Efficient water management in building: an approach to promote sustainable building construction in India.

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EFFICIENT WATER MANAGEMENT IN BUILDING: AN APPROACH TO PROMOTE SUSTAINABLE BUILDING CONSTRUCTION IN INDIA

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EFFICIENT WATER MANAGEMENT IN BUILDING: AN APPROACH TO PROMOTE SUSTAINABLE BUILDING CONSTRUCTION IN INDIA

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Abstract

The growing concerns surrounding water scarcity have spiked an interest in embodied water (EW) studies globally. The EW of a building is the sum of the amount of water needed to manufacture all the building materials throughout their supply chain (indirect embodied water (IEW)), plus the amount of water needed for the building construction (direct embodied water (DEW)). For a building with an operational period of fifty years, this EW can constitute almost 35% of the total building water footprint.

India is currently under an urban boom that has resulted in an increased demand for residential building construction projects. The growing water scarcity within the country and the huge contribution of EW in the total building water footprint, suggests the need for EW management in the country. This study thus aims at developing a framework for EW management to promote sustainable building construction in India. To achieve the research aim, this study adopts a sequential explanatory multiphase mixed method research design and uses case studies, archival search, online questionnaires and semi-structured interviews as its research strategy.

Reinforced concrete (RC) frame buildings with clay masonry walls are the most common type of residential building construction in India constituting 45% of the residential building stock and are selected as case study buildings for analysis. Two case study buildings were analysed to determine the commonly used construction materials and construction activities undertaken for their construction. These materials and activities were further analysed to determine their embodied water coefficient (EWC) which is the amount of water needed for their manufacturing and execution respectively. These EWC values were used to calculate the EW of the case study buildings to be in the range of 0.32-0.35kL/m^2. Moreover, an analysis of the IEW and embodied carbon (EC) of these case study buildings revealed that both the EW and EC need to be considered when selecting construction materials to aid in the selection of materials with the lowest environmental impact. An online questionnaire conducted with construction professionals working in India revealed that 45.7% construction sites in India meter their water consumption to monitor their usage as they have to pay to purchase this water. Furthermore, semi-structured interviews with construction professionals and construction material manufacturers revealed that there is a lack of government regulations for EW management and where they exist, the company faces many challenges for its implementation. The proposed framework created for EW management thus focuses on minimising the challenges for the implementation of government regulations, creation of benchmarks for optimum water consumption and creation of awareness among people regarding water management.

The findings of this research have many contributions in practice and theory. The development of optimum water consuming benchmarks, and the proposed framework can aid in water management on construction sites and material manufacturing plants during their planning and operation stages. Moreover, this research contributes to theory by developing a methodology for EW measurement that has previously been adopted globally but not in India.

Keywords: Building construction, Embodied water, Embodied water coefficient, Material manufacturing.

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I am deeply indebted to the industry professionals who have been very helpful in providing me with the necessary data required for the completion of this study. Although they remain anonymous due to the confidentiality agreements, their contribution has been crucial for the completion of this study.

I would also like to thank my parents Mr. Vipin Chawla and Mrs. Ritu Chawla, my brother Mr. Advik Chawla, and Mr. Mohit Lalwani, for their unwavering belief in me and constant encouragement that has been my source of strength to complete this PhD. Last but not the least, I am extremely grateful for my pet Oscar whose existence has been a source of comfort throughout this journey.

Dedication

I would like to dedicate this PhD to my parents Mr. Vipin Chawla and Mrs. Ritu Chawla, who have been my constant bedrock, encouraging me and celebrating my successes. Their continuous belief has always motivated me to pursue my dreams and achieve my best.

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Publication

1) "Embodied Water Management for Sustainable Construction: A Case of India" – Conference proceeding in the 2024 International SEEDS Conference from 27th-29th August 2024.

Abbreviations

AAC	Autoclaved aerated concrete
AWM	Agriculture water management
BIS	Bureau of Indian Standards
BOQ	Bill of quantities
BRE	Building Research Establishment
DEW	Direct embodied water
DM	De-mineralised
EC	Embodied carbon
ECC	Embodied carbon coefficient
EE	Embodied energy
EEC	Embodied energy coefficient
EPD	Environmental product declarations
ETP	Effluent treatment plant
EW	Embodied water
EWC	Embodied water coefficient
GCCA	Global Cement and Concrete Association
GRI	Global Reporting Initiatives
GWP	Global warming potential
IEW	Indirect embodied water
IS	Indian Standard
ISO	International Organization for Standardization
IWM	Industrial water management
LCA	Life cycle analysis
O&G	Oil & Gas
OPC	Ordinary Portland cement
PC	Plain concrete
PCR	Product category rules
RC	Reinforced Concrete
RGU	Robert Gordon University
RMC	Ready-Mix Concrete
RWH	Rainwater harvesting
STP	Sewage treatment plants

SDG	Sustainable development goal
SWM	Sustainable water management
TDS	Total dissolved solids
WF	Water footprint
Eq	Equivalent
Kg	Kilogram
kL	Kilo litre
l	Litre
m3	Cubic meter
m2	Square meter
ton	Tonne

Chapter 1 : Introduction

1.1 Background of the Study

Water is known as the "engine" of life as it is an essential substance to sustain life on earth and maintain the environment and ecosystem (Bardhan and Choudhuri 2016; Halmaghi and Mosteanu 2019). Water is the input for all human activities including construction activities, ranging from residential building construction to the construction of infrastructure for the development of a country. While the construction sector is crucial for the economic and social development, it is also greatly responsible for environmental degradation due to its huge demand for natural resources like water (Ding 2014; Gokarakonda et al. 2019; Mannan and Al-Ghamdi 2020).

