the third section presents applicable WEMs. The fourth section discuss relevant drivers, barriers, and other attributes that impact on water efficient practices in construction industry and presents positive actions towards enhancing sustainable use of water in construction projects. Finally, validity and reliability of variables are presented in the subsequent section followed by a chapter summary. Results of rating questions (quantitative data) are presented as descriptive statistics, whereas general opinions of construction practitioners (qualitative data) are presented as narratives and as quotation form.

6.2 Questionnaire Survey Administration and Background Information

6.2.1 Questionnaire Survey Administration and Response Rate

A self-administered questionnaire (administered through internet) was used here to collect data from respondents (refer to Section 4.8.2.2). The selected professionals for the questionnaire survey are Project Managers (PM), Civil Engineers (CE), Quantity Surveyors (QS), and Architects (ARCHT). These professionals were chosen from contractor and consultant organizations in Sri Lanka using purposive sampling method (refer to Section 4.8.2.2.). Saunders *et al.* (2009) suggests that two to six (2-6) week period is reasonable for an online questionnaire survey, depending on the number of follow-ups. Accordingly, the online questionnaire survey access links were emailed on 16th February 2015 to 160 participants. According to the research plan of this study, the survey period was limited to eight (08) weeks and intended closing date was 10th April 2015. Telephone and email follow-ups were processed for all non-respondents in three-week intervals of the specified period. During the first follow-up round, it revealed that some respondents had missed the email, which accompanied the online questionnaire access link, since the email has reached respondents' bulk mailboxes. Some respondents stated that they had to postpone responding to the questionnaire due to work commitments and will respond prior to the survey closing date. At the originally stipulated closing date of the survey, 81 questionnaires were received, which produced a response rate of 51%.

The survey duration was further extended by another three (03) weeks from the original closing date to allow the survey non-respondents to complete the questionnaire survey. The survey non-respondents were notified about the extended survey period via emails, which again accompanied the online questionnaire survey access link. A total of 110 questionnaires were received from the survey respondents at the extended survey closing date. Figure 6.1 demonstrates progress of the questionnaire administration period.

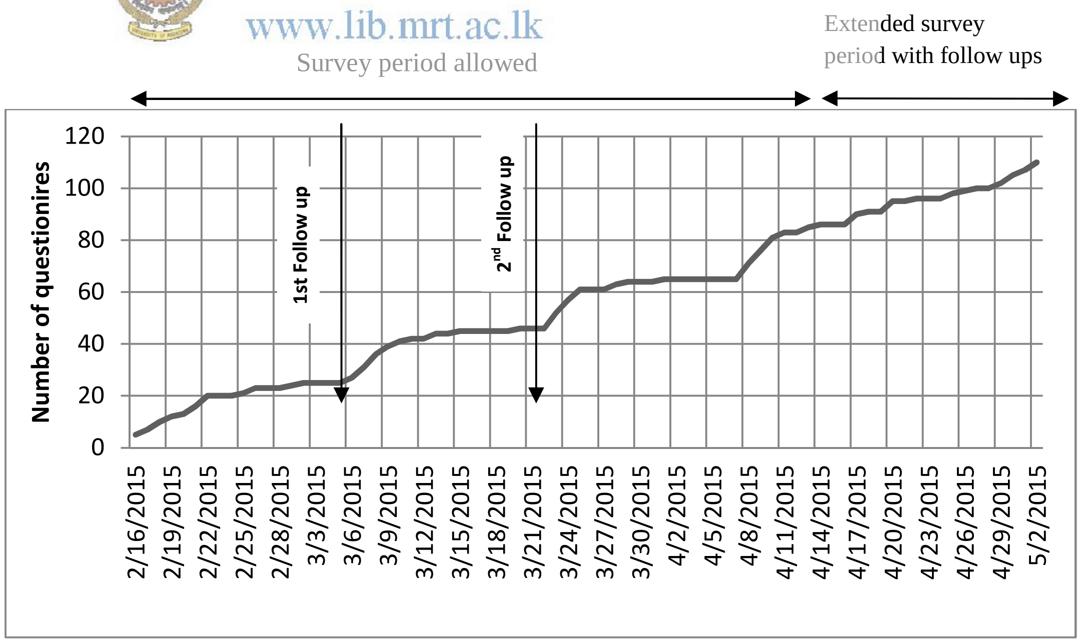


Figure 6.1: Questionnaire Survey Administration Duration

Five (05) questionnaires received from the respondents were incomplete, and hence, 105 questionnaires were selected for data analysis. As presented in Table 6.1, individual response rate of each professional group for the survey was recorded as above 50% and overall response rate indicates as 65.6%.

Table 6.1: Response Rate by Total Number of Participants

Details of Questionnaire	Project Managers	Civil Engineers	Quantity Surveyors	Architects	Total
Number of questionnaires distributed	40	40	40	40	160
Number of questionnaires received	22	33	32	23	110
Number of incomplete questionnaires (rejected)	0	1	2	2	5
Number of valid questionnaires considered	22	32	30	21	105
Active response rate (%)	55%	80%	75%	52.5%	65.6%

6.2.2 Professional Views

A one-way ANOVA test (independent measures between more than two groups) was performed as the first step towards determining whether statistically significant differences exist between mean scores among different respondent groups: project managers, civil engineers, quantity surveyors, and architects (refer to Section 4.10.2). The criterion for accepting or rejecting the hypothesis was set as 0.05, and if p-value is less than .05, the null hypothesis is rejected. The p-values for all items of the questions that were considered for one-way ANOVA test (i.e. Question 2 of Section II, Questions 5, 6, 7, 8 and 9 of Section III of the questionnaire) were greater than 0.05. It means, null hypothesis is not rejected. This indicates no statistically significant difference between respondents' mean scores (or views) on each variable, which provided a solid basis to analyse data considering all survey participants as one sample. Results of ANOVA are provided in Appendix C.

6.2.3 Background Information

Section I of the questionnaire aimed to gain background information about survey participants. The respondents were requested to provide name of their profession and number of years of work experience in construction industry. Table 6.2 illustrates the composition of total respondents (N=105) in terms of their profession. The total respondents consist of 21% project managers, 30.5% civil engineers, 28.6% quantity surveyors, and 20% architects.

Table 6.2: Composition of Survey Respondents by Profession

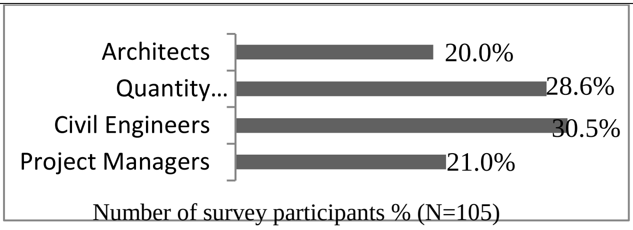
Respondents category		No.	Composition of the total survey respondents by profession
Profession	Project Managers (PM)	22	
	Civil Engineers (CE)	32	
	Quantity Surveyors (QS)	30	
	Architects (ARCHT)	21	

Figure 6.2 illustrate work experience of survey respondents by their professional category. Approximately 60% project managers, 23% civil engineers, 23% quantity surveyors, and 32% architects possessed over 25 years of working experience in the construction industry.

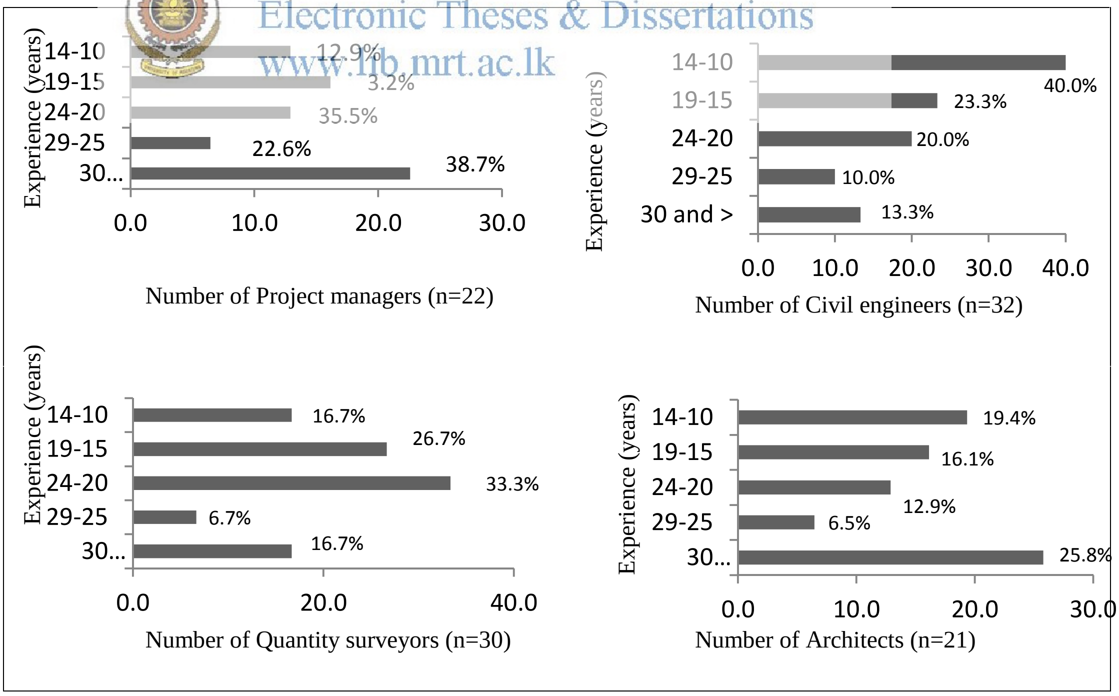


Figure 6.2: Construction Industry Work Experience of Respondents by Profession

Only the survey respondents with a minimum of 10 years experience in construction industry were invited to respond the questionnaire. Table 6.3 presents the construction industry experience distribution of total respondents. Out of 105 respondents, approximately 27% has more than 25 years of experience whilst about 23% has 20-24 years of experience in the construction industry. Approximately, 24% of the total respondents belonged to the experience category of 15-19 years. The least experience category, 10-14 years, represents approximately 26% of the total respondents.

Table 6.3: Respondents' Experience Distribution

Experience Category (Number of Years)	Number of Respondents	Percentage of the Number of Respondents
Over 30	20	19.0%
29 -25	09	8.6%
24 -20	24	22.9%
19- 15	24	23.8%
14-10	27	25.7%

6.3 Current Water Management Practices in Sri Lankan Building Construction Projects

Respondents were requested to rate the current water management practice during the construction phase in Sri Lanka on a scale from 1 (very low) to 5 (very good). Figure 6.3 depicts that 46.7% respondents viewed the current water management practice during the construction phase of construction projects in Sri Lanka is 'moderate'.

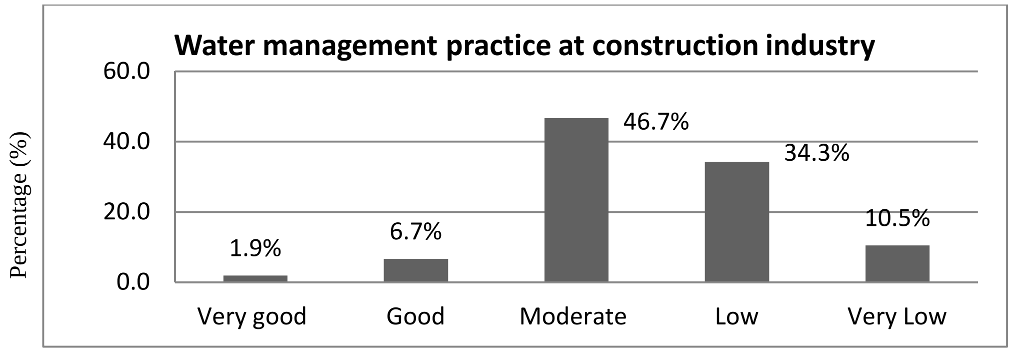


Figure 6.3: Current Water Management Practices during Construction Phase

Another 34.3% and 10.5% reported this as 'less' and 'very less' respectively. Only a minimum number of respondents opined that the current water management practice during the construction phase of construction projects in Sri Lanka as 'very good' (1.9%) and 'good' (6.7%)'.

In addition, respondents were expected to indicate what factors could influence efficient use of water on construction sites with an open-ended question to identify a wide range of factors. Over two-third of the sample respondents provided at least one or two factors. Few respondents mentioned that water management is mostly neglected in the local construction industry. Project location (55), water source (43), project scope (39), site conditions (32), worker behaviour (31), and project team commitment (19) were the most prominent factors identified (frequency of responses given in parentheses). In addition, some respondents identified factors such as senior or executive management commitment (10), climate (07), cost significance (06), lack of awareness of water crisis (06), staff experience (04) and contractual requirements (03). Some related statements of the respondents are as follows:

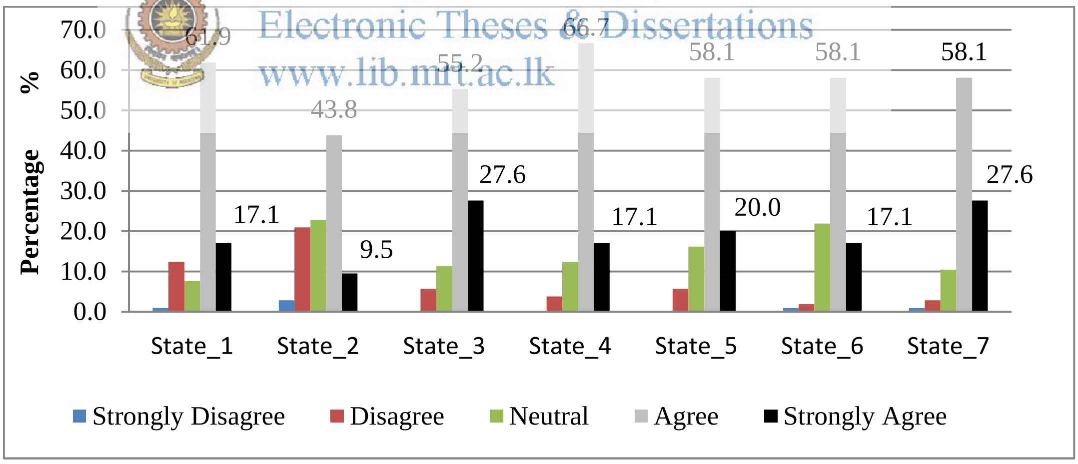
"Importance of water usage during construction is highly dependent on the scale of the project, staff experience, availability of water, and cost of water usage" [QS-5].

"Water quantity required for curing may less during the rainy season and completely opposite during the dry season"[CE-9], and *"It is predicted that by 2025, 1.8 billion people will have no freshwater even for drinking; thus, people must be constantly reminded of the crisis ahead of them"* [PM-12].

Respondents were given a list of common water sources and asked to select the ones that are being used in building construction projects. About two-third of respondents indicated that 'well water (71%)', 'main water (69.5%)', and 'tube well (59%)'as common sources of water used in building construction projects. 'Rain water harvesting' and 'surface water' received less percentage as 10.4% and 8.5% respectively in terms of water sources in building construction projects. Five (05) respondents highlighted that the use of ‘water trucks’ to supply water during high water demand periods. One comment made by a respondent was *“rainwater harvesting is compulsory in many construction projects and currently, LEED certification oriented activities are becoming frequent in construction industry”* [PM-16]. This suggests that the respondents’ awareness on the requirements of implementation of certain water sustainability related practices during the construction phase on construction sites. Majority of respondents identified ‘mains water line’ as extensively being used as water source in construction projects.

6.4 “Water Efficiency” and “Water Conservation” in the Context of Construction Industry

Respondents were asked to rate on a scale from 1 (Strongly Disagree) to 5 (Strongly Agree) on the statements given for Water Efficiency and Water Conservation in the context of construction industry. According to Figure 6.4, more than 75% of the respondents reported that they ‘agreed’ or ‘strongly agreed’ on given statements except statement 2 (State_2) in terms of water conservation.



State_1	WE and WC are two different meanings
State_2	WC means doing less by sacrificing needs
State_3	WE focuses on achieving the same result with the minimal amount of water usage
State_4	WC relies on individuals to change their behaviour to achieve results
State_5	WE relies on individuals to change their behaviour to achieve results
State_6	WC directs towards reducing wastage of water
State_7	WE encourages best technology to achieve long-term sustainability without sacrificing quality

Figure 6.4: Views on WE and WC for Construction Industry

As per Figure 6.4, statement 2 (Conservation means doing less by sacrificing needs) was rated as ‘strongly agree’ and ‘agree’ by 53.3% of the respondents. However, 22.9% of respondents held ‘neutral’ position on the State_2 whilst approximately the same percentage (23.8%) of the respondents rated State_2 to indicate that they ‘disagree’ to ‘strongly disagree’. This shows 50% of the respondents agree on the given statement on water conservation and *vice versa* in the context of construction industry. As it is apparent in Figure 6.4, results of State_4 and State_5, it clearly indicates that not only WC, but also WE relies on individuals to change their behaviour to achieve results. One respondent mentioned that, “*Conservation is possible by educating people, but efficiency needs research and development*” [ARCHT-14].

The above results bear evidence to state that respondents accepted the statements made on water efficiency, and water conservation are matched in the context of construction industry as well. Other sections of this chapter would continued with further discussion on measures, drivers, and barriers that could influence efficient use of water on construction sites.

6.5 “Water Using Activities” and “Water Wasting Activities” in Building Construction Projects

This section reports respondents’ views on ‘water using activities’ and ‘water wasting activities’ in building construction projects. The respondents were provided with a list of 15 activities identified from the literature review as water using activities in building construction projects (Refer Appendix B). From the given list of fifteen (15) activities, respondents were expected to state at least three (03) key activities that consume more water. Similarly, the respondents were asked to declare at least three key activities that induce water wastage. It was observed that not all respondents answered this question as requested. Some reasons that “since *the topic is about overall water use in construction process during construction, it cannot be commented*” [QS-18], and “*the answers may vary according to the location and site condition*” [PM-9], and, “*possible answers vary and depends on location of construction, nature of project, scope of construction, and other environmental and logistic facilities within and around the particular project*” [QS-11]. Based on the given responses, Table 6.4 presents water using activities and water wasting activities in building construction projects according to the order of frequency as reported by the respondents.

Table 6.4: Water Using Activities and Water Wasting Activities

Water Using Activities	**Number of Respondents**	**Water Wasting Activities**	**Number of Respondents**
Site cabins and sanitation	99	**Site cabins and sanitation**	69
Concrete curing	87	**Site cleaning**	64
Concreting	72	Vehicle washing	55
Brick work	70	Dust controlling	48
Site cleaning	70	**Concrete curing**	24
Commissioning and testing	67	Structural and seal testing	19
Plastering and rendering	66	Commissioning and Testing	13
Ground work (excavation, filling, compaction)	58		
Vehicle washing	24		
Structural and seal testing	17		
Dust controlling	17		
Piling Work	11		
Landscaping	09		
Painting	01		

It is apparent in Table 6.4 that a majority of respondents identified site cabins and sanitation, concrete curing, concreting, brickwork, site cleaning, commissioning and testing, plastering and rendering, and groundwork, as water using activities. One important finding emerging from Table 6.4 is that the 'site cabins and sanitation' activity is identified as the highest activity in both water using activities and water wasting activities. 'Site cleaning' and 'curing' are reported within the top five (05) activities in both lists.

Few respondents mentioned that since most of the projects use ready-mix concrete, it does not affect the site water consumption. This assumption may be the reason that concreting item received 72 responses although it is considered as a wet trade, which needs more water according to literature. In addition, few respondents (PM-7, PM-18, CE-5, CE-7, CE-22, QS-12, QS-21, and ARCHT-5) mentioned that re-testing work for leaks in swimming pools, water tanks, and plumbing systems as more water using activities. For instance *"Curing, leak proof testing and retesting of pools, and plumbing systems tend to use more water at sites"* [QS-12].

Other comment made by thirteen (13) number respondents was that when labourers are accommodated on-site, 'site cabins and sanitation' tends to consume most of the water and it accounts for high water wastage in comparison to other construction activities. For instance, "*labour accommodation at site and in-situ wet construction use lot of water*" [CE-12].

In addition, some suggestions were made by few respondents to reduce water wastages in construction sites. "*Efficiency water practices can be controlled by cultivating positive attitudes among the staff at the site level"* [PM-1]. "*People will be much obliged to conserve water if they have sound awareness about scarcity of drinkable water*" [CE-30].

6.6 Water Efficiency Measures (WEMs)

This section reports the views of respondents on applicability of water efficiency measures (WEMs), which can assist reducing water usage or enhance water sustainability during the construction phase in Sri Lanka. Respondents were provided with a level of applicability scale from 1 (Not Applicable) to 5 (Highly Applicable) and middle point represent 3 (Moderately Applicable). Thirty-one (31) total potential WEMs were presented under four (04) main categories in the questionnaire survey. The four (04) main categories are Policies and Planning (PP), Attitudes and Behaviours (AB), Alternative Construction (AC) methods, and Efficient Technologies (ET). Following subsections present findings of each category.

6.6.1 Applicability of WEMs: Policies and Planning (PP)

Ten measures have identified with the category of policies and planning (refer to Section 3.3.2 of Chapter 3). Table 6.5 summarises result findings.