The construction of a building consumes water during its entire lifecycle including material manufacturing, construction, operation and demolition phases (Choudhuri and Roy 2015; Bardhan and Choudhuri 2016; Abd El-Hameed et al. 2017). The water consumed in the construction phase is known as the direct embodied water (DEW) while that consumed in the material manufacturing phase throughout the supply chain is known as the indirect embodied water (IEW) (McCormack et al. 2007; Bardhan 2011; Mannan and Al-Ghamdi 2020). The sum of the DEW and IEW is known as the embodied water (EW) of the building (McCormack et al. 2007; Bardhan 2011; Mannan and Al-Ghamdi 2020) and is shown in Figure 1.1.

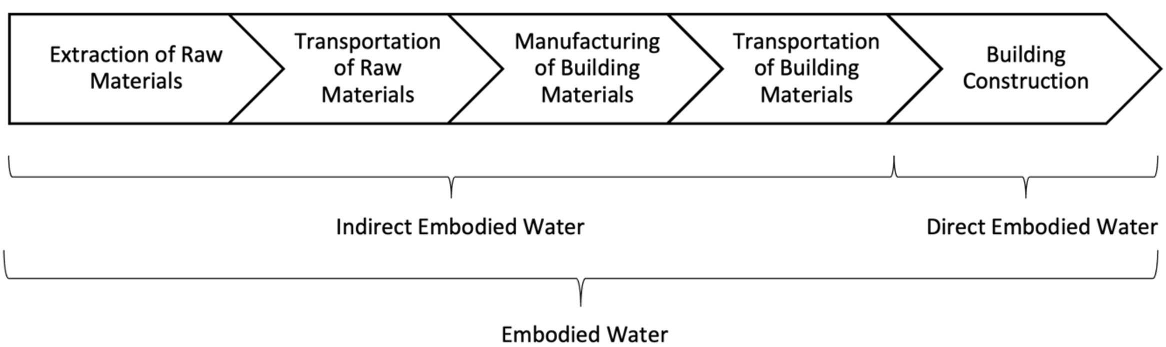

Figure 1.1: Embodied water of a building (Source: Author)

Stephan and Crawford (2014) noted that for a conventional Australian residential building for an operational period of 50 years the EW accounts to 38.2% of the total building water footprint (WF). A similar study for a four-star rated hotel conducted in India by Choudhuri (2015) noted that the EW constitutes 31.65% of the total building WF. This highlights the huge contribution of the EW in the total building WF and the need for its management. Choudhuri (2015) also noted that the DEW constitutes 10.4% of the EW of the building. Another study by Heravi and Abdolvand (2019) calculated the EW of six residential buildings in Iran and noted that the DEW constitutes 20% of the EW. The high contribution of the IEW in the EW signifies the huge impact the materials used for the construction of the building has on the total WF of the building.

The United Nations have set up seventeen sustainable development goals (SDG) to address the environmental, economic and political challenges the world is facing. These goals focus on tackling various issues like poverty, inequality, peace, climate change and environmental degradation, to help in creating a sustainable world. Two goals amongst these seventeen goals focus on water management and define the need for EW management. These are SDG 6 that focuses on ensuring the availability and sustainable management of clean water and sanitation for all people, and SDG 12 that focuses on ensuring sustainable consumption of resources and production patterns (United Nations 2024a).

All SDGs define targets that must be accomplished by 2030 to achieve the specified goal. Broadly both SDG 6 and SDG 12 are related to EW management. However, target 6.3 (improve water quality by reducing pollution and increasing the recycling and reuse of wastewater) and target 6.4 (increase water use efficiencies across all sectors) of SDG 6 applies directly to EW management (United Nations 2024b). Similarly, target 12.2 (sustainable management and efficient use of natural resources) and target 12.5 (reduce wastes through prevention, reduction, recycling and reuse) of SDG 12 specify the management of resources (United Nations 2024c). The term "resources" includes water; thus, this SDG also has a focus on EW management.

Owing to the growing worldwide water scarcity, and the increasing water consumption across all sectors of a country (including the construction sector and material manufacturing industries), the targets of both SDG 6 and SDG 12 must be accomplished to ensure that water resources are not misused and overexploited. Moreover, as aforementioned, the EW of a building constitutes a significant portion of the building WF, and its management can help advance the goals of SDG 6 and SDG 12.

The most common methodology to calculate EW of buildings is by adopting a life cycle analysis (LCA) approach. Majority of the past studies like Crawford and Pullen (2011) and Dixit, Kumar and Haghighi (2022) have used the hybrid LCA approach while few studies like Bardhan (2011) and Heravi and Abdolvand (2019) have used the process LCA approach. The two approaches differ in the source of input data and system boundary considered. While the process LCA approach only relies on input data in terms of water consumption, the hybrid LCA approach combines the water consumption data from process LCA with the input-output economic data of the country to calculate its water flows within the economy.

1.2 Research Gap

Majority of the previous studies on water management in buildings have focused on the operational water management (Treloar and Crawford 2004; McCormack et al. 2007; Stephan and Crawford 2014; Abd El-Hameed at al. 2017; Rahman et al. 2019; Mannan and Al-Ghamdi 2020). Studies focusing on EW have increased over the last decade with various studies conducted in Australia and United States of America (USA). The embodied water coefficient (EWC) of a material or an activity is the amount of water consumed (in kL) to manufacture a unit of that material (in ton, m^3, etc.) or conduct a unit of that activity (in m^2, m^3, etc.) respectively. This EWC plays a crucial role for EW management as it defines the optimum amount of water required to manufacture that material or execute that activity. Past studies conducted in India highlight two major research gaps related to this EWC as discussed below.

Firstly, there is a lack of data availability related to the EWC of construction materials in Indian context, and where they exist, they are outdated. There are a limited number of published articles on the EWC of construction materials (Central

Pollution Control Board (2009) for cement, Central Public Health and Environmental Engineering Organisation (1999) for steel, Bardhan (2011) for clay bricks, and Bardhan (2015a) for concrete blocks). The recorded EWC of cement from Central Pollution Control Board (2009) specifies the EWC of cement manufactured using the wet process to be in 1kL/ton, however, over the past decade manufacturing industries have transitioned to a dry or semi-dry process. Similarly, the EWC of steel published by the Central Public Health and Environmental Engineering Organisation (1999) specifies an EWC value of 200kL/ton. Sharma and Chani (2022) note this value to be unrealistically high. Moreover, comparing this value of steel EWC to the EWC value considered in other studies such Treloar et al. (2004) (39 kL/ton), Crawford and Pullen (2011) (98.64 kL/ton) and Heravi and Abdolvand (2019) (84 kL/ton) highlight the need to recalculate this value in Indian context. Bardhan (2011) states the EWC of clay bricks to be 0.71kL/ton and this value was assumed based on the amount of water required to make M20 grade concrete. The only article with a reliable EWC is for concrete blocks by Bardhan (2015a). The EWC of hollow and solid concrete blocks was determined by a site visit to a manufacturing plant located in east India. On the contrary, countries like Australia and USA have a larger database for the EWC of sixteen and twelve different construction materials respectively, which highlights the need for a similar database in Indian context for EW management.

Secondly, there is a lack of recorded data for EWC of different construction activities on construction sites in India and globally. All the studies for DEW in India have used approximate values of water consumed on construction sites by taking into account the volume of water supplied by water tankers or the volume of water withdrawn from bore wells during the entire project duration. Similarly, majority of the studies conducted globally have adopted an input-output based hybrid LCA technique to determine the approximate DEW of buildings which often leads to assumptions and an overestimation of the DEW. None of these studies have identified the amount of water consumed for carrying out different construction activities (EWC). The identification of the EWC of construction activities is essential to determine how much water is required for conducting an activity and whether construction sites are overusing water for these activities due to a lack of benchmarks. This is essential to ensure sustainable construction of buildings.

In addition to the lack of these EWC values in Indian context, there is also a lack of studies in India that compare the embodied carbon (EC) and EW of different construction materials to determine if any trade-off exists between the two to aid in selecting materials that contribute to low carbon and low water footprint. A study conducted by Dixit and Kumar (2022) compared the embodied energy (EE) and EW intensity of different construction materials in the USA and found a weak correlation between the two. The study suggests that selecting materials based on only one component might not result in the selection of a material with low environmental impact since a material might have a low EE but high EW and vice versa.

1.3 Problem Statement

With the increase in construction activities due to the increase in human population, the pressure on natural water resources to meet these construction demands has also increased resulting in an urgent need to manage this resource (Read 2005). Dixit, Kumar and Haghighi (2022) note that building construction activities consume almost 16% of global freshwater resources. Conventional construction techniques use potable water for various construction activities. Once potable water is used, it is labelled as wastewater and discharged to the wastewater treatment facility (Joustra and Yeh 2015). Such linear water management practices lead to unnecessary resource depletion and detrimental environmental impacts (Joustra and Yeh 2015).

The industrial sector (which includes construction material manufacturing industries) is globally the second largest consumer of freshwater resources after the agricultural sector (Nezamoleslami and Hosseinian 2020). Hence, the construction of buildings is responsible for huge freshwater uptake. Though these activities consume large quantities of water, they also offer numerous possibilities for its conservation through the implementation of sustainable water management (SWM) practices (Russ, Hamid and Ye 2008; Bardhan and Choudhuri 2016; Mannan and Al-Ghamdi 2020). Sustainable water management practices consider all kinds of water (including wastewater) to be useful and focus on identifying alternative sources of water to potable water (Waidyasekara, De Silva and Rameezdeen 2017). They encourage the application of water conservation measures like reuse and recycling of wastewater to reduce potable water demand (Chanan et al. 2003; Joustra and Yeh 2015; Waidyasekara, De Silva and Rameezdeen 2017). The 6R (review, replace, reduce, reuse, recycle, remove) water hierarchy developed by Waylen, Thornback and Garrett (2011) is an example of a SWM practice that can be applied on construction sites to manage and conserve water. By following the six stages, potable water consumption on a construction site can be reduced while the consumption of other alternative sources (like rainwater and greywater) can be increased.