Table 6.5: Applicability of WEMs: Policies and Planning during the Construction stage

Ref.	Policies and Planning (PP)	Scale Range*		Mean Score	Effect Level	Std. Dev.	Rank
		Min	Max				
PP_10	Introduce water leak detection monitoring systems	2	5	**4.543**	HA	0.621	**1**
PP_9	Implement water auditing	1	5	**4.429**	HA	0.691	**2**
PP_6	Introduce a water action plan at the inception	2	5	**4.276**	HA	0.700	**3**
PP_8	Introduce sub-metering systems	2	5	**4.229**	HA	0.788	**4**
PP_2	Implement environmental policies on natural resources (EMS, LEED, GreenSL, BREAM)	2	5	4.181	A	0.585	5
PP_1	Develop a builder's guidebook for reference	3	5	4.162	A	0.590	6
PP_5	Integrate water efficient techniques during the pre-design and tender stage	2	5	4.076	A	0.730	7
PP_7	Implement Rainwater collection and reuse	1	5	4.067	A	1.281	8
PP_3	Implement licensed water extraction system (Surface water/ tube well)	1	4	2.971	MA	0.753	9
PP_4	Increase the unit rate for water	1	5	2.886	MA	0.891	10

Significant measures are given in bold, based on the degree of central tendency (Mean Score >4.2)
1.00 ≤ 'Not Applicable≤ 1.80 ; 1.80 < ' Less Applicable ≤ 2.60 ; 2.60 < 'Moderately Applicable ≤ 3.40 ; 3.40 < 'Applicable (A) ≤ 4.20; 4.20<' Highly Applicable (HA) ≤ 5.00
** minimum and maximum scale rated by respondents for each measure from 1-5 Scale*

As presented in Table 6.5, respondents identified all the measures except two [i.e. implement licensed water extraction system (PP_3) and increase the unit rate (PP_4)] under policies and planning, as applicable (mean score > 3.4) policies and planning related measures to enhance water efficient practices during the construction phase. Of these measures, four measures were identified as highly applicable since the respective mean scores of each driver was greater than 4.2; i.e. introduce water leak detection monitoring systems (PP_10), implement water auditing (PP_9),introduce a water action plan at the inception (PP_6), and introduce sub-metering systems (PP_8).

These four (04) factors are summarised in Figure 6.5 according to the type of responses of the participants.

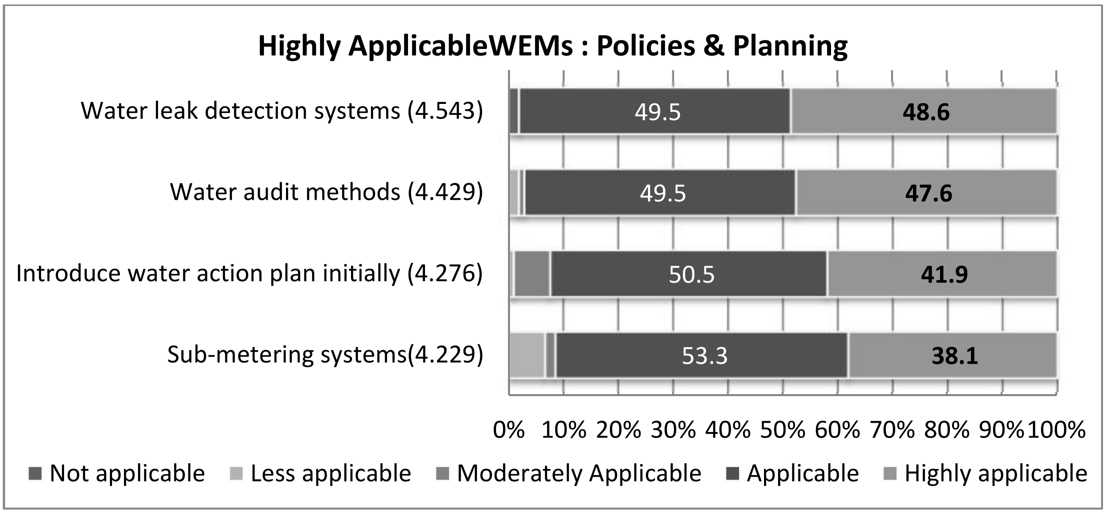


Figure 6.5: Participants' Response on Highly Applicable Measures under PP

Among ten (10) factors considered under PP, implementation of environmental policies on natural resources (e.g. EMS, LEED, Green[SL], BREAM) was rated within the top five (05) highly applicable factors (MS= 4.18; SD= 0.585). This further supported with a comment made by one respondent as, "*it is critical to use sustainability measures according to the project complexity making use of available rules and regulations. For example IEE, EIA, and green rating systems LEED and these should be incorporated in the project specific documents*"[PM-10]. Another respondent stated, "*Following environmental standards during waste water disposal is important*" [ARCHT-18]. One quantity surveyor stated, "*water efficiency requirements should be included to condition of contract*" [QS-8]. This statement accords with the applicability of 'integrated water efficient techniques during the pre-design and tender stage (MS=4.076; SD= 0.730).

6.6.2 Applicability of WEMs: Attitudes and Behaviours (AB)

Four (04) soft measures were identified with the category of attitudes and behaviours (refer to Section 3.3.2 of Chapter 3). As indicated in Table 6.6, respondents have considered the four (04) measures under 'attitudes and behaviours' category as applicable to WEMs. Three (03) of those four measures, namely, improve monitoring and supervising (AB_3), assign responsibilities and targets to site staff (AB_1), and increase water awareness among workers (AB_4) were considered by the respondents as highly applicable measures (Mean score > 4.2).

Table 6.6: Applicability of WEMs: Attitudes and Behaviours during the Construction Stage

Ref.	Attitude and Behaviour (AB)	Scale Range*		Mean Score	Effect Level	Std. Dev	Rank
		Min	Max				
AB_3	Improve monitoring and supervision	3	5	**4.352**	HA	0.571	**1**
AB_1	Assign responsibility and targets to site staff	3	5	**4.238**	HA	0.613	**2**
AB_4	Increase water awareness among workers	2	5	**4.229**	HA	0.654	**3**
AB_2	Introduce penalty for unsustainable practices by site staff	1	5	3.781	A	0.855	**4**

Significant measures are given in bold based on the degree of central tendency (Mean Score >4.2)
1.00 ≤ 'Not Applicable≤ 1.80 ; 1.80 < ' Less Applicable ≤ 2.60 ; 2.60 < 'Moderately Applicable≤ 3.40
3.40 < ' Applicable (A) ≤ 4.20; 4.20<' Highly Applicable (HA) ≤ 5.00
** minimum and maximum scale rated by respondents for each measure from 1-5 Scale*

These three (03) factors were again summarised in Figure 6.6 according to the type of responses of participants.

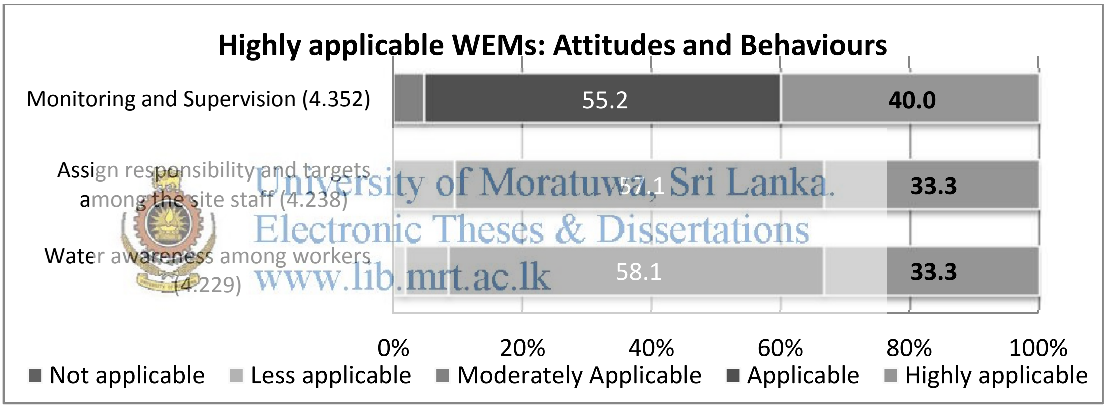


Figure 6.6: Participants' Response on Highly Applicable Measures under AB

Among many statements made by the questionnaire respondents, one PM respondent highlighted the importance of highly applicable factors mentioning, *"Project managers must be responsible and accountable to the top level Management in terms of total sustainability aspects of the project. He in turn, must make other key professionals, consultants, subcontractors and charge hands, foremen, and labourers responsible on efficient water handling on site''* [PM-2]. Another respondent revealed about the lack of knowledge on value of water and conservation methods and stated *"many Sri Lankans lack of knowledge on the value of water and conservation methods. Thus, it is very important to enhance awareness about the value of water and water conservation methods among water users, so that it enables* *effective implementation of water efficient management systems across construction projects"* [ARCHT-3].

Moreover, it is apparent in Table 6.6 that respondents believe 'introduce penalty for unsustainable practices by site staff (MS = 3.781'; SD = 0.855)' as applicable WEMs. One respondent mentioned, "*Granting incentives for innovative ideas for saving water might give good results* [QS-27]".

This statement suggests that penalties as well as rewarding as a mechanism have potentials to contribute and to improve sustainable use of water in construction sites.

6.6.3 Applicability of WEMs: Alternative Construction (AC) methods

Table 6.7 summaries the results of applicability of alternative construction methods to enhance the efficiency of water usage in construction projects. Seven (07) measures were identified within the category of alternative construction methods and these measures are considered as hard measures in nature (refer to Section 3.3.2). While six (06) out of seven alternative construction methods were considered applicable, none of them was identified as highly applicable.

Table 6.7: Applicability of WEMs: Alternative Construction (AC) methods During the Construction Stage

Ref.	Alternative Construction (AC) Methods	Scale Range*		Mean Score	Effect Level	Std. Dev	Rank
		Min	Max				
AC_3	Introduction of curing agents	1	5	4.010	A	1.236	**1**
AC_2	Implement closed loop systems	1	5	3.857	A	0.985	**2**
AC_1	Use admixtures /chemical additives	1	5	3.733	A	1.187	**3**
AC_4	Introduce dry wall partitions instead of brick and block walls	1	5	3.686	A	1.013	**4**
AC_5	Use pre-cast or prefabricated construction methods	1	5	3.724	A	0.966	**5**
AC_7	Use steel intensive construction methods	1	5	3.448	A	0.980	**6**
AC_6	Use pre-mixed concrete and pre-mixed mortar	1	5	3.152	MA	0.852	**7**

Significant measures are given in bold based on the degree of central tendency (Mean Score >4.2)
1.00 ≤ 'Not Applicable (NA) ≤ 1.80 ; 1.80 < ' Less Applicable (LA) ≤ 2.60 ; 2.60 < 'Moderately Applicable (MA) ≤ 3.40
3.40 < ' Applicable (A) ≤ 4.20; 4.20<' Highly Applicable (HA)≤ 5.00
** minimum and maximum scale rated by respondents for each measure from 1-5 Scale*

It is apparent from Table 6.7, the highest rank was reported as applicable for 'introduce curing agents (AC_3)' followed by 'implementing closed loop systems (AC_2)'.

The above survey findings were further supported by a statement made by a respondent as, *"according to my research, water curing is more effective than membrane curing. Water curing delays the initiation of corrosion more than the membrane curing"* [CE-14] whereas, as noted by another respondent, *"application of alternative technology and alternative material drive the industry towards sustainable use of potable water"* [ARCHT-9].

One quantity surveyor [QS-7] expressed his opinion as, *"although less water quantity is needed for dry construction, cost is more than double for the masonry and it uses lot of fossil fuels"*. 14 respondents stated that the impact of cost implications on certain alternatives. This confirms cost as one barrier when implementing alternative materials during the construction phase.

It is apparent from Table 6.7, some respondents less favour the option of 'use of steel intensive construction methods (AC_7)'. 'Use pre-mixed concrete and pre-mixed mortar (AC_6)' is the only measure identified out of the seven measures, as 'moderately applicable'.

Above statements give positive and negative views on application of alternative construction methods in order to enhance efficient water use in construction projects.

6.6.4 Applicability of WEMs: Efficient Technologies (ET)

Ten (10) measures that are considered as 'hard' have identified with the category of efficient technologies (refer to Section 3.3.2). The results are summarised in Table 6.8, which denote seven (07) measures out of ten (10) can be considered as applicable under efficient technologies (Mean Score >3.4). However, only one, i.e. 'high pressure trigger operated spray gun hoses (ET_4)' was considered highly applicable (Mean Score > 4.2). 'Fan misting systems for dust suppression (ET_3)

[MS= 3.076; SD= 1.432]' and 'Vacuum toilets (ET_8) [MS=2.819, SD= 1.35]' received 9th and 10th ranks respectively and identified as moderately applicable WEMs.

Table 6.8**:** Applicability of WEMs: Efficient Technologies During the Construction

Ref.	**Efficient Technologies**	**Scale Range***		**Mean Score**	**Effect Level**	**Std. Dev**	**Rank**
		Min	**Max**				
ET_4	High pressure trigger operated spray gun hoses	1	5	**4.238**	HA	0.966	**1**
ET_6	Pressure reducing valves	2	5	4.181	A	0.585	**2**
ET_5	Low flush cisterns/urinals/waterless urinals	1	5	3.924	A	0.851	**3**
ET_2	Efficient showers : Low-flow showerheads	1	5	3.762	A	1.043	**4**
ET_7	Sprinkler systems for curing concrete	1	5	3.695	A	0.942	**5**
ET_1	Dust suppression vehicles with sprinklers	1	5	3.381	A	1.382	**6**
ET_10	Water efficient taps	1	5	3.362	A	1.234	**7**
ET_9	Washing bays for wheel washing	1	5	3.229	A	1.495	**8**
ET_3	Fan misting systems for dust suppression	1	5	3.076	MA	1.432	**9**
ET_8	Vacuum toilets	1	5	2.819	MA	1.350	**10**

Significant measures are given in bold based on the degree of central tendency (Mean Score >4.2)
1.00 ≤ 'Not Applicable (NA) ≤ 1.80 ; 1.80 < 'Less (LA) 2.60 ; 2.60 < 'Moderately Applicable (MA) ≤ 3.40
3.40 < ' Applicable (A/R) ≤ 4.20; 4.20<' Highly Applicable (HA) ≤ 5.00
** minimum and maximum scale rated by respondents for each measure from 1-5 Scale*

6.6.5 Discussion on Overall Findings of WEMs

Out of the 31 measures presented to respondents, only eight were identified as highly applicable WEMs and are presented in Table 6.9. According to Table 6.9, all eight (08) WEMs have a mean score over 4.20 (i.e. approximately 90% of the respondents), indicating these eight (08) WEMs are highly applicable to enhance efficient use of water during the construction phase. Moreover, it was noted that respondents' responses percentage is almost 100% for water audit (PP_9), and water leak detection monitoring systems (PP_10) as highly applicable measures.

Table 6.9: Highly Applicable WEMs to Enhance Water Use Efficiency Practices During the Construction Phase

Ref.	Highly Applicable WEMs	Mean Score	Category	Overall Rank	% of respondents scoring		
					≤2	3	≥4
PP_10	Introduce water leak detection monitoring systems	**4.543**	Policies and Planning	**1**	1.9	-	98.10
PP_9	Implement water auditing	**4.429**	Policies and Planning	**2**	1.9	1.0	97.10
AB_3	Improve monitoring and supervision	**4.352**	Attitude and Behaviour	**3**	-	4.8	95.20
PP_6	Introduce a water action plan at the inception	**4.276**	Policies and Planning	**4**	1.0	6.7	92.40
ET_4	High pressure trigger operated spray gun hoses	**4.238**	Efficient Technology	**5**	7.6	-	92.38
AB_1	Assign responsibility and targets to site staff	**4.238**	Attitude and Behaviour	**6**	-	9.5	90.48
AB_4	Increase water awareness among workers	**4.229**	Attitude and Behaviour	**7**	1.9	-	91.43
PP_8	Introduce sub-metering systems	**4.229**	Policies and Planning	**8**	6.7	1.9	91.40

Results on Table 6.9 reveal that respondents have favoured mainly ‘soft’ measures against ‘hard’ measures as highly applicable WEMs to enhance water efficient practices during the construction phase. The results further indicate that three (03) out of four (04) under ‘Attitudes and Behaviours’ WEMs and four (04) out of ten (10) under ‘Policies and Planning’ WEMs are highly applicable to enhance water efficient practices during construction phase. Thus, respondents have given a clear message that soft measures are more appropriate to enhance water efficient practices during the construction phase. Interestingly, none of the seven (07) ‘Alternative Construction’ WEMs and only one out of ten (10) ‘Efficient Technologies’ WEMs were rated as highly applicable to enhance water efficient practices during the construction phase. This suggests that soft measures have many implications for enhancing water efficient practices during the construction phase. Some respondents were of the opinion that cost is a barrier to implement alternative construction methods and efficient technologies.

The results reveal that only six (06) out of 31 measures presented to the respondents were identified as moderately applicable WEMs (2.6 < Mean Score < 3.4) and these are presented in Table 6.10.

Table 6.10**:** Moderately Applicable WEMs to Enhance Water Efficient Practices During Construction Phase

Ref.	**Moderately Applicable WEMs**	**Mean Score**	**Category**	**Overall Rank**	**% of respondents scoring**		
					≤2	**3**	**≥4**
WT_9	Washing bays for wheel washing	**3.329**	Efficient Technologies	**26**	35.2	1.9	62.9
AC_6	Use of pre-mixed concrete and pre-mixed mortar	**3.152**	Alternative construction methods	**27**	24.8	37.1	38.1
CT_3	Fan misting systems for dust suppression	**3.076**	Efficient Technologies	**28**	35.2	16.2	48.6
PP-3	Licensed water extract system	**2.971**	Policies and Planning	**29**	16.2	63.8	20.0
PP_4	Increase of unit rate	**2.886**	Policies and Planning	**30**	36.2	40	23.8
ET_8	Vacuum toilets	**2.819**	Efficient Technologies	**31**	47.6	7.6	37.1

It is important to note, that a majority of respondents reported none of the measures as 'not applicable'. One respondent stated that, "*approval for shallow tube wells may be included in tender documents and the use of unlimited water is a threat to water resources in near future*" [ARCHT-4]. The results confirm that most respondents are in 'neutral' view and identified that increasing the unit rate of water as 'moderately applicable'. However, one respondent mentioned that "*treated water should not be provided free of charge under any circumstances. This leads to a severe misuse*" [PM-2]. The respondents identified 'Increase of unit rate (PP_4) as moderately applicable WECMs. However, one respondent stated, "*unnecessary use and waste of potable water can be controlled by introducing water pricing strategies*" [ARCHT-8]. Moreover, one Architect stated "importance of consideration of economic values to the cost of water" which is currently not considered by many sectors including construction sector" [ARCHT-4].

6.7 Drivers, Barriers, and Other Attributes that Impact on Efficient Water-Use in Building Projects

6.7.1 Drivers for Enhancing Water Efficient Practices

Respondents were requested to rate the relevance of the potential eleven (11) drivers to enhance water efficient practices during the construction phase, on a scale of 1

(Not Relevant) to 5 (Highly Relevant). The given eleven (11) drivers were identified through literature review and preliminary interviews. According to the results presented in Table 6.11, the responses mean score was greater than 3.4 for all eleven (11) drivers, which report that respondents have considered all drivers relevant in terms of enhancing water efficiency practices during construction phase. Cost of water (Driv_2) and water source (Driv_11) are identified as highly relevant drivers in terms of impact on enhancing water use efficiency practices during construction phase (mean score greater than 4.2).

Table 6.11**:** Drivers that Influence Enhancing Water Use Efficient Practices during Construction Phase

Ref.	Drivers	Scale Range*		Mean Score	Effect Level	Std. Dev	Rank
		Min	Max				
Driv_2	**Cost of water**	1	5	**4.381**	HR	0.836	**1**
Driv_11	**Water source**	1	5	**4.352**	HR	0.784	**2**
Driv_1	Attitude and behaviour of site staff	2	5	4.190	R	0.952	**3**
Driv_10	Water quantity	1	5	4.143	R	0.914	**4**
Driv_5	Project specific documents	1	5	4.000	R	0.920	**5**
Driv_6	Quality of water	1	5	3.952	R	0.813	**6**
Driv_7	Responsibility	2	5	3.943	R	0.757	**7**
Driv_9	Sustainability rating systems	1	5	3.829	R	0.945	**8**
Driv_4	Policies and regulations	1	5	3.762	R	1.079	**9**
Driv_3	Experience	2	5	3.714	R	0.840	**10**
Driv_8	Research and development	1	5	3.657	R	1.055	**11**

Significant measures are given in bold based on the degree of central tendency (Mean Score >4.2)
1.00 ≤ 'Not Relevant (NR) ≤ 1.80 ; 1.80 < ' Less Relevant (LR) 2.60 ; 2.60 < 'Moderately Relevant (MR ≤ 3.40
3.40 < ' Relevant (R) ≤ 4.20; 4.20<' Highly Relevant (HR) ≤ 5.00
** minimum and maximum scale rated by respondents for each measure from 1-5 Scale*

Several respondents provided their views on relevant drivers that would impact enhancing water efficient practices during the construction phase. Many of them accord that cost of water is a highly relevant driver with an impact on enhancing water efficient practices. One respondent stated, *"Unlike water received from wells, when water is obtained from city water line, the site management is more careful about water usage on site because water received from city line has a payable cost"* [PM-1]. Another respondent explained how the cost of water encourages clients towards water efficiency practices. "*If the client is cost conscious, then there is a* *greater chance to encourage water efficient practices, thereby to reduce water costs"* [QS-7]. Twelve (12) number of respondents (12) mentioned that project specific water efficiency measures should be identified from early stages of projects. For instance, one respondent mentioned, *"the requirement for water efficient practices needs to be identified in Tender Documents. Otherwise, if the contractors have to incur any additional costs to implement water efficient practices, then the contractors do not allow for such costs when pricing tenders, considering the fact that such additional cost for none specified requirements in the tender documents tend to risk losing the tender"* [QS-6].