India is the seventh largest and second most populous country in the world (India Water Resource Information System 2021). It covers 2.4% of the total world area, houses 17% of the world population and consists of 4% of the world's water resources (India Water Resource Information System 2021). With its continuously growing population, the demand and consumption of water in the country has also been on the rise. India is now classified as a "water stressed" country that is responsible for 25% global water extraction (Press Information Bureau 2024; Sharma and Chani 2022). This situation is further worsened by the fact that 54% of the country faces high to extremely high levels of water stress and 200,000 people are dying each year due to inadequate access to safe water (World Resources Institute 2015; National Institution for Transforming India Ayog 2019). Figure 1.2 shows the baseline water stress in India in 2010, and Figure 1.3 shows the projected water stress in the country in 2030. The changing trend in both graphs clearly highlights how water stress in the country is increasing. As of 2010, majority of the Northwestern parts of the country were facing severe water stress conditions. This is expected to expand to all other areas of the country by 2030.

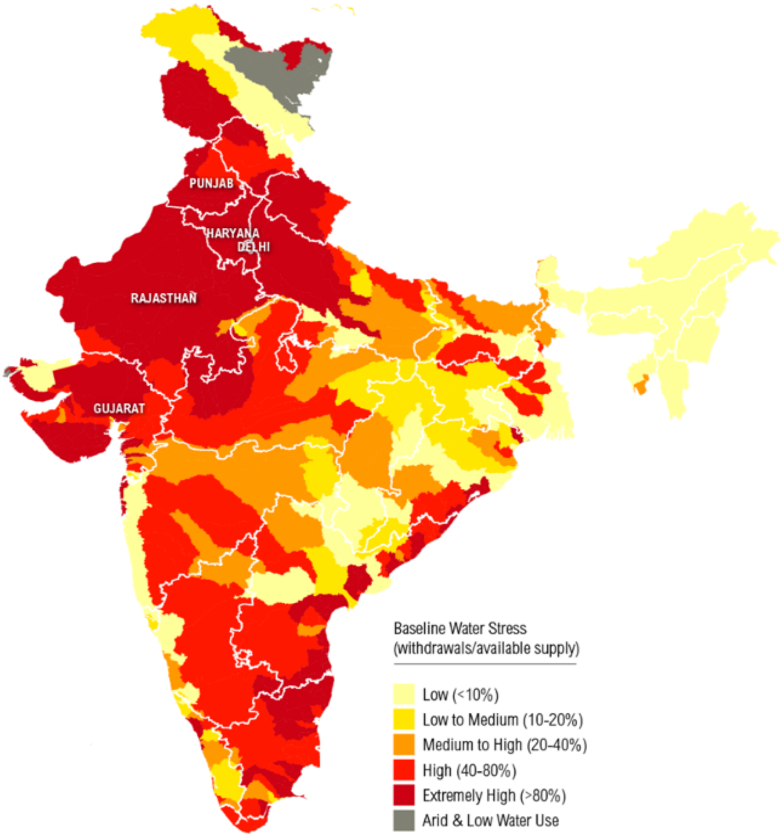

Figure 1.2: Baseline Water Stress in India in 2010 (Source: World Resources Institute 2015)