Attitudes and behaviours of site staff (Driv_1) [MS= 4.19; SD= 0.952] is rated as the next top relevant driver. Although 'research and development (Driv_8)' received the last rank according to responses given by the respondents, mean score is indicated as 3.657, which bears evidence that respondents believe all drivers are relevant and influence on enhancing efficient use of water during the construction phase of projects. Another comments made by few respondents was water quality. One comment was management is responsible of checking quality of water sources used by workers [PE-C4].

6.7.2 Barriers that Affect on Enhancing Water Efficient Practices

Respondents were asked to rate on the same scale of 1 (Not Relevant) to 5 (Highly Relevant) on the relevance of given eight (08) barriers that affect enhancing water efficient practices during the construction phase. The given eight (08) barriers were identified through literature review and preliminary interviews and presented in Table 6.12.

According to the results presented in Table 6.12, the responses mean score is greater than 3.4 for all eight (08) barriers, which confirm that respondents considered all barriers to be relevant on enhancing water efficiency practices during construction phase. Low priority for water management (Barr_6) was identified as highly relevant barrier that influence enhancing efficient use of water during construction phase (mean score greater than 4.2).

Table 6.12**:** Barriers that Influence Enhancing Water Efficient Practices during the Construction Phase

Ref.	**Barriers**	**Scale Range***		**Mean Score**	**Effect Level**	**Std. Dev**	**Rank**
		Min	**Max**				
Barr_6	**Low priority for water management**	2	5	**4.276**	HR	0.740	**1**
Barr_1	Absence of standards to integrate WEMs during pre-design stage	1	5	4.105	R	0.909	**2**
Barr_2	Absence of standards to integrate WEMs during construction stage	1	5	4.038	R	0.909	**3**
Barr_8	Value of water is not apparent	1	5	3.981	R	0.888	**4**
Barr_4	Additional cost to contractor	2	5	3.876	R	0.885	**5**
Barr_5	Unaware of new techniques	2	5	3.829	R	0.765	**6**
Barr_7	Resistance to change	1	5	3.714	R	0.958	**7**
Barr_3	Additional cost to client	2	5	3.581	R	0.998	**8**

Significant measures are given in bold based on the degree of central tendency (Mean Score >4.2)

1.00 ≤ 'Not Relevant (NR) ≤ 1.80 ; 1.80 < ' Less Relevant (LR) 2.60 ; 2.60 < 'Moderately Relevant (MR ≤ 3.40

3.40 < ' Relevant (R) ≤ 4.20; 4.20<' Highly Relevant (HR) ≤ 5.00

** minimum and maximum scale rated by respondents for each measure from 1-5 Scale*

As one quantity surveyor mentioned, *"the management is paying less attention on water usage during the pre-construct stage from briefing to preparation of tender documents and during post-contract stage implementation of water efficiency measures"* [QS-19]. Another respondent stated, *"water as a resource is not given a priority in construction process compared to materials and workmanship"* [ARCHT-3]. The same respondent further elaborated, *"water wastage is not even considered as an economic loss (i.e. loss of profit)"* [ARCHT-3]. The above statements clearly support that construction industry still provide a low priority for water management and the value of water is concealed in construction projects.

According to the results, 'absence of standards to integrate WEMs during pre-design stage (Barr_1)' and 'during the construction stage (Barr_2)' is the next two important barriers. Several respondents (15) specified number of shortcomings relevant to current on site practices: lack of education and lack of awareness on water efficiency, cost of water, lack of commitment, and lack of proper allocation of water responsibilities. For instance, one respondent mentioned, *"one of the main reason for inefficient use of water in construction sites is lack of awareness of labourers on* *water efficient practices, while middle and upper level managements irresponsible (neglect) behaviour account for on-site water inefficiencies"*[QS-25]. As another respondent mentioned, *"main cause for wasting water on construction sites is the insignificant payment (cost) for water; hence, no incentive to save water and water responsibility of individuals is not established, and thus, waste of water is inevitable"* [CE-6].

6.7.3 Assessment of Exiting 6R and New 3R Principles in the Context of Efficient Use of Water during Construction Phase

6.7.3.1 Applicability of R Principles to Enhance Efficient Water-Use

Respondents were requested to rate on a scale of 1 (Not applicable) to 5 (Highly applicable) about the applicability of R principles to enhance water efficient practices during construction phase. Detailed distribution of responses in terms of the applicability of R principles is summarised in Table 6.13.

As presented in Table 6.13, all R principles were considered as 'applicable' to enhance efficient use of water during construction phase, since mean score of each concept is more than 3.4. Over 70% respondents rated Reduce, Review, Responsibility, Replace, and Regulations as 'applicable' to 'highly applicable'. Thus, Reduce, Review, Responsibility, Replace, and Regulations are the top five applicable R principles to enhance efficient use of water during the construction phase. Results also report that 51.4% of respondents consider Re-use and Recycle 'applicable' to 'highly applicable' (ranked 8th and 9th respectively) to enhance efficient use of water during the construction phase.

Table 6.13**:** Applicability of R Principles to Enhance Efficient Use of Water during Construction Phase

9R	**#1 %**	**#2 %**	**#3 %**	**#4 %**	**#5 %**	**Mean Score**	**Std. Dev.**	**Effect Level**	**Relative Rank**
Reduce	0	1.9	19.0	40.0	39.0	4.162	0.798	Applicable	1
Review	0	5.7	10.5	47.6	36.2	4.143	0.825	Applicable	2
Responsibility	3.8	4.8	13.3	32.4	45.7	4.114	1.059	Applicable	3
Replace	1	3.8	18.1	41.0	36.2	4.076	0.885	Applicable	4
Regulation	1.0	4.8	22.9	41.0	30.5	3.952	0.903	Applicable	5
Removal	1.9	4.8	27.6	36.2	29.5	3.867	0.961	Applicable	6
Reuse	3.8	13.3	31.4	29.5	21.9	3.524	1.093	Applicable	8
Reward	3.8	7.6	23.8	40.0	24.8	3.743	1.038	Applicable	7
Recycle	7.6	12.4	28.6	29.5	21.9	3.457	1.185	Applicable	9
1.00 ≤ 'Not Applicable≤ 1.80 ; 1.80 < ' Less Applicable ≤ 2.60 ; 2.60 < 'Moderately Applicable≤ 3.40 3.40 < ' Applicable (A/R) ≤ 4.20; 4.20<' Highly Applicable ≤ 5.00									

6.7.3.2 Application of Existing 6R Principles in Water Hierarchy to Achieve Efficient Use of Water

Respondents were asked to comment on application of steps of water hierarchy; Review, Replace, Reduce, Reuse, Recycle and Removal. Twenty (25) out of 105 respondents mentioned their responses to this open-ended question. All who responded, commented on application of Review, Reduce, Reuse, and Recycle in terms of use of water.

Comments of nine (09) respondents highlighted their attempt to Reduce water consumption as it provides cost benefits. For instance, one respondent explained how one past project that he was involved reduced water usage by making simple changes to on-site water usage arrangements: "*I was personally responsible to apply water efficiency measures to reduce water quantity when working for A Company at the B Cricket Stadium site in 2003/2004. The labour accommodations had long tanks filled with potable water for bathing and washing, which I recognised wastes more water. Thus, I instructed to remove the tanks instead introduced showers and taps to replace long tank. Further, we introduced one-liter plastic water bottle in the cistern mechanism in the site toilets, which enable to save water on each flush. We got* *results immediately and the monthly water bill reduced by approximately 70% after making those changes"* [PM-8]. Another respondent mentioned that application of water usage reduction methods is, *"a highly rewarding practice on the economics of the monthly cost on overhead cycle of a contractor"* [QS-23].

Thirteen (13) number of respondents stated that application of Reuse and Recycle concepts benefit in many ways such as reducing fresh water consumption, minimising water wastages, elimination or reducing environment impacts due to disposal of waste water, and cost savings. For instance, one respondent said, *"look for alternative water sources, rainwater harvesting, reuse and recycle, and encourage such measures within construction sites"* [PM-4].

Further, one respondent was, *"it is important to establish project specific on-site waste water recycling treatment centre"* [QS-20], while another respondent provided an example on how water can be recycled and reused on-site; *"batching plant water run-off and the truck wash water are passed through a sedimentation and settling tank. Then that water is sent through a filtering process to obtain recycled water (somewhat purified water). This water is then used for curing work"* [CE-12]. The same respondent further stated about the benefits gained from this process; *"it was so cost effective and reduced the amount of water disposed from the site. Also, I think display of this process to on-site workers enable to positively change their attitudes towards water consumption"* [CE-12].

Eleven (11) respondents stated about the importance of reviewing alternative water sources, namely rainwater, lagoon water, and treated seawater. The respondents indicated that the use of alternative water sources at site level should be encouraged to conserve freshwater (water from city water supply/potable water) for other none-construction consumers. One respondent described the need of conserving potable water as, *"use of potable water must be constantly monitored, excess investigated, and strictly controlled, to make consumers understand the need for conserving potable water"* [CE-19]. The same respondent mentioned about another source of water and how it should be used on-site, *"if ground water is not of potable quality* *that must be collected and stored separately for activities/processes which need non-potable standards"* [CE-19].

Analysing the comments of respondents suggests that their views are in agreement with that more benefits can be gained from application of steps of water hierarchy during the construction phase. The benefits stated by the respondents are cost savings, reduction of fresh water usage, minimise wastewater disposal, eliminate, or reduce environment impacts and change of people's attitudes towards water usage.

6.7.3.3 Application of New Three R (3R) Principles for Achieving Efficient Use of Water

Eighteen (18) respondents described their views on how new 3R, i.e. Regulations, Responsibility, and Rewards affects efficient use of water during the construction phase. In terms of regulations, eight (08) respondents recognised the importance of implementation of regulatory requirements relevant to water management. For instance, one respondent mentioned, "*most important factor in water management process is the implementation of regulatory methods, relevant guides, and manuals*" [PM-16]. Another respondent further explained the importance of regulatory authorities and government involvement in terms of assigning water related responsibilities and targets, "*active involvement of government and other regulatory authorities is extremely important when assigning water conservation targets and responsibilities*" [ARCHT-4]. One respondent mentioned, "*not only construction companies, but government and other institutes also should take responsibility of water management in construction projects"* [QS-28]. Seven (07) respondents explained the importance of assigning water targets and responsibilities among on-site project team. For example, one mentioned that, "*assigning water targets and responsibilities among construction team is very important"* [PM-12]. However, another respondent described the requirement of a reward system as, "*allocation of water responsibility among project team alone will make no sense unless a reward system is introduced"* [QS-19]. Similarly, another respondent stated how incentives can help minimising water wastages, "*site workers must be encouraged to report leaks in the water supply lines through yielding some incentives, so that wastage* *could be minimized at site level*" [PM-12]. Further, seven (07) respondents remarked on introducing a nationwide rewards mechanism to promote innovative and sustainable practices in terms of efficient use of water. As one respondent explained, *"the contractors who initiated the improvement must be recognized by CIDA (Construction Industry Development Authority) at the time of contractor grading, registering, and selecting for awards"* [PM-15].

6.7.4 Sustainability Assessment Criteria for Efficient Use of Water during the Construction Phase

Respondents were asked to rate on a scale of 1 (Strongly disagree) to 5 (Strongly agree) to express their agreement on PREREQUESITE (no credit assign) and REQUISITE (credits assign) criteria applicable to enhance water efficient practices during the construction phase and include under the category of 'Water Efficiency' section in Green^{SL} assessment tool as shown in Figure 6.7.

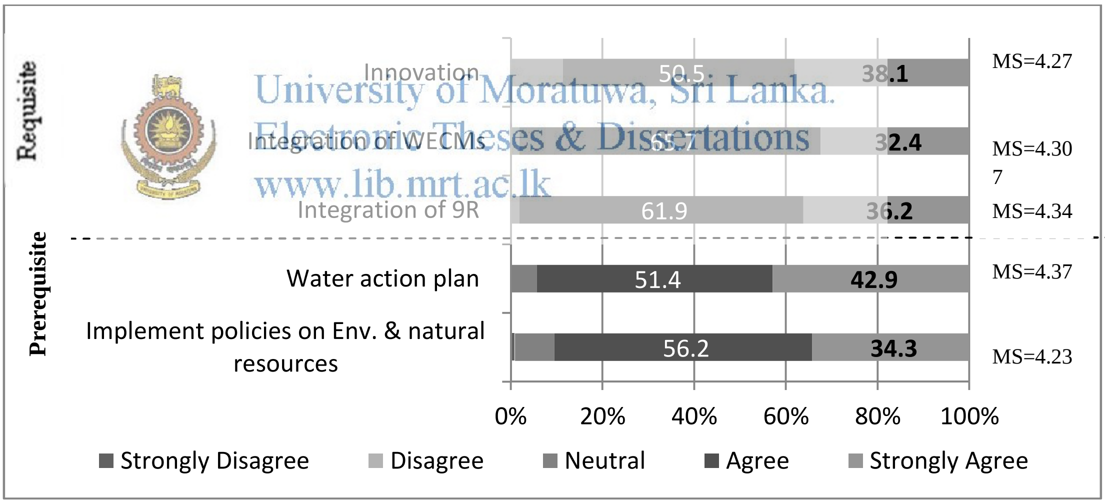


Figure 6.7: Respondents' Agreement Level on Prerequisite and Requisite Criteria for Green^{SL} for Efficient Use of Water during the Construction Phase

It is apparent from Figure 6.7, all listed criteria are reported as 'agree' to 'strongly agree' by majority of respondents. Since mean score of each criterion is over 4.2, respondents agree that all criteria are applicable to enhance water efficient practices during the construction phase. Among Prerequisite criteria, the highest rank is 'water action plan (MS = 4.37)' and combined results of 'agree' and 'strongly agree' is reported as 94.3%. ‘Integration of 9R’ (MS = 4.34) and ‘Integration of WEMs’ (MS=4.30) are agreed as top requisite criteria.

6.8 Actions for Enhance Efficient Water Use in Construction Projects

The chapter presented views of respondents on water efficient practices, existing barriers and drivers. Less consideration in the area of water efficiency practices during the design and construction stages identified by many respondents as a shortcoming for implementing water efficiency practices in construction projects. Moreover, respondents make recommendations to establish sustainable use of water in construction projects. Some important findings are summarised in Figure 6.8.

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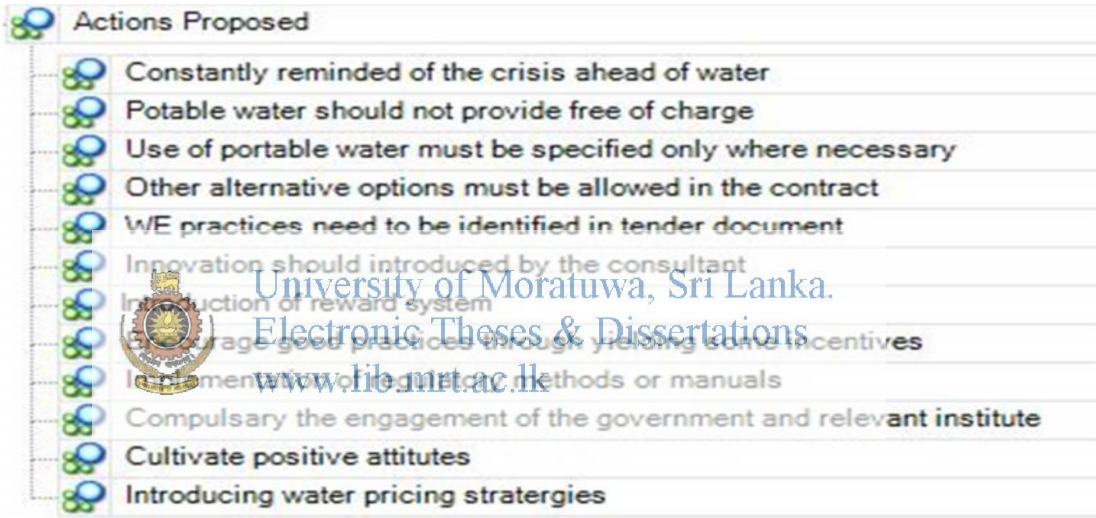

Figure 6.8: Actions Proposed through the Structured Survey

6.9 Validity and Reliability

Chapter 4 (refer to Section 4.9) discussed measures taken to ensure validity and reliability of survey data. Content validity of the questionnaire was ensured through a detailed literature review and refinements to questionnaire via preliminary interviews. In terms of reliability of data, attempts were made to ensure careful selection of respondents for the survey. All respondents selected for the survey had a minimum of 10 years of experience in the building construction industry. The sample consists of a good range of experience from not less than 10 to maximum 43 years of experience (refer Table 6.3). This provides evidence that respondents were adequately experienced professionals in the field. All questions were designed to measure respondents' perceptions, which were separately analysed and checked for internal reliability and summarised in Table 6.9. As discussed in Section 4.11 of Chapter 4, if Cronbach's Alpha is greater than 0.7, it is considered as 'high reliability'. As presented in Table 6.14, Cronbach's alpha (α) of questions (Questions 5, 6, 7 and 8) was greater than 0.7 (and nearly 0.7 for Question 9). This indicates high level of internal reliability among the data set (detailed results are presented in Appendix D). Other positive evidences indicated that the survey involved acceptable validity and reliability, as no question was left unanswered and approximately more than half of the participants (53) responded to majority of the open-ended questions

Table 6.14: Internal Reliability of Questionnaire Data

Question	Intended to Measure	Cronbach's Alpha (α)	*F*-statistic	sig.	Number of Items	Reliability
Q5	WECMs	0.796	29.953	.000	31	High in Reliability
Q6	Drivers	0.854	12.091	.000	11	High in Reliability
Q7	Barriers	0.715	8.700	.000	8	High in Reliability
Q8	9R principles	0.752	19.971	.000	9	High in Reliability
Q9	Sustainability assessment criteria	0.665	1.366	.245	5	Reliable

6.10 Chapter Summary

This chapter presents the analyses of the questionnaire survey findings in line with the research objectives identified in Chapter 1. The questionnaire survey aimed to investigate the perception of stakeholders drawn from the Sri Lankan construction industry concerning drivers, barriers, and measures applicable for efficient use of water on construction sites. Descriptive and inferential statistical analyses were made during the analysis. One-way ANOVA was determined statistically significant differences between 'mean scores' between different participant groups. General opinions of construction practitioners are presented as narratives and in quotations form. Eight (08) highly applicable WEMs were identified. Among four measures belong to Policies and Planning, three measures belong to Attitude and Behaviour and one measure belong to Efficient Technology. Thus, the survey results indicated that respondents clearly favour ‘soft’ measures as opposed to ‘hard’ technology oriented ones, for efficient use of water. The findings revealed that “cost of water” and “sources of water” were ranked as highly relevant drivers while “low priority for water management” to be the only highly relevant barrier. Moreover, the chapter presents the applicability and current application of existing 6R and new 3R principles and sustainability criteria to enhance water efficient practices in construction sites. Finally, Chapter 6 presents actions to enhance practical measures to improve water efficient practices on sites.

The next chapter discusses the research findings of case studies and questionnaire survey, together with literature findings.

CHAPTER SEVEN

7 DISCUSSION ON RESEARCH FINDINGS

7.1 Introduction

This chapter discusses the overall findings of the research. It contains information collated from findings of literature review made in Chapters 2 and 3, four (04) case studies findings presented in Chapter 5 and questionnaire survey findings in Chapter 6. This chapter therefore provides a triangulated discussion on the current research study. Accordingly, this chapter is structured as follows:

The first section of the chapter presents water efficient practices in construction projects in Sri Lanka. The second section discusses the extended water hierarchy model for the construction industry. The third section presents actions recommended to establish best practices on the efficient use of water during the construction phase. Finally, the framework developed by integrating all of the research findings, for the sustainable use of water in construction projects is presented in Section 5 followed by a chapter summary.

7.2 Existing Water Management Practices during Construction Phase

7.2.1 Water Management Practices

From the literature review, it was revealed that during the operational stage of a constructed facility, water management practices are being more focussed on and implemented and that comparatively less focus is made on water management during construction stage (Goodrum, 2008). Similarly, the survey results revealed that approximately 50% of the respondents were of the view that the current on-site water management practices of construction projects in Sri Lanka are 'moderate' (refer to Section 6.3), whereas case study results revealed that there are no explicit water management practices at the four (04) sites studied (refer to Section 5.9.3). Thus, the aforementioned findings suggest that not sufficient attention is being given to on-site water management practices in construction projects.