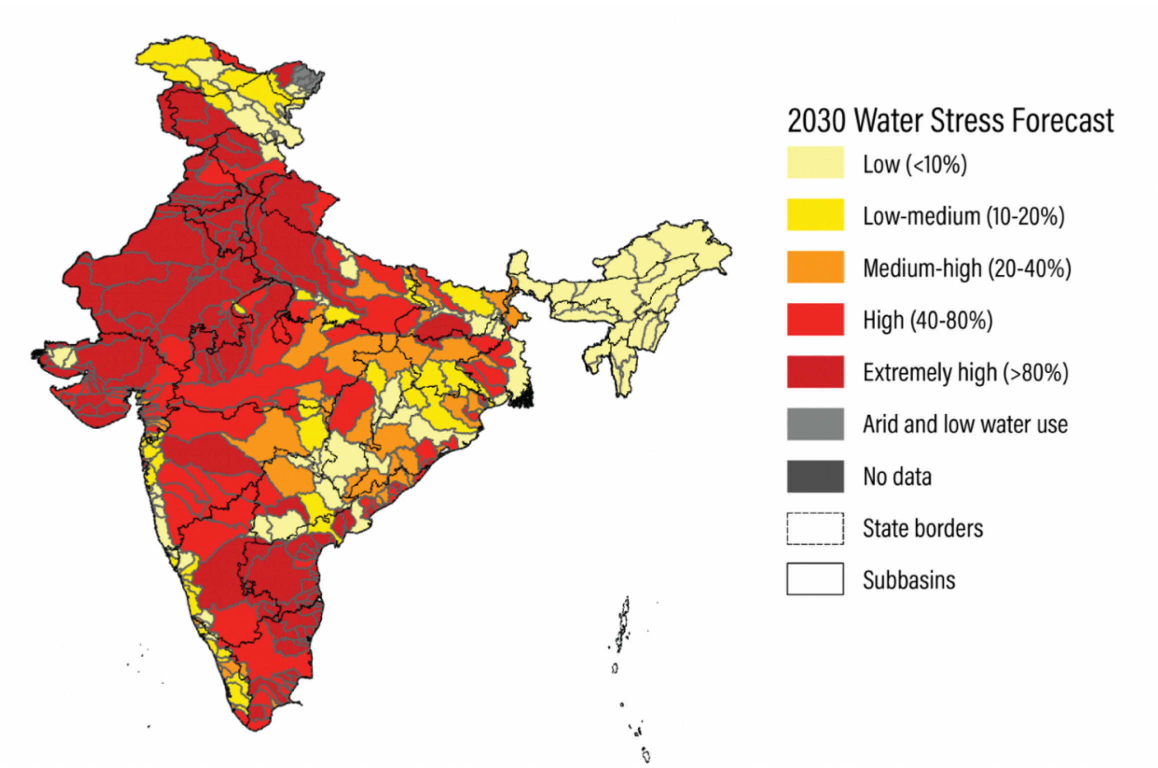

Figure 1.3: 2030 Water Stress Forecast in India (Source: World Resources Institute 2021)

The increasing population and water demand have also resulted in an imbalance between the water supply and water demand in the country. In 2008, the water supply and demand in the country were balanced with the water supply being 650 billion cubic meter and water demand being 634 billion cubic meter (National Institution for Transforming India Ayog 2019). However, by 2030, this demand and supply is expected to become unbalanced as the demand for water is projected to increase to 1,498 billion cubic meter while the water supply will remain at 744 billion cubic meter (National Institution for Transforming India Ayog 2019). This 101% increase in the water demand will contribute to the water stress in the country as noted in Figure 1.3. The growing water supply and demand imbalance has resulted in various episodes of water scarcity in the country over the last decade such as the ban on construction activities in few states (such as in Pune in 2014) and the declaration of "day zero" in a state to mark the absolute absence of water in that region (such as in Chennai in 2019). The growing water scarcity in India can further be observed in the visual increment in desertification in many regions of the country (Sharma and Chani 2022).

Half of the population of India relies on groundwater for its water demands. As a result, it is the largest consumer of groundwater in the world with an estimated consumption of 251 billion cubic meter per year which is more than quarter of the global groundwater consumption (The Energy and Resources Institute 2022). The huge imbalance between the water supply and water demand is also projected to impact the groundwater levels of the country. Groundwater levels for 54% of the country's wells have been declining (World Resource Institutes 2015). Figure 1.4 shows how most of the wells in the Northwestern part of the country have an extremely low groundwater level, while the levels range from medium to medium-to-high levels for other parts of the country. With the increasing imbalance between water supply and demand, these groundwater levels are going to continue to decline.

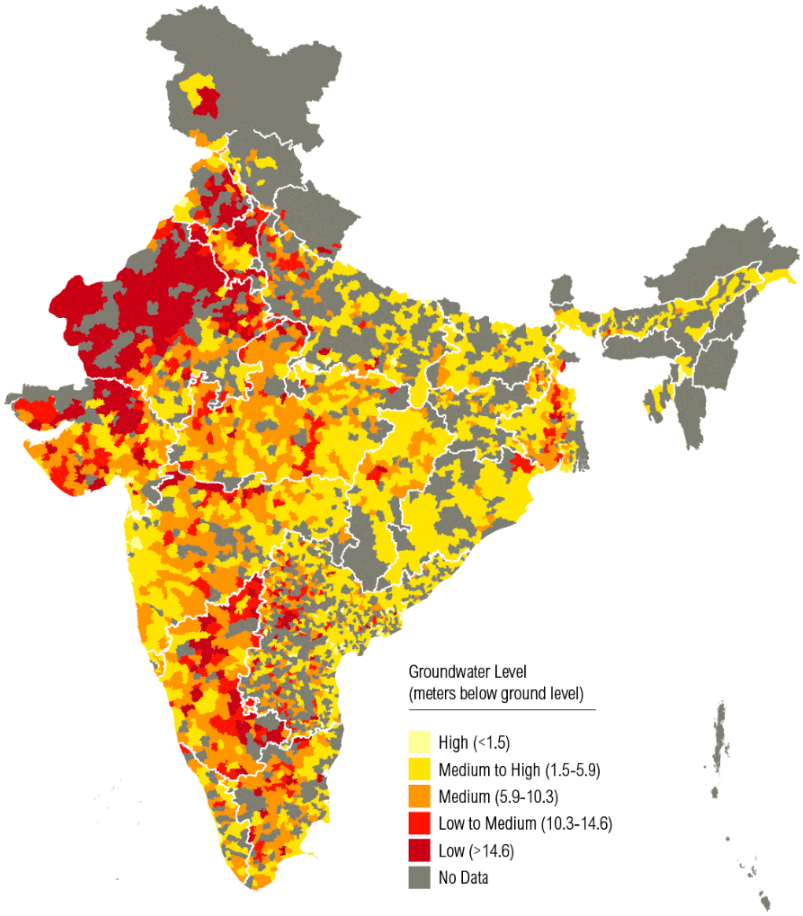

Figure 1.4: Groundwater Level in India in 2010 (Source: World Resources Institute 2015)

Besides suffering from declining water quantities, India is also suffering from declining water quality. According to World Resources Institute (2015), more than 100 million people of the country live in areas of poor water quality. Figure 1.5 shows the declining groundwater quality in the country. India is currently ranked at 120 out of 122 in the water quality index (National Institution for Transforming India Ayog 2019).