7.2.2 Water Efficiency and Water Conservation

Literature highlighted that the optimum use of water covers both conservation and efficiency. Many scholars state that Water Efficiency (WE) and Water Conservation (WC) are two different concepts although they are interchangeably used in the literature and that they identify WE as a smarter investment for future than solitary water conservation (refer to Section 2.3).

Results of this study reveal that not only water conservation but also water efficiency rely on individuals changing their behaviour to achieve results. Moreover, results of the study match well with the characteristics of WE identified by WRAP (2011) and this further confirms the use of WE as a terminology in this study instead of using the terms 'water efficiency' and 'water conservation' (refer to Section 2.3) interchangeably.

7.2.3 Water Sources for On-Site Construction

When reviewing literature it was revealed that the 'main water supply' and 'storm water' are the usual sources of water in construction work (refer to Section 2.5.3.3). Results of the questionnaire survey indicated that 'well water' (71%), 'mains water line' (69.5%), and 'tube well' (59%) are the common sources of water used in building construction projects (refer to Section 6.3). The four (04) cases that were studied obtained water for construction activities from the city water supply. One case study results showed that 'bottled water' was used for drinking by the management staff. Case study results also revealed that ground water contamination was a main barrier for the use of 'well water' and 'tube well' water. When survey results are considered, a question arises as to whether the water used in construction sites has the required quality for construction activities (while 'well water' was the most used source, 'tube well water' was the third most used water source). If water quality is maintained at the required level, then higher costs would have to be incurred in overcoming barriers revealed in the case study results.

According to survey results and literature, 'main water supply' is the second most used water source which is also the most commonly used water source for direct and indirect activities in construction projects. Furthermore, case study results revealed that water from the 'main water supply' is supplied unlimited to construction sites, and that water bills are paid according to a volumetric basis per month. These results suggest that water from the 'main water supply' would be preferred in construction sites because of factors such as quality (absence of contamination), unlimited supply, ease of access and the availability of a simple payment mechanism for the water consumed.

In addition, survey and case study results show that construction sites get water from 'water trucks (bowsers)' during high water demand periods (refer to Section 6.3 and Section 5.7.1.2). However, survey results revealed that the use of 'rain water harvesting' and 'surface water' had a percentage as low as 10.4% and 8.5% respectively and that they are rarely practised in construction projects. This result partially contradicts with literature in which 'storm water' was recognised as the usual source of water for construction works.

However, the importance of use of alternative water sources has been already identified by study respondents though it is rarely practiced. For instance one comment was that rainwater harvesting is compulsory in many construction projects and currently, LEED certification oriented activities are becoming common in the construction industry [PM-16]. Therefore, the findings of this study further reinforce literature review findings as far as the investigation and adoption of alternative sources in construction projects are concerned.

Moreover, the results of the case study findings revealed that the water main supply is generally more expensive than water extracted directly from tube wells or water obtained from wells. Water supplied through trucks is also more expensive than the water from the main (city) supply. On the other hand, it was found that the unit price of bottled water is high compared to that of water from the main supply (refer to Section 5.5.2). However, the use of bottled water is limited only to drinking purposes at the sites.

7.2.4 On-Site Water Storage Methods

Empirical results of this study show that 'plastic shell tanks' are mainly used to store water received from the 'main water supply' and trucks (refer to Section 5.4.2). Similarly, according to the literature, in-situ and portable tanks are used in construction sites to store water (refer to Section 2.3.3). As revealed from the four (04) case studies of this research, the capacity of tanks and the number of tanks used are totally dependent on the water demand which varies according to work trades (construction programme activities) and the number of on-site labourers. Case 1 revealed that underground sumps also can be used to collect and store water on-site for construction activities in addition to plastic shell water storage tanks (refer to Section 5.7.2).

7.2.5 On-Site Quality Control of Water

It was found from case studies that the assessment of the water quality is based on subjective measurements. Although specifications were provided in contract documents, the supervision of the quality of water used in construction activities (such as concreting, plastering and curing during construction) is not practised, according to case study interviews (refer to Section 5.4.2.3). Similarly, previous studies (Utraja, 2010; McNab, et al. 2011) identified that construction activities such as concreting, rendering, curing and commissioning and testing require water of potable standard and that many builders still do not realise the importance of it (refer to Section 2.5.3.3).

Having noted the above, the quality control of water used in construction sites was identified as important by the interviewees of the four (04) case studies (refer to Section 5.7.3). Furthermore, the survey results also indicate the respondents' opinion about the importance of checking the quality of water used by on-site workers (refer to Section 6.7.1). These findings further verified the literature findings. For instance, Greenroads TM Manual (2005) mentioned that in instances where non-potable water is used, there is an obligation to ensure that workplace health and safety is not negatively affected by the use of water (refer to Section 2.5.5.3).

Study findings clearly show that even though people who are involved in the construction process recognise the importance of the on-site quality control of water, actual implementation of water quality control activities in construction sites receives less consideration.

7.2.6 Cost of Water Used in Construction Activities

During literature review, it was identified that the true value of water is still not fully considered and reflected in all water related decision-making due to the presence of various socially constructed barriers (Joyce 2012). As stated by Roger et al. (2002), the full cost of water is equal to the sum of all these costs, that is the full supply costs (operation and maintenance + capital costs incurred by water companies) plus the full economic costs (opportunity costs + economic externalities), plus environmental and social externalities. Therefore, it can be stated that the (refer to Section 2.5.3.4). Similarly, one of the respondent during the survey reported that the cost of water for construction should include in-use sustainable values.

However, the results of case studies revealed that fewer standards are available for pricing water and the interviewees were of the view that the cost of water is given little consideration when pricing bids during the tendering stage. Case study documents revealed that there is a significant cost deviation of the average monthly on-site water bill (cost of water consumed at the site) from the amount that was allocated during the tendering stage (refer to Section 5.4.3.1). Some interviewees (refer to Section 5.4.3.1) attributed the reasons for such cost deviations to the little attention paid to the water source during the tendering stage; lack of consideration on ground water conditions; inaccurate assessment of the type and nature of construction activities and the number of labourers accommodated at the site. Site management staff still believe that the cost of water represent only a low percentage of the preliminary bill. Case study results reported that none of the sites had calculated the water quantity required for the sites. This indicates that contractors may need further attention for improving internal strategies related to the pricing of the water during the tendering stage. On the other hand, even though case study interviewees strongly indicated that the quantity of water required is under-priced during the tendering stage, it could be counter argued that there is an excess consumption of water on-site thereby probably increasing the cost of water beyond what was actually assumed as the cost of the total quantity of water required for the site. This argument is further discussed and validated in Section 7.3 where a number of on-site water wasting activities are presented.

Although literature and survey results indicated the importance of including environmental costs with the cost of water (refer to Sections 2.5.3.4, 2.5.3.5 and 6.6.5), according to interviewees and site documents, none of the sites considered environmental costs. It was pointed out by case study interviewees that contractors always try to get maximum profit by minimising as much as possible the cost of construction, by ignoring environmental costs of water unless it is made a mandatory requirement. Moreover, this tends to highlight the requirement for setting specific legislations, policies and criteria on pricing water by getting the relevant regulatory authorities to identify the value of water resources and establish appropriate legislation, policies and criteria related to the value of water resources, and making them available for construction stakeholders (i.e., clients, contractors and consultants).

7.3 On-Site Water Consumption

It was apparent from the four (04) case studies that water supplied to the sites was used for direct and indirect construction activities and for the consumption of on-site management staff and labourers. Direct construction activities include wet trades such as concreting, plastering, rendering etc. Indirect construction activities include curing, testing and commissioning, site cleaning, wheal washing, dust controlling and other supportive construction activities.

Case study results further revealed that water wastage due to direct construction activities is minimal. Indirect construction activities such as curing, cleaning, bathing, washing and sanitation were identified as activities that contribute most to the waste of water at a site when not properly monitored and supervised (refer to Section 5.9.1). In addition, results of this study revealed that the use of ready-mix concrete had a lesser impact on on-site water consumption. Curing and washing of concrete trucks were identified as associated indirect activities that need more water for the concreting process even when ready-mix concrete is used (refer to Section 5.9.3).

During the survey on water consuming and wasting activities in construction sites, all four (04) case study respondents reported similar activities. Both case study and survey results show 'site cabins and sanitation' as the main activity related to both water consumption and water waste. There was no reference to previous studies in the literature confirming this finding that was revealed from the results of this study. Another interesting finding was that major water using and wasting activities revealed from this study are similar to those found in the previous studies. For example, the Strategic Forum for Construction (SFfC) recognised major water using activities and water wasting activities in construction sites in the UK (refer to Section 2.5.3.2). The findings of this study and SFfC recognised water using activities and water wasting activities are presented and mapped in Table 7.1.

Table 7.1: Water Using Activities and Water Wasting Activities

Description	Findings of the Present Study	Findings of SFfC (Waylen et al. 2011)
Key Water Using Activities	• Site cabins and sanitation • Concreting • Concrete curing • Brick work • Site cleaning • Commissioning and testing -plants and services • Plastering /rendering • Ground work • Vehicle washing • Structural testing before and after applying waterproofing paint • Dust controlling	• Site cabins and temporary accommodation • General site activities including tool washing • Wet trades: brick work, concreting, plastering and screeding • Ground work • Dust suppression and wheel washing • Hydro demolition • Cleaning of tools and plant equipment and lorry washing • Commissioning and testing of building plants and services
Key Water Wasting Activities	• Site cabins and sanitation • Site cleaning • Vehicle washing • Dust controlling • Commissioning and testing of plants and services • Structural testing before and after applying waterproofing paint • Landscaping	• General dust suppression, suppression on site roads and wheel washers • Hydro-demolition with high pressure water • Lorry washouts • Site and general cleaning • Specialist and high pressure cleaning • Commissioning of plants and services

The implication of this finding is that site management staff should carefully scrutinise these activities at the inception of a construction phase and include them in the water action plan, so that suitable mitigation measures can be incorporated into the construction planning process. Moreover, it was found that by using water efficient technologies, water requirements for direct construction activities can be reduced up to a certain extent. However, as stated by Waylen, et al. (2011), since water is a relatively 'cheap' resource compared to other resources required for construction activities, it is unlikely that the introduction of expensive processes at temporary construction sites will be viable. Any technology must be robust and be able to stand up to the demands of construction sites.

As per literature, testing should be done according to guidelines published by the relevant institutes (refer to Section 2.5.3.3). Thus, adhering to such guidelines is very important for achieving sustainable construction. Controlling of on-site water wastage is not currently practised at appropriate level as revealed from the four (04) case studies. Empirical findings from the case studies bear evidence that some deviations exist between site practice and the current norms available for wet trades (i.e., plastering, concreting). As a data base on water usage activities is not available, accurate work studies are highly recommended in respect of on-site water usage and water wastage.

7.3.1 On-Site Record Keeping of Water Consumption

In reviewing the literature, it was identified that maintaining proper records of water consumption is a main step of water auditing (refer to Section 2.8.1) and also in the water action plan (refer to Section 2.8.7). As found from case studies, monthly water bills were the main records available on the quantity of water consumed at a given site and there was no proper record of the quantity of water that was consumed from alternative water sources. Case study 2 had a system to record daily water consumption for internal auditing purposes.

Moreover, case study results show that none of the four construction sites had a detailed water schematic plan (i.e., layout of the temporary water distribution system indicating the locations of water outlets and distribution pipe lines) and a water action plan for the site. Results of the study further revealed that none of the four (04) sites analysed water quantity consumed by significant water consuming activities. One reason for this was the fact that water conservation is still not an item in the contractor's priority list. This confirms that it is of paramount importance to monitor the daily or monthly consumption of water and minimise unnecessary wastages considering the environmental cost, which is missing in the existing process. These findings seem to be consistent with those of other studies (Bossink & Brouwers, 1996; Ofori, 1992; Tam & Lee, 2007), which highlighted that construction industry is less responsive to environmental issues.

7.3.2 Computing Water Requirements for Construction Activities

The literature revealed that the amount of water consumed by construction is unknown and that it is not adequately measured (Goodrum, 2008). Based on data that was gathered from the case study documentary review and from water audits, the study attempted to present a method of calculating a benchmark for site water consumption in the form of a ratio of water volume to building area (m^3/m^2). However, the study revealed that the type of project and its scope, water source, project duration, number of employees, location of accommodation provided to labourers (i.e. on-site or off-site), and weather conditions are some key variables that would impact on the final values of the ratio.

Similarly, Horn (2012) identifies that in construction projects, the quantification of water consumed is difficult and a challengeable task (refer to Section 2.5.3.5). Therefore, the current study will not make any conclusions based on the figures obtained from case studies. Instead it will show the process of developing benchmarks and important key variables that need to be considered at the initial stage if it is proposed to calculate the water quantity. Previous studies identify that benchmarking will allow an industry or an individual to measure its/his/her own performance against similar sites elsewhere and identify a useful method to identify any improvements and reduce the water usage through cost effective measures (Alberta Water Council, 2007; Corr & Adams, 2009).

In addition, case study results revealed that water requirements of some direct activities (e.g. concreting, brick work, plastering and rendering) are based on published norms given in BSR (refer to Table 2.10) and project BOQs. The study found from direct construction activities that the concreting required a significant quantity of water compared to plastering and rendering. In Case study 1, almost 17% of the total water consumption was used for concreting. When collating the results of the four case studies (refer to Sections 5.6.3.3, 5.4.3.3, 5.5.3.3 and 5.6.3.3), it was revealed that 5%-6% of water needs for other direct activities such as brick work, plastering and rendering. If so, the results show that more than 75% of water is required for indirect activities.

Moreover, results of case studies indicated the non availability of sub-metering systems, absence of poor recording systems and lack of quantitative data as some limitations when computing the exact quantity of water used by individual activities especially by indirect construction activities. These findings seem to be consistent with the findings of previous studies (McNab, et al. 2011). They have suggested to utilise robust metering systems.

Another important finding that emerged from the case studies was the significant deviations that could be observed between the results of standard norms and the industry practices on water quantity required for wet trades. Therefore, these findings provide a solid background to identify the key factors that impact on computing the water quantity and development of benchmarks for construction sites conducting work studies.

7.3.3 Factors Affecting On-Site Water Consumption Levels

Results of case studies identified several factors, namely the condition of materials (wetness/dryness), types of construction methods or techniques adopted, water source, location of labour accommodation (on-site or off-site), weather conditions, quality of on-site supervision and labour behaviour as affecting on-site water consumption. Similarly, survey results reported, project location (55), water source (43), project scope (39), site conditions (32), worker behaviour (31), and project team commitment (19) as the most prominent factors (frequency of the responses are given within parentheses) that influence the efficient water-use in construction sites (refer to Section 6.3). In addition, factors such as senior or executive management commitment, cost, staff experience, contractual requirements, workers' lack of awareness, and the type of climate were also identified through the survey.

7.3.4 Water Efficiency Measures (WEMs) for Enhancing On-Site Water Efficiency Practices

Thirty one (31) WEMs that are specific to the construction sector have been identified in the literature. All measures were categorised into four groups that is Policies and Planning (PP), Attitude and Behaviour (AB), Alternative Construction Methods (AC) and Efficient Technologies (ET). For each category 10, 04, 07, 10 measures have been identified respectively. Results of survey studies reported on eight (08) highly applicable, seventeen (17) applicable and six (06) moderately applicable WEMs. Highly applicable WEMs are presented in Table 7.2. In addition, application of each WEMs in the four (04) case studies are also presented in Table 7.2.

Table 7.2: Highly Applicable WEMs and Current Applications in Case Studies

Ref.	Highly Applicable WEMs	Mean Score	Category	Application in Case Studies			
				1	2	3	4
PP_10	Introduce water leak detection monitoring systems	**4.543**	Policies and Planning	X	X	X	X
PP_9	Implement water auditing	**4.429**	Policies and Planning	X	*	X	X
AB_3	Improve monitoring and supervision	**4.352**	Attitude and Behaviour	√	√	√	√
PP_6	Introduce a water action plan at the inception	**4.276**	Policies and Planning	**	X	X	X
ET_4	High pressure trigger operated spray gun hoses	**4.238**	Efficient Technologies	√	√	√	√
AB_1	Assign responsibility and targets to site staff	**4.238**	Attitude and Behaviour	√	√	√	√
AB_4	Increase water awareness among workers	**4.229**	Attitude and Behaviour	√	√	√	√
PP_8	Introduce sub-metering systems	**4.229**	Policies and Planning	X	X	X	X

*Having a system for recording daily water consumption at the site (Case 2)
** EMS leads to apply WEMs at the site (Case 1)
X - Not in practice
√ - Practiced at the site

An important finding of the four case studies is that among the eight (08) highly applicable WEMs, monitoring and supervision, high pressure tiger operated spray gun hoses, assign responsibility and water awareness among workers are practised on the sites. Among four (04) measures identified, except for the high pressure tiger operated spray gun hoses, all other seven (07) measures belong to Policies and Planning (PP) and Attitudes and Behaviour (AB). Thus, it is apparent from Table 7.2 that the sites have implemented more attitude and behaviour oriented measures to enhance water efficiency practices with little attention on other WEMs that come under water efficient technologies and alternative construction methods (refer to Table 5.10 and Section 5.11.1). These findings are consistent with literature findings in which creating a water efficiency culture within the construction sector through 'attitude and behaviour of staff' is identified as a fundamental requirement (refer to Section 2.5.3.2). Results of the study indicated that the respondents have clearly favoured 'soft' measures as opposed to 'hard' technology oriented measures for an efficient water use. Thus, one important finding that emerged from the study was that the change of workers' behaviour coupled with policies and planning to reduce water wastage could be the way forward for a meaningful efficient water use at construction sites.

This clearly shows the acceptance of Norm Activation Model (NAM) to explain the workers' behaviour on efficient water use (refer to Section 2.5.2). This is a sequential model where awareness of consequences influences personal norms through ascribed responsibility as shown in Figure 2.13 (refer to Section 2.5.2). It shows a person should be well aware of the consequences before sensing a personal responsibility towards it which triggers the personal norms. With regard to the behaviour on efficient use of water on sites, worker should be behaving in a sensible manner to prevent water from being wasted in his own work activities as well as supporting water efficiency in general.

Cost was mentioned as the main hindrance for implementing some of the water efficient techniques (e.g. curing agents) and alternative construction methods (e.g. steel construction, dry partitions, etc.) during the construction phase (refer to Section 5.11.1). Similarly, case study results show that cost and site space as limitation when collecting rainwater during the construction. Therefore, the study results show some of the favourite methods used in green buildings such as rainwater harvesting, are not considered to be significant WEMs in traditional construction projects. Another finding was that although survey respondents believed the water leak detective system to be highly applicable in construction sites, case study results showed that 'water leak detective monitoring system' as very expensive water efficiency measure.

Table 7.3 summarises the results of moderately applicable WEMs identified from the survey and their application in the construction industry based on case study findings. It can be seen that all WEMs that are identified as moderately applicable are not being practiced in construction sites except washing bays used in case study 2.

Table 7.3: Moderately Applicable WEMs and their Applications in Case Studies

Ref.	Moderately Applicable WEMs	Mean Score	Category	Application in Case Studies			
				1	2	3	4
WT_9	Washing bays for wheel washing	**3.329**	Efficient Technologies	X	√	X	X
AC_6	Use of pre-mixed concrete and pre-mixed mortar	**3.152**	Alternative construction methods	X	X	X	X
CT_3	Fan misting systems for dust suppression	**3.076**	Efficient Technologies	X	X	X	X
PP-3	Licensed water extract systems	**2.971**	Policies and Planning	X	X	X	X
PP_4	Increase of the unit rate	**2.886**	Policies and Planning	X	X	X	X
ET_8	Vacuum toilets	**2.819**	Efficient Technologies	X	X	X	X

X - Not in practice
√ - Practice in the site

Survey findings show that an increase in the unit rate is not yet considered favourably in Sri Lanka. Similarly, during case studies positive and negative views were expressed on the present water tariff system. For instance, some interviewees personally believed that the existing process of estimating cost of water should be incorporated into the current water tariff system that has to be reviewed if the water resource is to be sustained for future generations (refer to Section 5.11.1). These findings are consistent with those of other studies (Savenjije and Van der Zaag 2002; Goodrum, 2008) suggesting the necessity of making changes to the water tariff system. However, study results show that these measures need higher level decision making to be implemented and that they require policy and organisational level collaboration.

Another arguable area is water extraction. Robert et al. (2006) recognise that it is not a problem when the actual amount extracted was below the sustainable level of extraction, but that over-extraction and subsequent overuse of river systems could exert undue pressure. However, according to case study results, water extraction is one of the important aspects that is currently neglected. However, it needs to be considered in construction projects if any future dilemmas are to be avoided.

It is clear that although individual perception towards WEMs is desirable, attention paid by the organisations could be very subjective.

7.4 Drivers for Enhancing On-Site Water Efficiency Practices

The results of the questionnaire survey revealed that among the eleven (11) drivers identified from literature review, the costs of water and water source are too highly relevant drivers that have an influence in enhancing the efficient use of water during the construction phase. All other nine (09) drivers (attitude and behaviour, water quantity, project specific documents, quality of water, responsibility, and sustainability rating systems, policies and regulations) were identified as relevant for enhancing on-site water efficient practices.