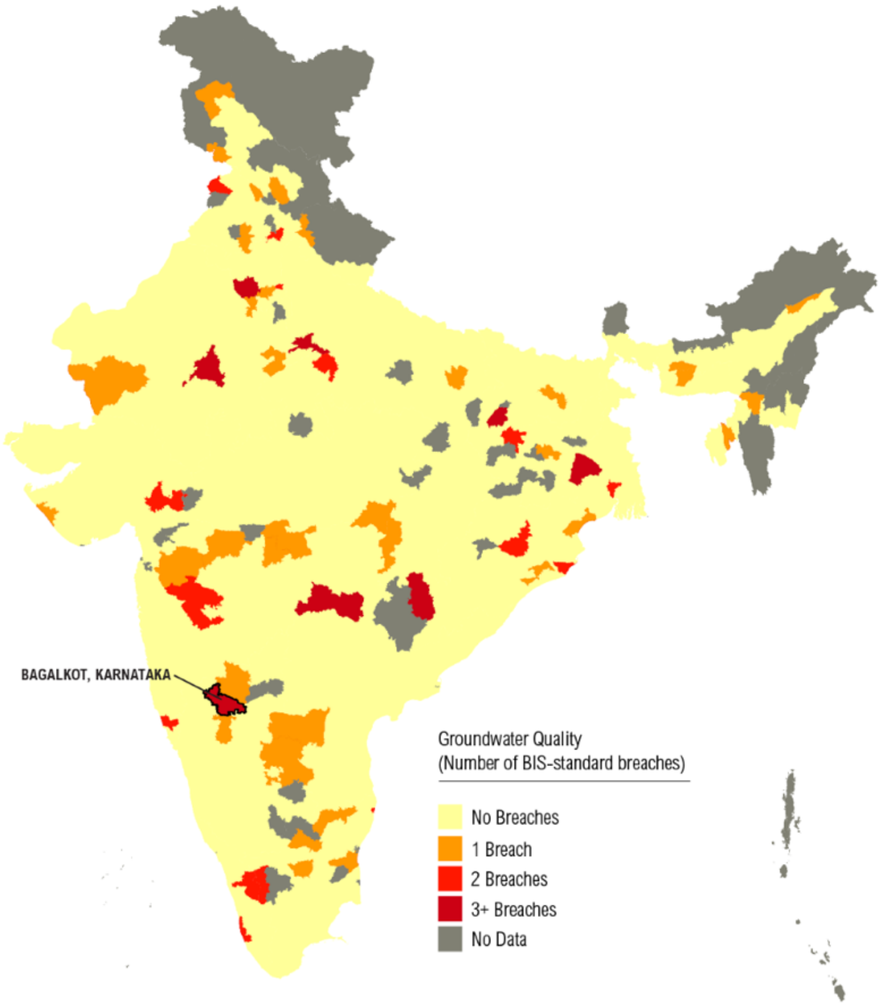

Figure 1.5: Groundwater Quality in India in 2010 (Source: World Resources Institute 2015)

Despite the water scarcity in India as discussed above, the country is currently under an urban boom. Its urban population increased from 27.8% of the total population in 2001 to 35.4% of the total population in 2021 (World Bank Group 2024a). If the current trend of population increase in the country continues, by 2050, India will be the most populous country housing 1.70 billion people with more than 50% of this population residing in urban areas (Bureau of Indian Standards (BIS) 2016a). Moreover, by 2050, the built-up area will be four times that of the current area signifying the huge increase in construction activities (BIS 2016b). This increase in construction activities coupled with the increasing water scarcity in India, signify the urgent need to implement SWM practices during their construction and the manufacturing of the materials used in the construction of these buildings. Knowledge regarding the EWC of construction materials and construction activities can serve as benchmarks for optimum water consumption for SWM. Moreover, the knowledge of the trade-off between EC and EW will ensure the selection of materials and activities with the lowest negative environmental impact.

1.4 Aims and Objectives

The aim of this research is to develop a national framework for efficient water management practices that focuses on maximising water efficiency and minimizing water consumption in the residential building construction sector to promote sustainable building construction in India.

To achieve the research aim, the following objectives are set up:

1) To identify water management policies and practices adopted on construction sites and material manufacturing plants worldwide and in India.
2) To identify the commonly used construction materials and construction activities undertaken for residential building construction in India.
3) To calculate the EW (DEW & IEW) of residential construction projects in India.
4) To investigate the relationship between EW and EC of the selected construction materials.
5) To investigate the adoption level of water metering on construction sites in India.
6) To analyse how to improve the efficiency of water management practices followed on building construction sites and construction material manufacturing process in India.
7) To develop and validate a framework for efficient water management practices that focuses on maximising water efficiency and minimizing water consumption in the residential building construction sector in India.

1.5 Research Questions

Objective 1: To identify water management policies and practices adopted on construction sites and material manufacturing plants worldwide and in India.

1) What are the water management practices that focus on EW management?
2) What are the existing government regulations related to EW management in India?
3) How efficient are these regulations and policies for EW management?

Objective 2: To identify the commonly used construction materials and construction activities undertaken for residential building construction in India.

1) What are the most common materials used for the construction of residential buildings in India?
2) What is the proportion of each material in the total building material stock?
3) What are the most common construction activities undertaken during residential building construction in India?

Objective 3: To calculate the EW (DEW & IEW) of residential construction projects in India.

1) How much water is consumed (kL) per unit (m^3, m^2) to carry out different construction activities?
2) What is the percentage contribution of each activity in the DEW of the building?
3) How much water is consumed (kL) to produce a unit (ton, m^3) of the most commonly used construction materials?
4) What is the percentage contribution of each material in the IEW of the building?
5) How does the quantity of a material and its EWC impact its contribution to the IEW of the buildings?

Objective 4: To investigate the relationship between EW and EC of the selected construction materials.

1) How are (if) EW and EC related?
2) What materials have a high embodied carbon coefficient (ECC) and are they the same as materials that have a high EWC?
3) How to trade-off when they are incompatible?

Objective 5: To investigate the adoption level of water metering on construction sites in India.

1) How often is water metered on construction sites in India?
2) What motivates construction professionals to meter (or not meter) their water consumption?

Objective 6: To analyse how to improve the efficiency of water management practices followed on building construction sites and construction material manufacturing process in India.

1) What water management practices are followed during residential building construction and construction material manufacturing?
2) What external factors impact water consumption patterns on construction sites and during material manufacturing?

Objective 7: To develop and validate a framework for efficient water management practices that focuses on maximising water efficiency and minimizing water consumption in the residential building construction sector in India.

1) How can the entire process of building construction and construction material manufacturing be made more sustainable by encouraging maximum water recycling and minimum water consumption?
2) How can the challenges that limit the adoption of water management practices be addressed?

1.6 Research Significance

The construction materials used, and construction techniques employed greatly affect the WF of a building and specific attention must be paid to their selection to ensure minimal water uptake by the building (Bardhan and Choudhuri 2016; Abd El-Hameed et al. 2017). Moreover, the growing concerns related to water scarcity and their huge contribution to the total building WF as aforementioned, highlight the need for more EW management studies (McCormack et al. 2007; Bardhan 2011; Stephan and Crawford 2014; Choudhuri and Roy 2015; Bardhan and Choudhuri 2016; Heravi and Abdolvand 2019; Dixit, Kumar and Haghighi 2022).

Data regarding all the direct and indirect sources of water consumption during the building construction and manufacturing of construction materials helps identify the most significant areas of water consumption and probable areas for water conservation (Crawford and Treloar 2005; Stephan and Crawford 2014; Mannan and Al-Ghamdi 2020). This data also helps make informed decisions regarding the choice of materials and activities with respect to their impact on water consumption. These choices significantly impact the building's performance and its environmental impacts during the entire building lifecycle (Ding 2014). Thus, these decisions must be carefully decided early during the conceptual stages of the project to ensure water is not exploited (Aboulnaga 2013; BIS 2016; Abd El-Hameed et al. 2017).

Though India is suffering from severe water stress, major water consuming activities like construction activities are on the rise in the country. Managing the water consumed during these construction activities can help conserve large quantities of water. This conserved water has the potential to be utilized for other activities in the country. EW studies can help manage water consumption and play an essential role to solve the water stress crisis of the country. Moreover, by ensuring sustainable consumption of water and water use efficiency in the construction sector of the country, India can make advances in accomplishing the goals of SDG 6 and SDG 12.

It is essential to keep up with the increased construction demand by increasing the speed of construction while also following sustainability principles (BIS 2016a). The goal is that construction activities must be in harmony with the environment during their planning, design, construction, operation, maintenance, and demolition stages (BIS 2016a). Proper planning before and during construction is extremely essential to create a sustainable, healthy, and safe built environment (BIS 2016a). However, the lack of knowledge and motivation among people to conserve water is a major barrier in ensuring that these construction activities are in harmony with the environment and that sustainability is considered throughout the entire lifecycle of buildings.

1.7 Scope and Boundary of Study

As per the United Nations Population Fund (2007), the building construction industry in India is expected to grow at a rate of 6.6% per year between 2005 and 2030 (Arukala et al. 2020) and it is projected that by 2050 the constructed floor space will be four times the current constructed floor space (BIS 2016b). Moreover, the Global Buildings Performance Network (2014) states that by 2030, 75% of the constructed Indian floor space will belong to residential buildings. Census India (2011) reports that reinforced concrete (RC) frame buildings with clay masonry walls is the most common type of residential building construction in India constituting 45% of the residential building stock. Therefore, this study focuses on this typology of residential buildings constructed in India. Other common materials for walls in RC frame residential buildings are stone and concrete that make up 15% and 8% of the construction in India respectively (Census India 2011).

India is a large country with different climatic conditions and water availabilities in different regions. For a robust comparison, residential buildings constructed in two regions of India (Delhi and Jaipur) with similar climatic conditions (hot-humid) and suffering from similar issues of water scarcity are selected. Moreover, these residential buildings are only analysed based on the construction materials used for the construction of the building superstructure and substructure.