The case analysis results revealed that individual experience and commitment were the main drivers that impact on water minimisation and efficient water use in construction sites. In addition, attitudes and behaviour of workers, water source and cost of water were identified as positively and negatively impacting on site water management. For instance, when a project gets water from natural resources like wells and rivers, none of the construction parties will monitor the amount taken up for consumption since no cost is incurred for the water consumed. In the meantime, the study found that when water is received free of charge, the chances of wastage is significant and consumption would be unlimited. As found from case studies, the same situation could be seen even if the water source is the city water supply. At present, no restrictions have been introduced for the consumption of city water. This is further proved by identifying "cost of water" and "sources of water" as highly relevant drivers that impact on efficient water use. The impact of other drivers has already been discussed in the previous sections (i.e. attitude and behaviour, project specific documents).

The incorporation of WE measures in project specific documents was identified as an important driver by interviewees. Similar findings could be observed from survey and case analysis results confirming literature findings. In addition, individual commitment was a new driver that was identified from case analysis for enhancing WE practices in construction sites.

Therefore, the priority given to these aspects is of paramount importance initially if water efficiency is identified as one of the project goals by the stakeholders.

7.5 Barriers that Effect On-Site Water Efficiency Practices

The results of the survey identified that the low priority given for water management was the most significant barrier which impacts on moderate water management practices in construction projects. The absence of WE provisions in bidding documents and during the construction stage were the next two important barriers that were identified (refer to Section 6.7.2). In addition to these barriers, the case studies further identified workers' attitude towards water as an unlimited resource, cost of water, site space (collect and store rain water), lack of commitment, and lack of proper allocation of water responsibilities as other hindrances that exist during the construction stage (refer to Section 5.11.2).

The results of the questionnaire revealed that there is little attention given to water management at organizational level. This is the main barrier identified through the study. The reason for this is that the cost of water is considered as comparatively insignificant (refer to Section 5.11.2). Another point highlighted during the survey was that the objective of many organisations is to make profits and that they are more concerned about resources which are of high cost (refer to Section 6.7.2). Similarly, past studies have revealed similar results and have highlighted that traditional contractor selection methods rarely involve environmental concerns (Watt, et al. 2010). Similarly, pre-qualification criteria are designed mainly to ascertain financial, technical and managerial capabilities of a builder and not necessarily the environmental capabilities (Jaskowski, et al., 2010). Therefore, one implication of this study is the recognition of builders' capacity to deal with efficient water use and the possible recommendation that should be used in pre-qualification and contractor selection, i.e. necessity to communicate with project requirements during early stages.

Study results show that certain barriers are beyond the control of site staff. For example, as stated by one interviewee, awareness on water conservation should come from grass root level with the responsibility going to all individuals including professionals and workers (refer to Section 5.6.5.3) and WE provisions in bidding documents considered before awarding the contract.

Results revealed that early attention and involvement of all parties through an integrated process will ensure better efficiency and sustainable practices in order to overcome the barriers that exist.

7.6 R Principles for Enhancing On-Site Water Efficiency Practices

7.6.1 Assessment of R Principles

The questionnaire results revealed that nine (09) different 'R' principles, i.e. Reduce, Review, Responsibility, Replace, Regulations, Removal, Rewards, Re-use and Recycle are applicable for improving on-site water efficient practices. The SFfC in the United Kingdom identifies that the reduction of water use in construction sites can be successful only if the challenges in the form of work environment and habits of workers can be overcome (Waylen, et al. 2011). Similarly, questionnaire survey respondents considered 'Reduce' as the most important 'R' principle in the context of water usage in construction sites. Results of the case studies revealed that monitoring, supervising, assigning responsibility and promoting worker awareness through meetings and posters are implemented to reduce water wastage due to construction activities. Pressure gun hoses have been employed additionally for vehicle washing and cleaning of sites to reduce water usage and minimise unnecessary water wastage (refer to Section 5.11.3.3). As found from case studies, ‘Removal’ is another ‘R’ principle that is practised in construction sites properly (refer to Section 5.11.3.6). Similarly, Hart’s Theory of Natural Resource Based View (NRBV) identify three strategies namely, prevent waste, integrate voice of environment into the development process and competitive advantages, and fewer environmental damages (refer to Section 2.5.2). Therefore, the study results indicate that the characteristics of NRBV strategies are well accepted and recognised when implementing sustainable use of water at construction sites. This encourages the consideration of environmental risks associated with construction activities and ways of minimising natural resources.

However, among nine (09) different R principles, Re-use’ and ‘Recycle’ were given lower rankings by questionnaire survey respondents. This result matches well with the findings of the four (04) case studies (refer to Section 5.11.3.4 and Section 5.11.3.5). The opinion of the majority of interviewees was that “re-use” and “recycle” though possible, are rarely implemented at sites if they are not identified as mandatory requirements in the relevant construction contracts. Conversely, the literature shows that ‘Re-use’ and ‘Recycle’ contribute positively to sustainability/ green concepts and to waste management processes as discussed under NRBV. Similarly, Kibert (1994) states that maximizing resource reuse and recycle are the important principles of sustainable construction. This highlighted the environmental regulations concerning water use in construction sites as it is a timely subject that require further analysis to ensure higher compliance.

Thus, findings suggest that the requirements of water reuse and recycle should be considered and incorporated into project requirements from the initial stage of a project.

Furthermore, all respondents of four (04) case studies emphasised that 6R water hierarchy is difficult to implement without showing direct and indirect benefits to the project, management staff and the workers. As a solution, the discussions revealed that the new three (03) dimensions identified could severally influence the desire of the stakeholders to follow the 6R water hierarchy. These three (03) new dimensions i.e. Regulation, Responsibility and Reward are explained in Sections 5.11.3.7, 5.11.3.8 and 5.11.3.9. Moreover, they highlighted that these new 3R principles could impact beyond on-site project level activities (refer to Table 5.15).

Therefore, the impact of Regulation, Responsibility and Reward on water efficiency can be presented in two ways, namely as 'On-site Project Level (post-contract)' and 'Beyond On-site Project Level (pre-contract)'. As presented in Table 7.4 'Beyond On-site Project Level' includes the impact of new 3R principles on relevant aspects commencing from project inception and continuing till the award of the contract both at organisational level and at policy level including social responsibility.

Table 7.4: Impact of new 3R on efficient water-use during On-site Project Level and Beyond On-site Project Level

	On-site , Project Level	**Beyond On-Site Project Level**
Regulations	• Control the unlimited use of main (city) water supply • Check water quality regularly • Follow environmental standards • Use alternative water sources	• Make sustainability requirements mandatory in project specific documents • Review water tariff • Include environmental values in the cost of water
Responsibilities	• Conduct awareness programmes on water efficiency • Conduct training prgrammes on water efficiency	• Educate community on the possibility of a water dilemma in the future • Recognise the commitments made by clients, consultants and contractors to water sustainability during annual grading/registration • Identify and incorporate water requirements into project documents during pre-tendering
Rewards	• Encourage innovative solutions by rewarding • Recognise employee commitments to water efficiency during the annual evaluation of employees	• Establish a rewarding mechanism at national level to recognize construction industry stakeholders who implement WE and sustainable measures

The results of this study reveal the following important concerns on the implementation of new 3R principles for achieving water efficiency and its sustainable use:

- Regulations do not work properly if there is no proper monitoring system (refer to Section 6.7.3.3
- Not only ‘rewards’ but also ‘penalties’ should come with the system. Then only people will recognise the value of taking steps on water saving measures (refer to Section 5.11.3.8).

In addition, the findings of case studies and questionnaire survey reveal that cost is a major factor that impact on the implementation of 6R principles in water hierarchy in construction projects (refer to Section 5.11.3 and Section 6.7.3). Introducing R principles at early stages of projects (i.e., briefing and designing stage to tendering stage) and making R principles as a competitive element of tendering will provide a better opportunity to implement R principles during the construction stage.

Based on the above discussion, the existing 6R water hierarchy model is extended with new 3R principles and named as **‘3R.6R extended water hierarchy model for the construction industry’**, which is explained in the following section.

7.6.2 3R.6R Extended Water Hierarchy Model for the Construction Industry

Among the water hierarchies available, the water hierarchy of the Strategic Forum for Construction (SFfC) was selected to check its applicability to the construction industry in Sri Lanka due to its simplicity.

The applicability of each R was explored with case studies (refer to Section 5.11.3) and examined during the questionnaire survey (refer to Section 6.7.3). Information that has been collated from findings of the case studies and the questionnaire survey together with literature findings are discussed in Section 7.6.1 and are further summarised as given below:

- Results of the questionnaire reveal that the 6R principles of the water hierarchy are applicable to the construction industry in Sri Lanka.

- Results of the four (04) case studies bear evidence that certain steps are still in place at the sites which were studied in this research and case study respondents also agreed that these 6R principles are applied in construction projects. However, most of them collectively noted that there are no proper mechanisms to properly establish 6R principles on-site (refer to Section 5.11.3).
- New 3R principles (which were identified from literature and further confirmed through preliminary interviews) were also accepted and identified by most of the respondents for implementing 6R principles of water hierarchy.

Based on the findings noted above (Section 7.6.1), Figure 7.1 presents a novel 3R.6R extended water hierarchy model for the efficient use of water in construction projects. 3R principles represent the three vertical sides of the inverted pyramid that support each 6R principle. This extended water hierarchy model has the potential to ensure the required control of the water resource and its potential uses under the sustainability agenda.

Figure 7.1: 3R.6R Extended Water Hierarchy Model for Construction Industry

7.7 Sustainability Assessment Criteria for Enhancing On-Site WE Practices

From the literature review, it was found that although the existing sustainability assessment tools fairly address water efficiency criteria during building operation, the few rating systems address water efficiency only during the construction phase (refer to Section 2.4). One case study interviewee stated that it is critical to use sustainability measures according to project complexity and the prevailing rules and regulations (IEE, EIA, Green^{SL}, LEED) and that it should be incorporated into project specific documents (refer to Section 6.6.1). As found from case study 1, EMS was the main driving factor for implementing successful water efficient practices during the construction phase (refer to Section 5.3.5.1).

The results of the questionnaire survey reveal that respondents strongly agreed with all prerequisites (no credits assigned) and the requisite criteria (credits assigned) identified through the literature (refer to Section 6.7.4). The results of this study further emphasised the importance of preparing a water action plan for a project (Prerequisite) and the application of 3R.6R extended water hierarchy model during the construction phase (Requisite) to ensure an efficient water use.

7.8 Actions Recommended to Improve Efficient Water Use in Construction Projects

7.8.1 Stakeholder Involvement: On-Site Project Level and Beyond On-Site Project Level

Results of the questionnaire survey (refer to Section 6.7) and case studies (refer to Section 5.12) identify certain actions that can enhance efficient water-use practices during the construction phase incorporating applicable WEMs. It could be observed that there are similarities between the proposed actions identified from the survey and those identified from the case studies. It could be observed that certain actions identified to improve efficient water-use practices during the construction phase need the intervention by other parties who are beyond on-site project level to be successful. In other words to implement water efficient practices at site level, certain actions need to be addressed prior to commencing the construction work. This is known as prerequisite actions, which should be implemented by responsible stakeholders or parties during different stages of a project life cycle. For instance, other than the contractor, the client and the consultants should give attention during design and tendering stages (i.e. pre-tendering project level) (refer to Sections 5.7.3 and Section 6.8). On the other hand, certain actions need support from the government, private institutes, NGOs, research and development institutes, and universities. Therefore, all the actions proposed would be grouped into two as 'On-site Project Level' and 'Beyond On-site Project Level'. Further, 'Beyond On-site Project Level' is divided into 'organizational level/pre-contract' and 'policy level' as illustrated in Figure 7.2.

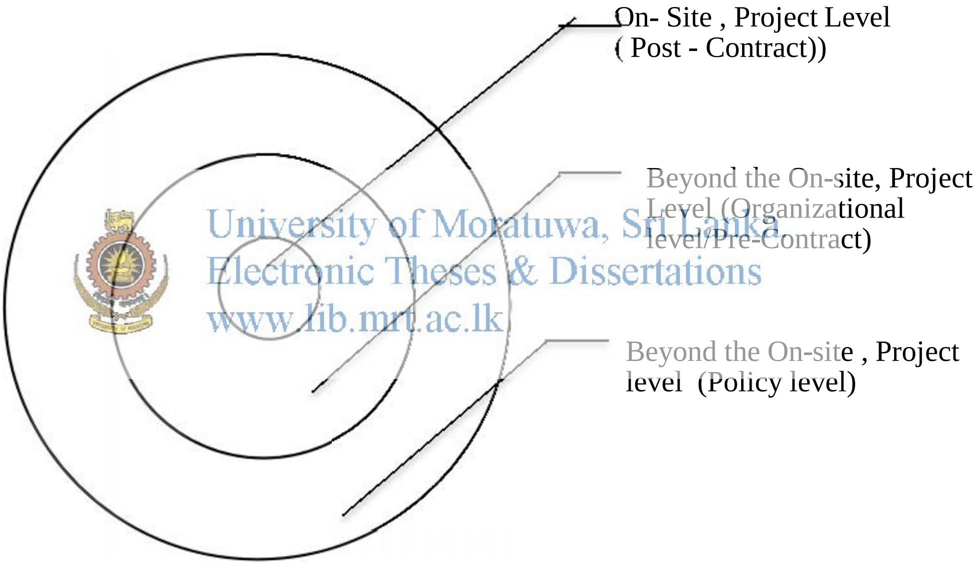

Figure 7.2: Three (03) Levels for Enhancing Efficient Water-Use in Construction Projects

On-site Project Level refers to the stage where actual construction activities take place. Results of the four case studies indicate that the site management of each project consisted of a different hierarchy representing positions at managerial level, executive level, and supervisory level. Project manager, project coordinator, construction manager or engineer, planning engineer, mechanical, electrical and plumbing (MEP) coordinator, health, safety and environmental manager, and quality assurance engineer represent the managerial level. Site engineer, site quantity surveyor, site architect or draftsman, and store manager represent the executive level. Supervisory level consisted of technical officers. In addition, there is administrative staff responsible for the management of site activities. Workers also have certain responsibilities for site activities. However, it was observed that the level of hierarchy and representatives varied from project to project depending on the availability of resource persons.

Organisational level (pre-contract) refers to the role of direct stakeholders, i.e. client, consultants' and the contractors' involvement from project brief preparation stage to the award of the contract. Policy level refers to the involvement of indirect stakeholders who engage with the society and in policy making and planning.

7.8.2 Actions Recommended to Enhance Efficient Water-Use: On-Site, Project Level

This section presents findings of empirical data, which suggested enhance water efficiency practices for sustainable use of water during the construction phase by providing solutions for the existing constraints identified. Twelve (12) specific actions integrating WEMs were identified at On-site Project Level (OS-Proj_L) and presented in Table 7.5. Application of 3R.6R extended water hierarchy model identified as a major contributor for efficient water-use during the construction phase.

Table 7.5: Actions Recommended to Enhance Efficient Water-Use at Construction Project Level

Ref	Actions
OS-Proj_L_A1	Prepare water action plan - set clear targets and expectations initially
OS-Proj_L_A2	Apply 3R.6R Extended water hierarchy model for water using activities - identify activities requiring potable water - check on alternative water sources before using the potable water option - identify water efficient measures to reduce water consumption - check re-use and recycle opportunities - check ways of disposing waste water - identify regulations specific to site operations - identify clearly the allocation of responsibilities - identify rewards (on site) - incentives for innovation
OS-Proj_L_A3	Implement water audit methods
OS -Proj_L_A4	Regularly monitor and inspect water using activities
OS-Proj_L_A5	Conduct training/ awareness programmes for staff and workers
OS-Proj_L_A6	Display water efficiency signs and posters
OS-Proj_L_A7	Display the schematic water design plan and water targets for site reference
OS-Proj_L_A8	Conduct work studies to develop benchmarks/Key Performance Indicators (KPI)
OS-Proj_L_A9	Learn from mistakes and setbacks
OS-Proj_L_A10	Ensure effective communications and proper recording systems
OS-Proj_L_A11	Ensure a proper temporary plumbing system to minimise leakages
OS-Proj_L_A12	Motivate people through collaborative team work and build positive attitudes

7.8.3 Actions Recommended to Enhance Efficient Water-Use: Beyond On-Site Project Level

This section presents actions and WEMs recommended to enhance efficient water-use, which are beyond the control of on-site project level stakeholders (BOS-Proj_L). Ten actions that were identified are presented in Table 7.6. This shows actions that come under organisational level (pre-contract) and policy level, which include social responsibility as well. The National Water Supply and Drainage Board (NWS&DB), Water Resources Department (WRD), Construction Industry Development Authority (CIDA), Central Environmental Authority (CEA), Urban Development Authority (UDA), Green Building Council, Sri Lanka (GBCSL), universities and research and development institutes are a few representative industry bodies identified at policy level and they have certain responsibilities when implementing the recommended actions or WEMs to enhance efficient water use in construction sites. Similarly, they also have a responsibility towards the society.

Table 7.6: Actions Recommended to Enhance Efficient Water Use at Construction Project Level - Beyond On-Site Project Level

Ref	**Actions**	**Organisation/ policy Level**
BOS-Proj_L_A1	Integrate project specific WE requirements during the design stage (water efficient designs, technologies)	Organisational Level
BOS-Proj_L_A2	Provide for WE practices in contractual documents – WE measures pricing strategies, - activities requiring potable water - alternative water sources - social , environmental aspects (EMS)/ Green^{SL}, EIA/IEE - proposals for innovations, - mandatory requirement for quality test and approval - regular inspections by client/ consultant	Organisational Level
BOS-Proj_L_A3	Reward the contractor during tender evaluation for sustainability aspects and innovations	Organisational Level
BOS-Proj_L_A4	Outshine the competitive advantages of WE measures and 3R.6R extended water hierarchy model	Organisational/policy Level
BOS-Proj_L_A5	Ensure effective communication and coordination among stakeholders	Organisational/ policy Level
BOS-Proj_L_A6	Clear allocation of responsibilities	Organisational Level
BOS- Proj_L_A7	Programmes on public awareness of water dilemma: Preservation of water is a civic duty coming from grass root level	Policy level and Society
BOS-Proj_L_A8	Review current legislations and policies on sustainable ways of water use: - review of water tariff system - parties responsible working together at the decision making stage - establishment of manuals and guidelines	Policy Level
BOS-Proj_L_A9	Reward contractors for sustainability practices at award ceremonies, and in the contractor grading process: contractor pre-qualification	Policy Level
BOS-Proj_L_A10	Facilitate research and development allocating necessary funds	Policy Level

7.9 Development of a Framework for Improving Sustainable Use of Water in Construction Projects

The proposed framework attempts to present directions for construction stakeholders on improving efficient water-use in construction projects. The framework provides guidance on how construction stakeholders should be committed to prevent water wastage and move towards water efficiency. Therefore, the contents of the proposed framework primarily provide directions to construction project stakeholders involved from the project initiation stage to the construction stage to identify ways of reducing water consumption in construction projects, implement water efficient measures and ultimately promote sustainable construction. The content of the proposed framework also presents directions and recommendations to construction stakeholders at policy making and strategic planning levels.

7.9.1 Structure of the Framework

According to the triangulated findings of this research on implementing water efficient practices at site level, a number of actions need to be implemented before the commencement of on-site construction work (refer to Sections 7.8.2 and 7.8.3). As discussed in Section 7.8, the study identify three main levels to provide guidance and recommendations for efficient water-use: On-site Project Level (post-contract stage) and Beyond On-site Project Level (Organisational Level: pre-contract stage); and Beyond On-site Project Level (Policy Level, Pre and Post Contract Stages).

7.9.1.1 On-Site Project Level (Post-Contract Stage)

On site Project level refers to the stage where actual construction activities take place (on-site). This level provides directions on how the contractor should establish on-site efficient water-use eliminating existing constraints for water efficiency.

7.9.1.2 Beyond On-Site Project Level (Organisational Level/Pre-contract Stage)

Organisational level refers to pre-contract level. This involves direct stakeholders namely, clients, consultants and contractors from the project brief preparation to the award of the contract in implementing efficient water-use practices in construction projects.

7.9.1.3 Beyond On-Site Project Level (Policy Level, both Pre and Post Contract Stages)

Policy level is basically beyond on-site project level boundary, which includes involvement of indirect stakeholders who engage in policy making and planning. Thus, this level provides directions and recommendations for public institutes (e.g. authorities, ministries), non-governmental organisations working on water related policies and planning, research and development institutes, universities, and the society.

7.9.2 Communication and Information Flow Diagram for Implementing the Directions Proposed in the Framework

These project stakeholders' understanding of efficient water-use has not yet been fully facilitated through the standard documents available at present. On the other hand, findings of this research support to identify information gaps in the existing system between each level due to poor integration among them (Refer to Section 5.11.2 and Section 6.7.2). Figure 7.3 shows the required communication flows at each level.

This diagram provides the basis to develop the framework shown in Figure 7.4. It is important to make sure that the collaboration of all relevant stakeholders throughout the life cycle of the project should be available when facilitating efficient water-use during the construction phase.

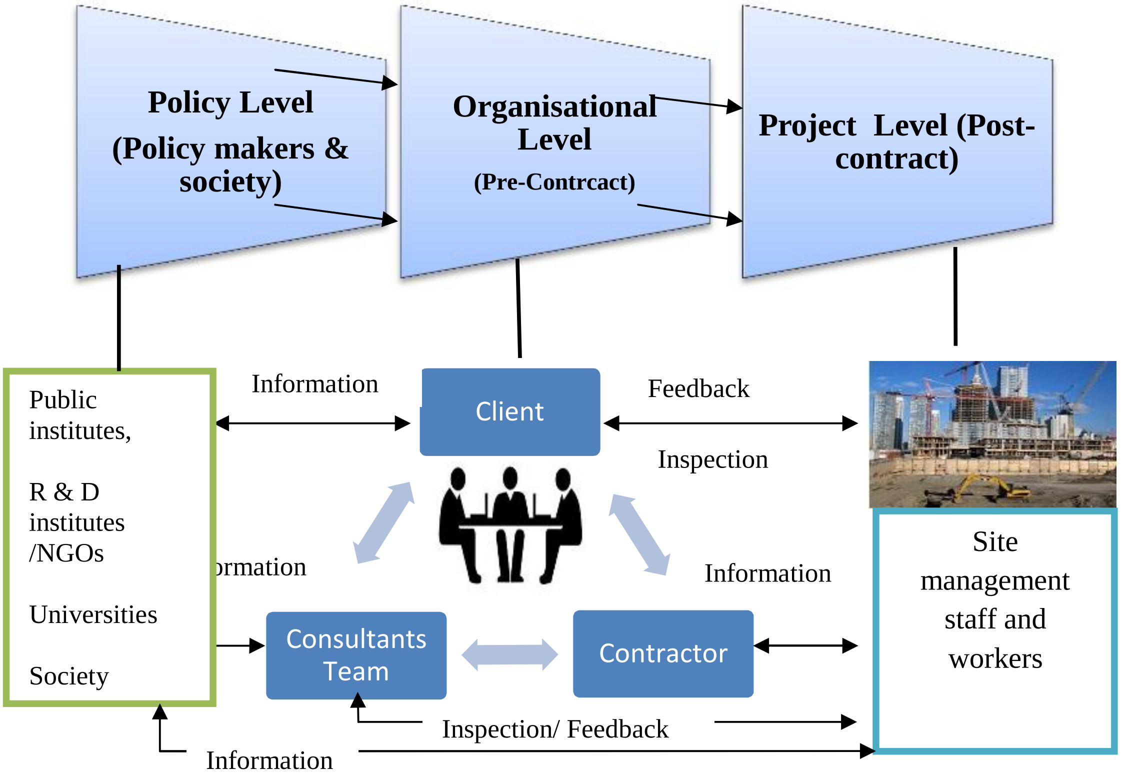

Figure 7.3: Communication and Information Flow Diagram between Three (03) Key Stakeholders

7.10 Framework for Sustainable Water Use in Construction Projects

This section presents the proposed framework for efficient water-use in construction projects where the overall aim is to contribute to achieve sustainable construction projects. Figure 7.4 presents the developed framework, which consists of three (03) main levels (i.e. policy level, organisational level and project level) as discussed in Section 7.9.2. Based on the research findings of this study, objectives and directions for the efficient use of water in construction sites presented under each stage / layer in the framework are presented in the sub-sections that follow.

FRAMEWORK FOR IMPROVING SUSTAINABLE USE OF WATER IN CONSTRUCTION PROJETCS

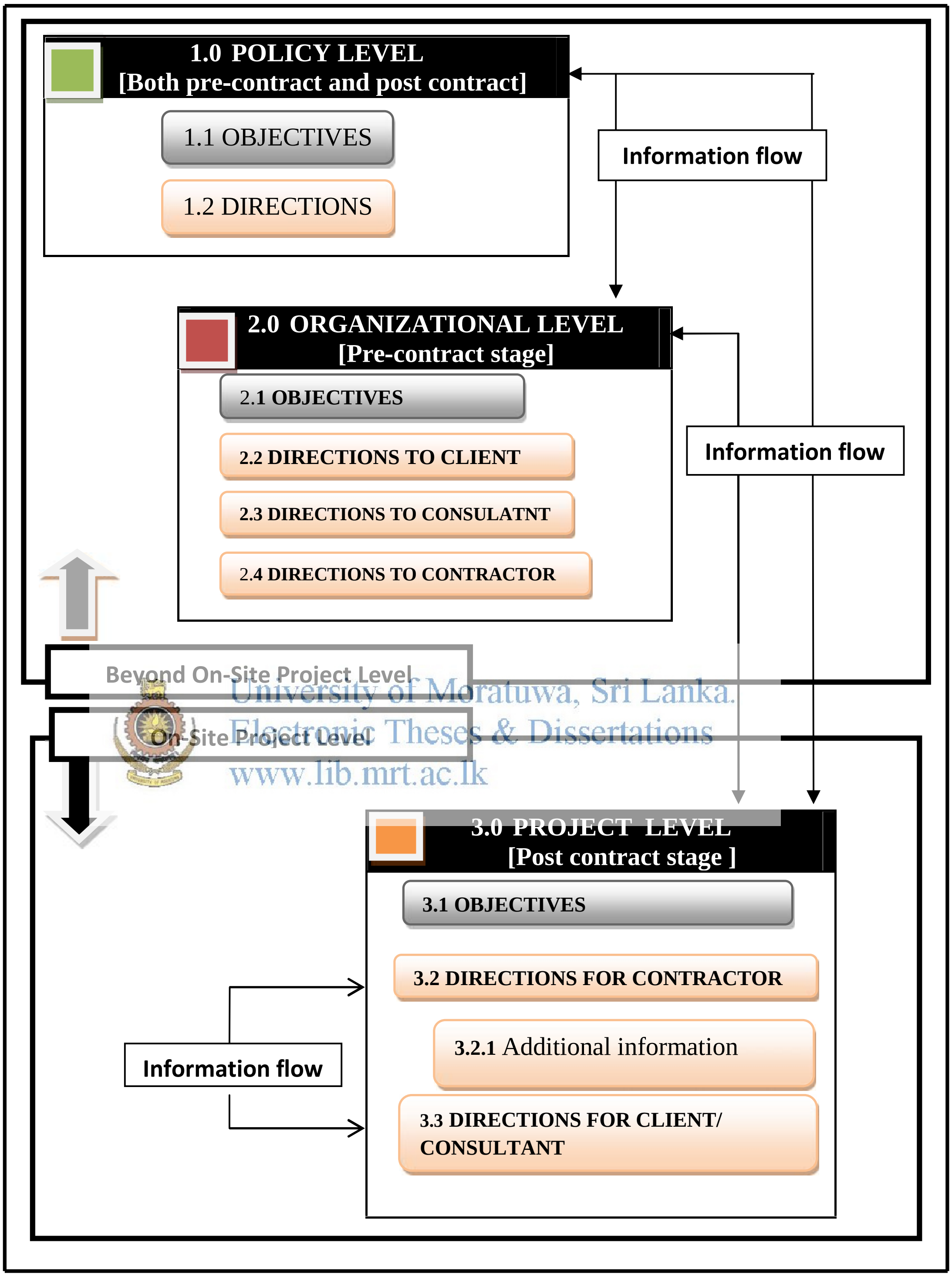

Figure 7.4: The Proposed Framework for Sustainable Use of Water in Construction Projects

LEVEL 1: POLICY LEVEL

[Beyond on-site project level - both pre-contract and post-contract stages]

1.1.OBJECTIVE

Facilitate and Regulate the implementation of water efficient requirements

1.2 DIRECTIONS

Direction to Policy Level Stakeholders

- Review the current legislations and policies on efficient water-use on a regular basis(e.g. review water tariff system, implement regulations on water extraction by relevant institutes i.e. NWS&DB, WRD and CEA and take remedial actions)
- Work together with the relevant authorities and institutes who are responsible for project decision making (i.e. NWS&DB, CEA, UDA,CIDA and WRD)
- Make sure that sustainable responses are seriously applied when making decisions
- Promote competitive advantages of water efficient measures (Rain water harvesting)
- Direct stakeholders who have initiated improvements to sustainable practices (including efficient water-use) to be recognised, rewarded and selected for awards (e.g. Authorities like CIDA should consider contractors sustainable achievements at the time of contractor grading and registration)
- Integrate builders' capacity to deal with efficient water-use and recommend possible actions that could be included in pre-qualification and contractor selection criteria
- Ensure effective communication and coordination among stakeholders on efficient water-use best practices & technologies, techniques, regulations, policies and guidance.
- e.g. Publish and promote construction related manuals and guidelines on water efficiency
- Conduct public awareness programmes and training programmes on water efficiency.
- Facilitate research and development (R&D) by allocating necessary funds and other research infrastructure.

**National water supply and drainage board (NWS&DB), Central environment authority (CEA), Urban development authority (UDA), Construction industry development authority (CIDA), water resource department (WRD)*

LEVEL 2: ORGANIZATIONAL LEVEL
[Beyond on-site project level: pre-contract stage]

2.1. OBJECTIVE
Integrate Water Efficient Requirements into Construction Projects and Monitor Implementation

2.2 DIRECTIONS

Directions to Clients

- Identify project specific water efficiency (WE) requirements in the client brief.
- Convey requirements to the design team.
- Review WE measures and outcomes on a regular basis and refine data where necessary.

Directions to Consultants

- Identify project specific WE (Water Efficiency) requirements in the design brief (Adopt 3R.6R extended water hierarchy model).
- Include water efficient devices /measures for construction activities in the project brief or specification.
- Make the use of environmental assessment tools (i.e. EMS, Green^{SL}, LEED) mandatory in the project documents.
- Specify activities and processes requiring potable water in the project brief.
- Prepare project specifications to be consistent in achieving water reduction during construction stage.
- Ensure effective communication and coordination among stakeholders during pre-contract stage.
- Include water efficiency requirements in contractor & consultant pre-qualification (e.g. to demonstrate their past experience in implementing water efficient practices and evidence on staff water related training) and tender documents (e.g. submission of an on-site water management plan), and allocate marks to assess consultant & contractor responses during prequalification and tender evaluation stages.

Directions to Contractors

- Work with project specific targets during tender pricing.
- Meet project specific requirements during tender pricing.
- Address WE measures and innovative proposals in the contractor method statement.
- Develop a water action plan and identify who will take the responsibility for implementation and incorporate the requirements in the tender submission.

WE: Water Efficiency , EMS: Environmental Management System , LEED:

LEVEL 3: PROJECT LEVEL
[On-site: Post-contract stage]

3.1. OBJECTIVE
Implementation of Water Efficient Requirements during Construction Stage

3.2 DIRECTIONS

Directions to Contractor

- Identify project tasks initially assigning them to relevant parties and prepare a project specific resource efficiency brief of the project.
- Identify and focus on WE drivers that are specific to the project (i.e., cost of water, water source etc)
- Prepare a site plan which includes the water flow diagram of the temporary water supply system
- Develop a water action plan on site
- Adopt 3R.6R extended water hierarchy model and WEMs
- Audit site water consumption
- Review the operation on a regular base
- Check regularly water quality when alternative sources are used
- Raise awareness on the water resource among site staff and workers
- Follow environmental standards where necessary (i.e, during waste water disposal, water extraction, etc.)
- Promote sustainable actions and innovative methods
- Report and handle proper documentation on project operation and future activities
- Share information with other sites (Cost data, water usage etc.)

__Additional Information to Contractor* (Refer Appendix E)__

Specimen forms for recording water consumption
Specimen template for water audits/records
3R.6R extended water hierarchy model
Water efficiency measures (WEMs)

Directions to Clients /Consultants

- Review construction activities and outcomes on a regular basis, provide instructions and get feedback if necessary.
- Promote incentives for contractors on sustainable approaches.

Information based on study findings. This information is basically intended for use during the construction phase as a guide on efficient water use practices in construction projects.

7.10.1 Uses of the Proposed Framework

The developed framework is mainly useful for project level management to take necessary proactive actions in implementing efficient water-use practices during the construction phase. In addition, it facilitates responsibility and understanding of other stakeholders of water sustainable practices in the construction industry. Appendix E presents additional information to contractor that come under project level. All details were developed through the triangulation of findings.

The empirical data of this study proved that not only through the intervention by organisational level and policy level stakeholders but also through the development of policies and other contractual documents, it should be possible to manage some of the barriers in implementing efficient water use practices during the construction stage. In addition, the framework showed the importance of feedback between each party and activities within the framework to enable working together in an inclusive and collaborative manner. Therefore, the proposed framework ensures the requirement for cohesiveness and coordination among construction stakeholders and it provides a means of guiding project parties within the construction project environment. The proposed framework facilitates construction industry stakeholders to work and be responsible for efficient water-use in construction projects.

7.10.2 Validation of the Content of the Proposed Framework

Validation is used to judge the accuracy and applicability of results obtained from a study (Angkananon, Wald & Gilberet, 2013). The purpose of the validation of this study is to obtain expert views on the proposed framework, which provides best practice guidelines to improve the sustainable use of water in construction projects. Angkananon, et al. (2013) state that an expert review is a process of asking opinions, suggestions and feedback from the experts. During the preliminary validation process, the following four (04) aspects were checked with industry experts as illustrated in Figure 7.5.

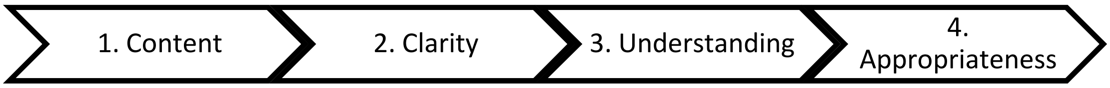

Figure 7.5: Steps of the Validation Process

Semi-structured interviews were carried out with four (04) construction professionals, excluding those who participated in the questionnaire survey and interviews of the case studies. A few quantitative and qualitative questions were posed during the interviews. Interviewees were given the five point likert scale where very high, high, moderate, low, and very low stand for quantitative questions. The findings of the quantitative data are summarised in Table 7.7.

Table 7.7: Summary of Validation Interviews on the Proposed Framework

Criteria	**Interview -1**	**Interview-2**	**Interview-3**	**Interview-4**
Profession	**Project Manager**	**Civil Engineer**	**Quantity Surveyor**	**Architect**
Work experience in the Construction Industry in years	**28**	**20**	**22**	**30**
1.Overall content of the framework	Very High	Very High	Very High	Very High
2. Contents cover under				
Industry Level	High	High	High	High
Organizational Level	Very High	High	High	High
Project Level	High	Very High	Very High	High
3. Clarity of the information	High	High	High	High
4. Level of understanding of the proposed framework	High	High	High	High
5. Would you recommend the proposed framework as useful for construction project stakeholders?	Yes	Yes	Yes	Yes

The interviewees agreed that there is a ‘very high’ level of overall content in the proposed framework. Moreover, Table 7.4 shows the ratings received for the content covered under policy level, organisational level and project level for which all experts have indicated either a ‘high’ or a ‘Very High’. Similarly, clarity and level of understanding of the information of the framework is considered as ‘high’ by all three interviewees. All interviewees have recommended that the proposed framework will be useful for construction project stakeholders. All of them have stated that the framework contents are comprehensive. Some of the significant comments made by the interviewees are presented below.

Interviewee-1 stated that it might be good to describe the constraints, advantages and shortcomings at the introductory stage. Since the study already discussed constraints under research findings and in order to reduce content it excludes from the framework.

Interviewee 2 mentioned that more clarification is needed on the methods to be applied for the short listing of contractors during tendering stages. Another comment made by him was that since in the construction industry, there are many specialist sub-contractors the clauses that should be included in contracts on water conservation need to be known.

Interviewee-3 claimed that the identification of the magnitude of the project is important and that if it is not arrested early, it might cause severe hardships to other users of the same sources. During framework development, 'procurement system' was considered as a variant since the proposed framework shows traditional parties at the organisational level.

Interviewee-4 said that "*when looking out for legislation and/or regulations to monitor this process, it will need a system of implementation because we as Sri Lankans are very good at finding loopholes in any rule or regulation*". Since the requirement mentioned was beyond the scope of the current study, it can be considered in the future when expanding the proposed framework.

One of the implications of this study is that it is possible to recognise the contractors' capacity to deal with efficient water-use and the recommendation that it should be used in pre-qualification and contractor selection. The development of detailed clauses and guidelines on these aspects can be considered in a future research.

7.11 Chapter Summary

This chapter presented the discussion on the results of the questionnaire survey together with case analysis findings and literature review. The chapter therefore provided a triangulated discussion of the current research study.

Existing water management practices, water usage and the ways of water waste, WEMs, drivers and barriers were discussed. The findings suggested that the change of workers' behaviour coupled with policies and planning to reduce water wastage could be the way towards of meaningful water use efficiency in construction sites. The chapter discussed the 3R.6R extended water hierarchy model for the construction industry based on the results of the case analysis and the questionnaire survey. It presented actions to improve efficient water use and discussed research findings with theories that are available. Finally, based on the triangulated findings, a framework was developed which includes three main levels namely, policy level, organisational level and project level. The proposed framework addressees objectives and directions under the three main levels in order to bridge the exiting gaps among construction stakeholders in implementing water efficient practices in construction projects. The next chapter presents the conclusions of the study and its recommendations for future research directions.

CHAPTER EIGHT

8 CONCLUSIONS

8.1 Introduction

This chapter presents the conclusions and recommendations of the study. The chapter is divided into four main sections. The first section presents how the aim and each objective of the study were achieved. The second section discusses the contribution of the current research to the existing body of knowledge. The third section presents limitations of the study. Finally, the forth section provides the recommendations for industry, policy-makers and future research.

8.2 Achievement of the Research Aim and Objectives

8.2.1 Objective 1: Review Principles and Practices of Sustainable Use of Water in Construction Projects

The first objective was to review principles and practices of sustainable use of water in construction projects. The review of literature included: value of water in the context of sustainability, water resource efficiency, water management, water conservation, water efficiency, water efficiency in sustainability tools, water efficiency measures, on-site water consumption and on-site water wastage, drivers and barriers.

The literature review enabled to gain an insight into the importance given for the water resource and its sustainable aspects at a time when the world is experiencing a scarcity of water due to its overuse and the ever-increasing demand for it. Though the amount of water used during construction is far less compared to that used during the operational stage of a building, the literature emphasized that there is still a high potential for saving water resources by improving water efficiency practices during construction stages of projects. Importantly, the literature review findings in the area of water management in construction clearly show that limited research is being carried out on on-site water efficiency, and highlighted the need for research on improving efficient water-use in construction projects. Based on the knowledge gained from the literature review, a conceptual framework was developed to present key literature concepts relevant for improving efficient water use in construction projects.

8.2.2 Objective 2: Evaluate Water Use Practices of Construction Projects in Sri Lanka

The second objective was to evaluate water use practices of construction projects in Sri Lanka. In this regard, case studies and questionnaire survey findings revealed the basic forms on how on-site water management is being practised in construction projects in terms of on-site water sources; on-site water storage; on-site water record keeping; water quality control and cost allocation for water in construction. The research findings also reported that water management is not given high priority in Sri Lanka for construction projects. The case study findings revealed that water efficiency practices are strongly influenced by conditions prevailing in the operational environment of a site, individual experience, and commitment and that there is no explicit way for water management practices. Results revealed that project location, water source, project scope, site conditions and weather conditions as main variables that impact on the implementation of on-site water efficiency practices.

It revealed that approximately more than two thirds of water used in a site is consumed by indirect construction activities Moreover, findings reported that water wastage is rampant among indirect construction activities whilst water wastage is minimal among direct construction activities. ‘Site cabins and sanitation’, ‘general site activities including tool washing’, wet trades (brickwork, concreting, plastering and rendering), ‘groundwork’ and ‘dust suppression’, and ‘wheel washing’ are identified as the main on-site activities, which consume the highest volume of water. Among on-site activities, ‘site cabins and sanitation’ was identified consuming the highest volume of water and also as an activity that causes water wastage.

Findings also revealed a number of inefficient on-site practices that impact on water efficiency. i.e. non availability of sub-metering systems; absence of proper water record keeping systems, lack of quantitative data, and lack of encouragement for implementing efficient water-use practices in construction projects. On the other hand, implementing on-site rules and regulations (e.g. disposal of wastewater) and EMS positively support to enhance water efficient practices in construction projects. Assign responsibilities, supervision and monitoring, site meeting, display posters and notices, use low flow shower heads, and high pressure gun hoses are some water efficiency measures practised in construction projects.

8.2.3 Objective 3: Investigate the Most Applicable Water Efficiency Measures (WEMs) for Construction Projects

The third objective was to investigate the most applicable Water Efficiency Measures (WEMs) for construction projects. The findings of the literature review identified 31 WEMs, of which ten (10) came under Policies and Planning (PP); four (04) under Attitudes and Behaviour (AB), seven (07) under Alternative Construction (AC) methods and ten (10) under Efficient Technologies (ET). Case study results that explored the practice of WEMs and the questionnaire survey, which identified highly applicable eight (08) WEMs enabled the fulfilment of this objective.

This study identified the following eight (08) highly applicable WEMs for building construction projects:

- Introduction of water leak detection monitoring systems (PP)
- Implementation of water auditing (PP)
- Improvement of monitoring and supervision (PP)
- Introduction of a water action plan at the inception (PP)
- High pressure spray gun hoses (ET)
- Assignment of responsibility and targets to site staff (AB)
- Increased water awareness among workers (AB)
- Introduction of sub-metering systems (PP)

The findings suggested that a change of workers' Attitudes and Behaviour (AB) coupled with Policies and Planning (PP) could be the way forward for efficient water-use practices in construction sites. Thus, the findings are clearly inclined towards 'soft' WEMs as opposed to 'hard' technology oriented WEMs in enhancing efficient water-use in building construction projects.

8.2.4 Objective 4: Determine Relevant Drivers, Barriers and Other Attributes for Efficient Water-Use Practices in Construction Projects

The fourth objective was to determine relevant drivers, barriers and other attributes for efficient water-use practices in construction projects. In this regard, literature reviews, case studies and questionnaire survey findings provided insights for identifying relevant eleven (11) drivers, eight (8) barriers and other attributes that impact on the sustainable use of water during the construction phase.

From both survey results and case studies, the 'cost of water' and 'sources of water' were identified as 'highly relevant drivers' for efficient water-use practices in construction projects. Importantly, except for these two drivers, survey results showed that other drivers (9 of 11) are also 'relevant' for efficient water-use practices in construction projects (attitude and behaviour of site staff ,water quantity, project specific documents, quality of water, social responsibility, sustainability rating systems, policies and regulations, experience, and research and development) whilst 'attitudes and behaviour of staff/workers', 'experience' and 'individual commitment' were also found from case studies as 'relevant drivers' for the efficient water-use in construction sites.

Survey and case studies identified 'low priority for on-site water management' as a 'highly relevant barrier', which impacts on the efficient water-use in construction projects. Importantly, survey results showed that other barriers (7 of 8) are also 'relevant' barriers (absence of standards to integrate WEMs during pre-design and construction stages, value of water being not apparent, additional costs to the contractor and client and being unaware of new technologies and resistance to change), whilst 'absence of water efficiency provisions in tender documents', 'lack of worker awareness', 'workforce culture and attitudes' and 'inadequate commitment' were also found from case studies as barriers for implementing WEMs during the construction phase.

The study has analysed R principles, and proposed 3R.6R extended water hierarchy model, which ensures excellent control of the water resource and potential uses of water under sustainability principles. Moreover, the study suggested new criteria for the existing Green^{SL} rating system to control water efficiency practices during the construction phase.

8.2.5 Objective 5: Develop a Framework for Improving Sustainable Use of Water in Construction Project

The fifth objective was to develop a framework for improving sustainable use of water in construction projects. In this regard, by collating findings of the literature review, case studies and questionnaire survey, this research has developed a framework for improving sustainable use of water in construction projects. The proposed framework is focused on both on-site and beyond on-site construction activities and thus the framework consists of three levels:

- On-site project level (post-contract stage): provides directions for the appropriate level of implementation of water efficient practices during construction stage;
- Beyond on-site project level/organizational level (pre-contract stage): provides directions to incorporate water efficient requirements into projects and monitor their on-site implementation.
- Beyond on-site project level/policy level (both pre-contract and post-contract stages): provides directions to facilitate and regulate the implementation of water efficient requirements and measures

The framework was validated for its content, clarity, understanding, and appropriateness by conducting four expert interviews. The overall feedback on validation objectives was positive, along with a few suggestions that were added for the improvement of the framework.

8.3 Contribution of the Research

The study has both theoretical and practical contributions to the sustainable use of water in construction projects. Accordingly, this research makes the following contributions to both theory and practice.

8.3.1 Contribution to Theory

According to the literature review, a considerable portion of the literature (current knowledge) on water-use during the operational stage of built assets is apparent, yet the literature pertaining to water-use during the construction stage of a construction project is limited. Therefore, the study has

- contributed to the current knowledge by identifying highly applicable, applicable and moderately applicable water efficiency measures (WEMs) for efficient water-use in construction projects.
- identified a list of main drivers to enhance efficient waster use in construction projects.
- contributed to knowledge by identifying barriers that prevent efficient water-use in construction projects.
- extended the existing 6R water hierarchy by integrating newly introduced 3R principles, i.e. Regulation, Responsibility, and Reward, and developed 3R.6R extended water hierarchy model.
- presented a framework for improving the sustainable use of water in construction projects. This framework contributes to the literature on approaches or methods that will improve water efficiency practices in construction projects.
- accepted from a theoretical perspective the compatibility of research findings with theories of Norm Activation Model and Hart's Theory of Natural Resource Based View.

8.3.2 Contribution to Practice

The overall findings of this research will assist in achieving the improvement of the sustainable use of water in construction projects. This research provides a direct contribution to practice as it provides directions to construction industry stakeholders who are involved in pre-contract and post-contract stages, and policy making and planning stages.

- The findings can direct practitioners to focus their efforts on the highly relevant drivers that will enhance efficient water-use, and implement identified highly applicable WEMs.
- 3R.6R extended water hierarchy model and the developed framework will provide principle guidance to construction practitioners to facilitate, regulate, integrate, monitor and implement sustainable use of water in construction projects.
- The findings will also be of interest and beneficial to those who are interested in built environment sustainability.

8.3.3 Limitations of the Study

There are certain limitations to the current study. This study has examined current water management practices focusing on building construction sites. Case selection criteria were limited to grade C1 contractors, high-rise building projects and locations in urban areas. Recognising the importance of calculating the actual amount of water consumed by individual activities in construction sites, the study was confined to showing the percentage of quantity of water consumed by all indirect activities. Although the researcher attempted to collect on-site data, according to individual activities it was not successful due to practical difficulties such as lack of on-site data records, inconsistency of details and data and absence of required technologies.

The sample of the research respondents was drawn in place of a sample of workers from experienced professionals who were believed be aware on water efficiency measures. This was one limitation of the study.

The other limitation of the study was that there was no consideration of the potential impacts on the extent of variability of water-use / water management practices in construction projects due to project procurement methods.

The developed framework is limited to giving directions to construction stakeholders on improving efficient water-use in construction projects. Due to time constraints and limited resources available, the framework was developed as a guide, although it can be transformed into a 'Desktop software' or a 'Mobile Phone Application' which will possibly facilitate user friendly communication leading to the effective implementation of the recommended directions for efficient water-use practices in construction projects (refer to Appendix -F).

8.3.4 Recommendations for Further Research

Based on the research findings and limitations of the current study, following recommendations are made for consideration in a future research in order to further improve sustainable water use in construction projects.

- The study identified certain limitations in quantifying the amount of water used in construction sites presently and proposed actions to overcome such limitations. The study has laid an important foundation for future research on computing water quantity and developing benchmarks. Therefore, it is recommended to quantify the processes and the activities that consume a large volume of water and develop benchmarks/Key Performance Indicators for water consumption at project level using participatory action research.

- The current study was limited to building construction projects. Thus, this study can be adopted to explore water-use practices in civil construction projects in general.

- One of the important outcomes of this study is the need for behavioural change among construction workers in order to instil in them an efficient water-use mentality. Therefore, it is worthwhile to conduct further research to test the Norm Activation Model on water-use behaviour covering a larger sample of workers who are involved in the day-to-day activities of construction sites.

- The findings bring to light the fact that efficient water-use practices are strongly influenced by the conditions prevailing in the operational environment of a site as well as factors external to it. Therefore, it is recommended to conduct future studies on reviewing external factors such as government policies, legislation and environmental regulations relating to water use in construction projects.

- The type of procurement methods used is one of the limitations encountered while developing the framework. It is recommended to extend the developed framework considering project procurement methods and procurement method specific stakeholders' roles and responsibilities.

- The developed framework can be transformed into a Desktop Software or Mobile Phone Application for its effective implementation, possibly to an advance commercial tool which can be used for broader water related aspects in construction projects.

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APPENDIX –A: CASE STUDY INTERVIEW GUIDE

SUSTAINABLE USE OF WATER IN CONSTRCUTION PROJECTS: THE CASE OF SRI LANKA

Dear Participants

I would like to invite you to participate in this research which I am doing for my doctoral degree at University of Moratuwa.

The aim of this research is to develop a framework for improving sustainable use of water in construction projects.

- To examine current practices of sustainable use of water in construction projects in Sri Lanka
- To identify water use efficiency measures currently used on construction sites followed by drivers and barriers
- To explore the causes of inefficient water consumption during the construction phase and actions need to be taken to enhance sustainability practices for efficiency use of water

Your site is identified as one that could provide valuable input into this research. This interview will take Maximum 1 hour to complete. If you agree to participate, your privacy and confidentially will be strictly maintained.

If you need any further clarification or information please feel free to contact the researcher via the contact details given below. The findings of this research will be disclosed to you upon your request. The outcomes of this research/survey would be used for my thesis and research publications in journals and conferences.

Your participation in this survey is highly appreciated.
Thank you

Researcher:

Anuradha Waidyasekara
Email : anulk15@yahoo.com / anuradha@uom.lk
Phone: 0773640989/ 0718570781

Supervisors

Prof. Lalith De Silva
lalith.consultantarch@hotmail.com

Dr. R.Rameezdeen
: Rameez.Rameezdeen@unisa.edu.au

Thank you for agreeing to take part in this research.

CASE STUDY INTERVIEW GUIDE

SUSTAINABLE USE OF WATER IN CONSTRCUTION PROJECTS: THE CASE OF SRI LANKA

Target Group: Project managers and Engineers

Section 1: Background Information

1.1 How many years have you been working in the construction industry?
1.2 Please describe your involvement in building projects?(Experience)
1.3 Please describe your involvement to this project? (i.e. Role and responsibility)

Section 2: Background information about the project

Aim of this section is to obtain background information about the project.

2.1	Project Name & Location	
2.2	Contractual parties Client/Consultant/Contractor	
2.3	Project Key Dates Contract Duration (Months) Commencement Date Anticipated Completion Date	
2.4	Brief Description of Scope of Works	
2.5	Contractual Arrangement	
2.6	Project Cost (Approx.)	
2.7	Project Area (m^2)	
2.8	Number of Staff (Avg)	
2.9	Number of Labourers (Avg)	
2.10	Sources of water For construction work For Management staff For Labour requirements	
2.11	Record keeping on water Consumption Record keeping Method(s)(including documentation)Water Consumption Quantification(methods, average volume per month)Responsible person (s) for water record keeping, Cost allocated in preliminary bill, and description provided	

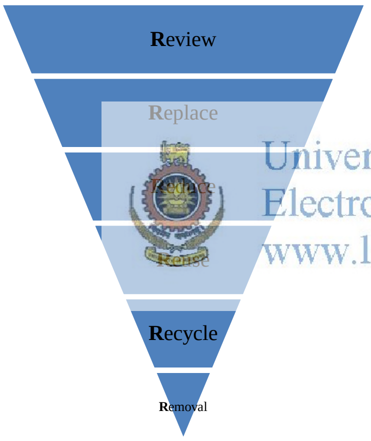
Section 3: Existing water management practice on the site: Water usage and water efficient practices

3.1	What are the current water efficient measures (simply techniques and strategies) are being used/ implemented on the construction sites?
3.2	What are major water consuming activities/processes during construction phase of in this project?
3.3 3.3.1	What are water wasting activities (use more water than actual water requirement)?ways of water wastage What may be the reasons/causes for such wasting water on construction sites?
3.4	What are the factors (drivers) that impact on water consumption on the site?
3.5 3.5.1	Does the site use 'reuse' and 'recycle' water during the construction phase? If yes, please explain. How does the site handle waste water disposal and storm water management?
3.6 3.6.1 3.6.2	Water action Plan/water audit systems identify a set of activities aimed at reducing water usage on construction sites at initially. Does your site have a Water Action Plan (WAP) If yes, please explain what does WAP include and its implementation procedure within the project. If no, would you recognise importance of having a WAP within this project? Please explain the reasons behind your answer.
3.7 3.7.1 3.7.2	Does this project have an Environmental Management System (EMS)/EIA? If yes, please explain what does EMS include and its implementation procedure within the project. If no, would you recognise importance of having an EMS within this project? Please explain the reasons behind your answer.
3.8 3.8.1 3.8.2	Does the current project related documents that make provisions on water efficiency practices during construction industry? [e.g Contract document – BOQ, specification, condition of contract, EMS, method statement etc.] If yes , please explain what are documents and how? If no, would you recognise importance of having provision within the project documents? Please explain the reasons behind your answer.
3.9 3.9.1	What is the current practice of pricing strategies use for water resource during the tender stage? Does the allocation made in preliminary bill for water deviate from the real requirement? Please explain.
3.10	What factors discourage the implementation of water management practices on this site?

Section 4: Suggestions for enhance sustainable use of water during the construction phase

4.1	Would you recognize application of R principles including steps of existing water hierarchy on construction sites? (refer table 1)
4.2	Based on your experience, please state your suggestions to minimise causes of water inefficiencies during the construction phase of building projects?
4.3	What measures would you suggest in order to enhance water efficiency practices?
4.4	Could you please state, construction stakeholders' responsibility towards establish water efficiency practices during the construction phase?
4.5	What factors encourage the implementation of water management practices in general?
4.6	Based on your experience, do you see any barriers on implementation of water efficiency practices during the construction phase?

Table 1

<table>
<tr><th>Steps of exiting water Hierarchy</th><th>Proposed term with R concept</th><th>Definition adopted for the Study Purpose</th></tr>
<tr><td rowspan="6">
</td><td>Review</td><td>Checks whether the process or activity really requires potable water.</td></tr>
<tr><td>Replace</td><td>Find cost effective alternative to potable water.</td></tr>
<tr><td>Reduce</td><td>Explore options to improve water efficiency. Basically applying water efficient technologies, techniques</td></tr>
<tr><td>Reuse</td><td>Water reuse elsewhere without being treated (as it is)</td></tr>
<tr><td>Recycle</td><td>Water recycled for reuse elsewhere</td></tr>
<tr><td>Removal</td><td>Disposal of excess water legally or responsibly to ensure that there is no flooding, pollution or inconvenience to others.</td></tr>
<tr><td rowspan="3">New 3R Principles
Regulations
Rewards
Responsibility</td><td>Regulations</td><td>Adhere to general rules and norms published during water consumption</td></tr>
<tr><td>Rewards</td><td>Remuneration for positives attempts at reducing water consumption and innovative ideas</td></tr>
<tr><td>Responsibility</td><td>Actions towards environmental & social conservation and preservation of natural resources</td></tr>
</table>

Section 5: Further Thoughts

3.1 Based on your experience, if there are any other comments that you would like to make regarding this research please feel free to do so.

Thank you for your cooperation and valuable time spent on participating in this study. Your views are highly appreciated.

APPENDIX – B : STRUCTURED QUESTIONNIRE SURVEY

SUSTAINABLE USE OF WATER IN CONSTRCUTION PROJECTS: THE CASE OF SRI LANKA

Dear Participants

I would like to invite you to participate in this research which I am doing for my doctoral degree at University of Moratuwa.

The aim of this research is to develop a framework for improving sustainable use of water in construction projects.

The purpose this questionnaire survey is to get your valuable inputs and insights on water management in construction industry and recommendations to establish good practices. This questionnaire survey is being distributed among civil engineers, project managers, architects and quantity surveyors who are experience and knowledgeable in the subject area and working in the construction industry in Sri Lanka. You are identified as one that could provide valuable input into this research. This survey will take Maximum 40 minutes to complete. If you agree to participate, your privacy and confidentially will be strictly maintained.

If you need any further clarification or information please feel free to contact the researcher via the contact details given below. The findings of this research will be disclosed to you upon your request. The outcomes of this research/survey would be used for my thesis and research publications in journals and conferences.
Your participation in this survey is highly appreciated.
Thank you

Researcher:

Anuradha Waidyasekara
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Supervisors
Prof. Lalith De Silva
Email : lalith.consultantarch@hotmail.com

Dr. R.Rameezdeen
Email: Rameez.Rameezdeen@unisa.edu.au

Thank you for agreeing to take part in this research.

SECTION I: GENERAL INFORMATION

Please provide the following Information

Name ……………………………………………………………………………

Profession...…………………………………………………………………..

Current Designation………………………………………………………..…

Experience in Construction Industry (Years):…………………………………….

SECTION II: RESPONDENTS' EXPERIENCES OF WATER MANAGEMENT PRACTICES IN THE CONSTRUCTION INDUSTRY

01. What you can say about the current water management practice during the construction phase in Sri Lanka?

Very Good [ ] Good [ ] Moderate [ ] Low [ ] Very Low [ ]

02. How would you agree with the following statements in terms of "**Water Efficiency (WE)'** and **'Water conservation (WC)'** in the construction industry?

5: Strongly Agree **4**: Agree **3**: Neutral **2** : Disagree **1** : Strongly Disagree

Statements WE and WC	5	4	3	2	1
Water efficiency and conservation are two different meanings					
WC means doing less by sacrificing needs					
WE focuses on achieving the same result with the minimal amount of water usage					
WC relies on individuals to change their behaviour to achieve results					
WE relies on individuals to change their behaviour to achieve results					
WC directs towards reducing the wastage of water					
WE encourages best technology to achieve long-term sustainability without sacrificing quality					
Other please specify ……………………………………					

03. What you can say about the common water source/s use in building construction projects? (Please tick (√) as appropriate).

Main Water (pipe water) [ ] Tube well water [ ]

Rainwater Harvesting [ ] Well water [ ]

Surface water (i.e. river, pond, streams, irrigation channels) [ ]

Other. Please specify. …………………………………………

04. The below list shows typical Water using Activities during the Construction phase of Building Projects.

Ground work (Excavation, filling, compaction)	Concreting	Site cabin and sanitation (drinking, bathing, washing, cooking , sanitation
Piling work	Curing work	Site cleaning
Brick work (soaking & mortar)	Plastering and rendering	Dust controlling
Block work & mortar	Structural and seal testing	Wheel washing
Painting work	Commissioning & testing	Landscaping

4.a) Which of the above activities **consume more water** during the construction phase of building projects? (State at least three activities)

……………………………………………………………………………………………
………………………………………………………………………………

4.b) Please specify any other activities which are not included in the list.
……………………………………………………………………………………………
………………………………………………………………………………

4.c) Which of the above activities in terms of **water wasting** during the construction phase of building projects?(State at least three activities)
……………………………………………………………………………………………
………………………………………………………………………………

4.d) Please specify any other wasting activities which are not included in the list.
……………………………………………………………………………………………
………………………………………………………………………………

SECTION III: Water efficiency measures (WEMs), Drivers, Barriers, and sustainability attributes

05. There are number of techniques and strategies available for ensuring low water usage during the construction. The study adopted term water efficiency measures (WEMs) instead of using techniques and strategies. Table 1 presents WEMs and grouped in to four categories namely **Policies and Planning, Attitude and Behaviour, Alternative Construction Methods and Efficient Technologies**. How would you rate the applicability of **each measure** to enhance the water use efficieny practices during the construction phase? Please use the given **Likert Scale** and tick (√) the relevant box.

Table 1 **5**: Highly Applicable **4**: Applicable **3**: Moderately Applicable **2** : Less Applicable **1** : Not Applicable

	Measures	**5**	**4**	**3**	**2**	**1**
Policies and Planning	Develop a builder's guidebook for reference					
	Implement environmental policies on natural resources (EMS, LEED, GreenSL, BREAM)					
	Implement licensed water abstraction system (Surface water/ tube well)					
	Increase the unit rate for water					
	Integrate water efficient techniques during the pre-design and tender stages					
	Introduce a water action plan at the inception					
	Implement Rainwater collection and reuse					
	Introduce of sub-metering systems					
	Implement water auditing					
	Introduce water leak detection monitoring systems					
Attitude & Behaviour	Assign responsibility and targets to site staff					
	Introduce a penalty for unsustainable practices of site staff					
	Improve monitoring and supervision					
	Increase water awareness among workers					
	…………………………………………………					
Alternative construction methods	Use admixtures /chemical additives					
	Implement closed loop systems					
	Introduce curing agents					
	Introduce dry wall partitions instead of brick and block walls					
	Use pre-cast or prefabricated construction methods					
	Use pre-mixed concrete and pre-mixed mortar					
	Use steel intensive construction methods					
	………………………………………………………					
Efficient Technologies	Dust suppression vehicles with sprinklers					
	Efficient showers : Low-flow showerheads					
	Fan misting systems for dust suppression					
	High pressure trigger operated spray gun hoses					
	Low flush cisterns/urinals/waterless urinals					
	Pressure reducing valves					
	Sprinkler systems for curing concrete					
	Vacuum toilets					
	Washing bays for wheel washing					
	Water efficient taps					
	…………………………………………………………					

06. Table 2 presents list of **drivers** which impact on water use efficiency practices on construction projects.

How would you rate the relevance of **each driver** to enhance the water efficient practices during the construction phase? Please use the given **Likert Scale** and tick (√) the relevant box.

Table 2 **5**: Highly Relevant **4**: Relevant **3**: Moderately Relevant **2** : Less Relevant **1** : Not Relevant					
Drivers	**5**	**4**	**3**	**2**	**1**
Attitude and behaviour of site staff					
Cost of water					
Experience					
Policies and regulations					
Project specific documents					
Quality of water					
Responsibility					
Research and development					
Sustainability rating systems					
Water quantity					
Water source					
Other ………………………………………………………					

07. Table 3 presents list of **barriers** which impact on water use efficiency practices on construction projects.

How would you rate the relevance of **each barrier** to enhance the water efficient practices during the construction phase? Please use the given **Likert Scale** and tick (√) the relevant box.

Table 3 **5**: Highly Relevant **4**: Relevant **3**: Moderately Relevant **2** : Less Relevant **1** : Not Relevant					
Barriers	**5**	**4**	**3**	**2**	**1**
Absence of standards to integrate WEMs during pre-design stage					
Absence of standards to integrate WEMs during construction stage					
Additional cost to client					
Additional cost to contractor					
Unaware of new techniques					
Low priority for water management					
Resistance to change					
Value of water not apparent					
Other ………………………………………………………					

08. a) Table 4 presents R concepts including steps of existing water hierarchy that can be used to enhance water usage and efficiency practices on construction projects.

How would you rate the applicability of **each R** to enhance the water use efficiency practices during the construction phase? Please use the given **Likert Scale** and tick (√) the relevant box.

Table 4 **5**: Highly Applicable **4**: Applicable **3**: Moderately applicable **2** : Less Applicable **1** : Not Applicable

No	**R Concept**	**Description**	5	4	3	2	1
	Review	Checks whether the process or activity really requires potable water.					
	Replace with alternative water sources	Find cost effective alternative to potable water.					
	Reduce	Explore options to improve water efficiency. Basically applying water efficient technologies , techniques					
	Reuse – without treatment	Water reuse elsewhere without being treated (as it is)					
	Recycle	Water recycled for reuse elsewhere					
	Removal of used or excess water	Disposal of excess water legally or responsibly to ensure that there is no flooding, pollution or inconvenience to others.					
	Rules and Regulations	Adhere to general rules and norms published during water consumption					
	Reward	Remuneration for positives attempts at reducing water consumption and innovative ideas					
	Responsibility	Actions towards environmental & social conservation and preservation of natural resources					

8. b. Based on your experience, please state application of steps of water hierarchy i.e. Review, Replace, Reduce, Reuse, Recycle and Removal practices are currently being used during the construction phase. State any example.

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

8. c. Please make comments on how Regulations, Responsibility and Reward impact on sustainable use of water during the construction phase.

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

09. Green building rating tools specify certain measures to improve water use efficiency at design, construction and commissioning stages. Below Table shows **PREREQUISITE** and **REQUISITE** criteria identified for improve water use efficiency during the construction phase.

How would you rate the level of agreement of **each factor** to enhance water efficient practices during the construction phase? Please use the given **Likert Scale** and tick (√) the relevant box.

5: Strongly Agree **4**: Agree **3**: Neutral **2** : Disagree **1** : Strongly Disagree					
PREREQUISITE (No credits assign)	5	4	3	2	1
Implementing policies on environment					
Water action plan					
Other .please specify………………………………..					
REQUISITE (credits assign)	5	4	3	2	1
Integration of water efficiency and conservation measures					
Integration of 9R principles					
Innovation					
Other .please specify………………………………..					

SECTION IV

10. Please state factors that could impact on water use efficiency on construction sites. ……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

11. Please state recommendations for enhance water use efficiency practices on construction projects.

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

12. Based on your experience, please add any other comments relevant to this research

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

Thank you for your cooperation and valuable time spent on this questionnaire

APPENDIX C : One-way ANOVA Test Results

The criterion for accepting or rejecting the hypothesis was set as 0.05, and if p-value is less than .05, the null hypothesis is rejected.

Question 5 : Policies and planning

		Sum of Squares	df	Mean Square	F	Sig.
PP_1	Between Groups	.901	3	.300	.859	.465
	Within Groups	35.346	101	.350		
	Total	36.248	104			
PP_2	Between Groups	.266	3	.089	.254	.858
	Within Groups	35.296	101	.349		
	Total	35.562	104			
PP_3	Between Groups	2.923	3	.974	1.758	.160
	Within Groups	55.991	101	.554		
	Total	58.914	104			
PP_4	Between Groups	1.425	3	.475	.591	.622
	Within Groups	81.204	101	.804		
	Total	82.629	104			
PP_5	Between Groups	.595	3	.198	.365	.778
	Within Groups	54.796	101	.543		
	Total	55.390	104			
PP_6	Between Groups	.915	3	.305	.615	.607
	Within Groups	50.075	101	.496		
	Total	50.990	104			
PP_7	Between Groups	4.497	3	1.499	.912	.438
	Within Groups	166.036	101	1.644		
	Total	170.533	104			
PP_8	Between Groups	3.939	3	1.313	2.189	.094
	Within Groups	60.576	101	.600		
	Total	64.514	104			
PP_9	Between Groups	1.490	3	.497	1.040	.378
	Within Groups	48.224	101	.477		
	Total	49.714	104			
PP_10	Between Groups	1.463	3	.488	1.276	.287
	Within Groups	38.594	101	.382		
	Total	40.057	104			

Attitude and behaviour

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
AB_1	Between Groups	2.295	3	.765	2.102	.105
	Within Groups	36.752	101	.364		
	Total	39.048	104			
AB_2	Between Groups	1.767	3	.589	.802	.496
	Within Groups	74.195	101	.735		
	Total	75.962	104			
AB_3	Between Groups	.610	3	.203	.616	.606
	Within Groups	33.352	101	.330		
	Total	33.962	104			
AB_4	Between Groups	1.444	3	.481	1.129	.341
	Within Groups	43.071	101	.426		
	Total	44.514	104			

Alternative construction methods

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
AC_1	Between Groups	10.570	3	3.523	2.617	.055
	Within Groups	135.963	101	1.346		
	Total	146.533	104			
AC_2	Between Groups	3.947	3	1.316	1.371	.256
	Within Groups	96.910	101	.960		
	Total	100.857	104			
AC_3	Between Groups	4.481	3	1.494	.976	.407
	Within Groups	154.509	101	1.530		
	Total	158.990	104			
AC_4	Between Groups	8.983	3	2.994	3.097	.160
	Within Groups	97.645	101	.967		
	Total	106.629	104			
AC_5	Between Groups	6.743	3	2.248	2.515	.063
	Within Groups	90.248	101	.894		
	Total	96.990	104			
AC_6	Between Groups	2.620	3	.873	1.209	.310
	Within Groups	72.942	101	.722		
	Total	75.562	104			
AC_7	Between Groups	3.710	3	1.237	1.298	.279
	Within Groups	96.251	101	.953		
	Total	99.962	104			

Efficient Technologies

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
ET_1	Between Groups	3.401	3	1.134	.586	.626
	Within Groups	195.361	101	1.934		
	Total	198.762	104			
ET_2	Between Groups	4.704	3	1.568	1.462	.229
	Within Groups	108.343	101	1.073		
	Total	113.048	104			
ET_3	Between Groups	8.184	3	2.728	1.343	.265
	Within Groups	205.207	101	2.032		
	Total	213.390	104			
ET_4	Between Groups	2.442	3	.814	.869	.460
	Within Groups	94.606	101	.937		
	Total	97.048	104			
ET_5	Between Groups	1.486	3	.495	.677	.568
	Within Groups	73.904	101	.732		
	Total	75.390	104			
ET_6	Between Groups	.266	3	.089	.254	.858
	Within Groups	35.296	101	.349		
	Total	35.562	104			
ET_7	Between Groups	4.686	3	1.562	1.802	.152
	Within Groups	87.562	101	.867		
	Total	92.248	104			
ET_8	Between Groups	6.099	3	2.033	1.119	.345
	Within Groups	183.463	101	1.816		
	Total	189.562	104			
ET_9	Between Groups	10.463	3	3.488	1.586	.197
	Within Groups	222.051	101	2.199		
	Total	232.514	104			
ET_10	Between Groups	1.813	3	.604	.390	.760
	Within Groups	156.434	101	1.549		
	Total	158.248	104			

Question 06
Drivers

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Driv_1	Between Groups	7.887	3	2.629	3.077	.051
	Within Groups	86.304	101	.854		
	Total	94.190	104			
Driv_2	Between Groups	2.603	3	.868	1.249	.296
	Within Groups	70.159	101	.695		
	Total	72.762	104			
Driv_3	Between Groups	5.889	3	1.963	2.935	.087
	Within Groups	67.540	101	.669		
	Total	73.429	104			
Driv_4	Between Groups	3.324	3	1.108	.951	.419
	Within Groups	117.723	101	1.166		
	Total	121.048	104			
Driv_5	Between Groups	3.746	3	1.249	1.497	.220
	Within Groups	84.254	101	.834		
	Total	88.000	104			
Driv_6	Between Groups	2.005	3	.668	1.011	.391
	Within Groups	66.757	101	.661		
	Total	68.762	104			
Driv_7	Between Groups	2.044	3	.681	1.195	.316
	Within Groups	57.613	101	.570		
	Total	59.657	104			
Driv_8	Between Groups	2.290	3	.763	.680	.566
	Within Groups	113.368	101	1.122		
	Total	115.657	104			
Driv_9	Between Groups	2.448	3	.816	.911	.439
	Within Groups	90.467	101	.896		
	Total	92.914	104			
Driv_10	Between Groups	1.512	3	.504	.596	.619
	Within Groups	85.346	101	.845		
	Total	86.857	104			
Driv_11	Between Groups	.560	3	.187	.297	.827
	Within Groups	63.402	101	.628		
	Total	63.962	104			

Question 07: Barriers

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Barr_1	Between Groups	1.263	3	.421	.503	.681
	Within Groups	84.585	101	.837		
	Total	85.848	104			
Barr_2	Between Groups	2.355	3	.785	.950	.420
	Within Groups	83.492	101	.827		
	Total	85.848	104			
Barr_3	Between Groups	1.764	3	.588	.583	.627
	Within Groups	101.798	101	1.008		
	Total	103.562	104			
Barr_4	Between Groups	1.803	3	.601	.763	.518
	Within Groups	79.588	101	.788		
	Total	81.390	104			
Barr_5	Between Groups	1.186	3	.395	.668	.573
	Within Groups	59.729	101	.591		
	Total	60.914	104			
Barr_6	Between Groups	1.747	3	.582	1.064	.368
	Within Groups	55.244	101	.547		
	Total	56.990	104			
Barr_7	Between Groups	3.641	3	1.214	1.336	.267
	Within Groups	91.787	101	.909		
	Total	95.429	104			
Barr_8	Between Groups	4.404	3	1.468	1.912	.132
	Within Groups	77.558	101	.768		
	Total	81.962	104			

Question 08: Nine (9) R Principles

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Review	Between Groups	.714	3	.238	.392	.759
	Within Groups	61.343	101	.607		
	Total	62.057	104			
Replace	Between Groups	.308	3	.103	.139	.937
	Within Groups	74.739	101	.740		
	Total	75.048	104			
Reduce	Between Groups	.043	3	.014	.019	.996
	Within Groups	76.757	101	.760		
	Total	76.800	104			
Reuse	Between Groups	.169	3	.056	.040	.989
	Within Groups	142.346	101	1.409		
	Total	142.514	104			
Recycle	Between Groups	6.217	3	2.072	1.386	.251
	Within Groups	150.983	101	1.495		
	Total	157.200	104			
Removal	Between Groups	2.653	3	.884	.879	.455
	Within Groups	101.594	101	1.006		
	Total	104.248	104			
Regulations	Between Groups	5.055	3	1.685	2.613	.055
	Within Groups	65.135	101	.645		
	Total	70.190	104			
Reward	Between Groups	4.389	3	1.463	1.792	.153
	Within Groups	82.468	101	.817		
	Total	86.857	104			
Responsibility	Between Groups	3.953	3	1.318	1.675	.177
	Within Groups	79.437	101	.787		
	Total	83.390	104			

Question 09: Criteria for Sustainability assessment tool

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Pre_Req_1	Between Groups	.727	3	.242	.512	.675
	Within Groups	47.787	101	.473		
	Total	48.514	104			
Pre_Req_2	Between Groups	1.203	3	.401	1.147	.334
	Within Groups	35.312	101	.350		
	Total	36.514	104			
Req_1	Between Groups	.561	3	.187	.697	.556
	Within Groups	27.096	101	.268		
	Total	27.657	104			
Req_2	Between Groups	.504	3	.168	.659	.579
	Within Groups	25.744	101	.255		
	Total	26.248	104			
Req_3	Between Groups	.294	3	.098	.224	.880
	Within Groups	44.239	101	.438		
	Total	44.533	104			

Question 02:Definitions for water efficiency and water conservation

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
WE_WC_1	Between Groups	2.684	3	.895	1.117	.346
	Within Groups	80.878	101	.801		
	Total	83.562	104			
WE_WC_2	Between Groups	.793	3	.264	.253	.859
	Within Groups	105.454	101	1.044		
	Total	106.248	104			
WE_WC_3	Between Groups	3.639	3	1.213	2.005	.118
	Within Groups	61.123	101	.605		
	Total	64.762	104			
WE_WC_4	Between Groups	3.254	3	1.085	2.509	.063
	Within Groups	43.661	101	.432		
	Total	46.914	104			
WE_WC_5	Between Groups	1.426	3	.475	.801	.496
	Within Groups	59.965	101	.594		
	Total	61.390	104			
WE_WC_6	Between Groups	1.017	3	.339	.616	.606
	Within Groups	55.611	101	.551		
	Total	56.629	104			
WE_WC_7	Between Groups	.571	3	.190	.322	.809
	Within Groups	59.658	101	.591		
	Total	60.229	104			

Appendix D: Internal Reliability: Cronbach's Alpha Values

Q5: Water efficiency and conservation measures

Case Processing Summary

		N	%
Cases	Valid	105	100.0
	Excluded[a]	0	.0
	Total	105	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.796	.812	31

Q6: Drivers

Case Processing Summary

		N	%
Cases	Valid	105	100.0
	Excluded[a]	0	.0
	Total	105	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.854	.854	11

Q7. Barriers for WE and WC

Case Processing Summary

		N	%
Cases	Valid	105	100.0
	Excluded[a]	0	.0
	Total	105	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.715	.718	8

Q9 Sustainability assessment criteria

Case Processing Summary

		N	%
Cases	Valid	105	100.0
	Excluded[a]	0	.0
	Total	105	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.665	.679	5

Q8. 9R concepts

Case Processing Summary

		N	%
Cases	Valid	105	100.0
	Excluded[a]	0	.0
	Total	105	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.752	.762	9

ON-SITE PROJECT LEVEL[POST CONSTRACT] : INFORMATION FOR EFFICIENT WATER USED

3R.6R EXTENDED WATER HIERACHY

Steps of hierarchy	Description	Remarks (application)
Review	Check whether the process or activity is really necessary potable water. Find cost effective alternatives to potable water.	During the design, tender and construction stages
Replace with alternate water sources	Find cost effective alternatives to potable water.e.g. Tube well, well water, rainwater etc.	During the tender and construction stages
Reduce	Explore options to improve the water efficiency. e.g applying water efficient technologies /conservation methods	Determine WEC measures during the design and construction stages
Reuse – without treatment	Reuse same water elsewhere without treat (as it is)	Determine possibilities during the design and construction stages
Recycle	Water be recycled for reuse elsewhere	Determine possibilities during the design and construction stages
Removal of used or excess water	Dispose of excess water legally or responsibly to ensure that there is no flooding, pollution or inconvenience to others.	During the design and construction stages
Regulations	Adhere to general rules and norms during the water consumption (quantity/quality/source/disposal)	During the design, tender and construction stages
Reward	Remuneration/incentives/appreciations towards positive attempts of individual and management commitments	During the tender and construction stages
Responsibility	Individual and management actions towards environmental & social conservation and preservation	During the design , tender and construction stages

Specimen Templates :Basic steps in a water audit system

a) Planning – Preparation of basic information

1. Site map Available ☐ Not available ☐
2. Flow chart for water distribution Available ☐ Not available ☐
3. Details of water sources according to the requirement at site

Ref	Requirement	Well water	City water	Tube well	Transported By Bowsers	Other
i	Construction work					
ii	Labour – drinking					
iii	Labour – bathing and washing					
iv	Management staff – drinking					
v						

4. Assigning responsible parties Done ☐ Not done ☐
5. Identify the priority water consumption activities and processes which need audit system during the construction.

Ref	Activity/process	Time frame*	In-charge	Re
i				
ii				
iii				
iv				
v				

*operating schedule of site

b) Recording – water use data
- Water Supply: Meter reading/ number of tanks/ number of bowsers/etc.
- Water bills/ invoices/etc.
- Water consumption quantity (daily/weekly/monthly)
  - In the selected construction activities and processes
  - Examine variations in rainy days, hot days, holidays, weekends

Ref	Meter reading	Date	Time	Activities taken place	Remarks
i					
ii					
iii					
iv					

c) Monitoring and Observation
- Identify real losses along water distribution, storage, valves, services, meters and fixtures and fittings (overflow, leakages, broken, dirty)
- Check responsibility of the assigned persons and worker behaviour
- Identification of water reuses, reduce and recycling opportunities

d) Analyzing :
- Water consumption quantity
- Water consumption patterns graphically

e) Discussion
- Identify the problems and solutions through brainstorming sessions
- Identify innovative methods

f) Reporting
- Ways to conserve and efficient water practices
- Remedial measures
- Integrate water data analyses with monthly progress reports
- Regulating laws if necessary
- Recommendations

Specimen Templates : RECORDS FOR SITE WATER CONSUMPTION

Water consumption of Construction activities
Person in charge ………………………………………………………………

Activity	Unit	Qty (BOQ)	potable/non potable	Required water (m3) (Norms)[a]	Actual water qty (m3) [b]	[a-b] = [c] if +C = saving - C =excessive	WECM adopted	Phase according to CP

Water Consumption of Management staff
Person in Charge ……………………………………………………………………………

	MM/YY										
Number of staff											
Main water use (m3)											
Number of water bottles (capacity)											
Total water use (m3)											
Water use m3/person/month											
Cost of main water (Rs)											
Cost of water bottles (Rs)											
Cost of water Rs/ person/month											

Water Consumption of Workers
Person in Charge ………………………………………………………..

	Month /year										
Number of direct labourers											
Number of subcontractors											
Number of workers at site accommodation											
Number of workers outside the site											
Total water use (m3)											
Water use m3/person/month											
Cost of water (Rs)											
Cost of water Rs/ person/month											

ON-SITE PROJECT LEVEL[POST CONSTRACT] : INFORMATION FOR EFFICIENT WATER USE

Water Efficiency Measures : (WEMs)

Policies and Planning	Attitude and Behaviour	Alternative Construction methods	Efficient Technologies
Highly Applicable Introduce water leak detection monitoring systems - Implement water auditing - Introduce a water action plan at the inception - Introduce sub-metering systems **Applicable** -Implement environmental policies on natural resources -Develop a builder's guidebook for reference -Integrate water efficient techniques during the pre-design and tender stage -Implement Rainwater collection and reuse **Moderately Applicable** -Implement licensed water extraction system (Surface water/ tube well) -Increase the unit rate for water	**Highly Applicable** Improve monitoring and supervision -Assign responsibility and targets to site staff -Increase water awareness among workers **Applicable** -Introduce penalty for unsustainable practices by site staff	**Applicable** Introduction of curing agents Implement closed loop systems Use admixtures /chemical additives Introduce dry wall partitions instead of brick and block walls Use pre-cast or prefabricated construction methods Use steel intensive construction methods **Moderately Applicable** Use pre-mixed concrete and pre-mixed mortar	**Highly Applicable** High pressure trigger operated spray gun hoses **Applicable** Pressure reducing valves Low flush cisterns/urinals/waterless urinals Efficient showers : Low-flow showerheads Sprinkler systems for curing concrete Dust suppression vehicles with sprinklers Water efficient taps Washing bays for wheel washing **Moderately Applicable** Fan misting systems for dust suppression Vacuum toilets

Water Wasting Activities

Possible water wasting activities on the site (Attention of Contractor)

- Site cabins and sanitation
- Site cleaning
- Vehicle washing
- Dust controlling
- Commissioning and testing of plants and services
- Structural testing before and after applying waterproofing paint
- Landscaping

Key terminologies/ Benefits

Key Terminologies

TERM	Description
Closed loop systems	Waste of one product is used for another process
Water Action Plan	Formulating and implementing overall sustainability practices by improving construction water use processes, technologies and behaviour allowing the focused actions on water use on sites. Basic components of Action plan are identify the tasks, identify the time horizon and identify the resource allocation
Water Audit	Determines the amount of water loss from a distribution system due to leakage and other reasons such as theft, unauthorized or illegal withdrawals from the system and the cost of such losses to the utility.
Water Hierarchy	Water hierarchy is a framework for prioritizing the most preferable options for water management and efficiency and is at the heart of any water efficiency programme.

Benefits to Contractor

Benefits and achievements by conducting water efficiency practices

To Contractor

- Competitive advantages against other organizations in the industry, adopting sustainable construction practices
- Rewards in the contractor evaluation process
- Cost savings
- Conservation in consumption of natural resources during construction
- Keep records as evidences for future construction projects during the estimating process and operation
- Rewards at annual awards ceremonies
- Credential when applying green certificates

APPENDIX –F : CONCEPT OF DEVELOPING A MOBILE APP FOR IMPROVING SUSTAINABLE USE OF WATER IN CONSTRUCTION INDUSTRY