A recent study by Dixit and Kumar (2022) reported a third component of EW known as the implied EW which refers to the water required for producing the energy that will be used during material manufacturing and building construction. This study does not include the implied EW and only considers the DEW and IEW. Moreover, majority of the past studies like McCormack et al. (2007), Meng et al. (2014) and Dixit, Kumar and Haghighi (2022) to name a few, that calculated the EW of buildings adopted an input-output based hybrid LCA approach. Two types of data are essential to adopt this methodology. These are process data related to amount of water consumed in the manufacturing process and input-output data related to the water flows within the economy of the country. There is a lack of input-output water flows table in Indian context, and creation of these input-output water flows table is outside the scope of this study. As a result, this study adopts a process LCA approach for EW calculations as was adopted by Heravi and Abdolvand (2019).

1.8 Thesis Layout

This thesis is divided into eight chapters followed by seven appendices.

Chapter 1 is the introduction to the research discussing the background of the research, research gap, the research problem statement, research aim and objectives and the research questions that formulated the basis of this study. This chapter also discusses the research significance, scope and boundary of the study.

Chapter 2 highlights the relevant literature related to this study. This chapter starts by introducing the need for water management in the Indian construction sector. This chapter also summarizes current government regulations and policies in India aimed at SWM during building construction and material manufacturing. It also discusses the different LCA approaches for EW calculation. Water consumption during the entire building life cycle is defined with special emphasis on DEW and IEW. Commonly used construction materials and construction activities are further defined, with focus on their water consumption. This chapter introduces the EE and EC concept with focus on EW. It also discusses two practices for EW management (three principles of sustainability for SWM and 6R water hierarchy).

Chapter 3 presents a review of existing frameworks related to water management in different sectors. It discusses each framework individually before comparing their similarities to assist in the development of the conceptual framework.

Chapter 4 discusses the drivers and challenges for EW management in India. It also highlights the key learnings from the different water management frameworks reviewed in Chapter 3 and their integration into the developed conceptual framework for EW management in India.

Chapter 5 discusses the research methodology developed for this study using the "research onion" model. It outlines the research philosophy, research approach, methodological choice, research strategy and time horizon for analysis. It also discusses the sample size selection, quantitative and qualitative data collection and analysis, and the ethical considerations of this study. This chapter concludes with a consideration of the limitations of the research design.

Chapter 6 summarises the data that was collected. It discusses the stage 1, 3 and 5 of the sequential explanatory multiphase mixed method research design of this study.

Chapter 7 analyses the collected data from Chapter 6. It discusses stage 2, 4 and 6 of the sequential explanatory multiphase mixed method research design of this study. It concludes by developing the proposed framework of EW management in India in stage 7 of the sequential explanatory multiphase mixed method research design.

Chapter 8 concludes the research by discussing the study aim and objectives. It further answers all the research questions developed in Chapter 1. It discusses the contribution of this study to practice and theory, highlights the study limitations and suggests recommendations for future studies based on the findings and limitations of this study.

Appendix A provides a glossary of the common terms used in this study.

Appendix B shows the detailed quantitative calculations of the two case study buildings.

Appendix C shows the anonymity letter issued to the questionnaire respondents.

Appendix D shows the confidentiality letter issued to the semi-structured interviewees.

Appendix E shows the summary of the semi-structured interview transcripts.

Appendix F shows the bill of quantities (BOQ) of the two case study buildings that was collected for analysis.

Appendix G shows the site water consumption records of case study 2 that was collected for analysis.

1.9 Chapter Summary

The concept of EW, its contribution to the total building WF, and the importance of EW studies to achieve SDG 6 and SDG 12 were introduced in this chapter. Furthermore, the three main research gaps identified were also discussed. These include the lack of EWC database of construction materials and construction activities, and the lack of integrated EC and EW studies in Indian context. The water intensive nature of the building construction industry highlights the need for SWM in this industry. The need for SWM in India was introduced by highlighting the increasing water stress, declining groundwater levels and decreasing water quality in the country, along with the rapidly growing residential building sector. The research objectives and the corresponding research questions that were developed to accomplish the research aim were also presented in this chapter. This chapter finally concluded by defining the research significance of this study and highlighting its scope and boundary.

Chapter 2 : Literature Review

This chapter presents a comprehensive review of the relevant literature related to the study topic. It starts by establishing the need for SWM practices in India followed by a review of the current regulations related to water management in the country (Section 2.2) and water management policies in general (Section 2.11 and Section 2.12) which are essential for accomplishing objective 1. Following this, the concept of EW is reviewed along with the various methodologies for its calculation to accomplish objective 3. This chapter also presents a discussion on the major construction materials and activities undertaken for residential building construction in India as a part of accomplishing objective 2. The concept of EC and EE with relation to EW is further defined for accomplishing objective 4.

2.1 Study Area: India

India is the seventh largest and second most populous country in the world (India Water Resource Information System 2021). It covers 2.4% of the total world area, houses 17% of the world population and consists of 4% of the world's water resources (India Water Resource Information System 2021). As per international standards, a country is classified as "water-stressed" when its per capita water availability is less than 1,700m^3, and "water scarce" when this value is below 1,000m^3 (Rathee and Mishra 2021; Press Information Bureau 2024). India is classified as a "water stressed" country since its per capita water availability in 2021 was 1,486 m^3 (Press Information Bureau 2024). This value is expected to decrease to 1,191 m^3 by 2050 (Rathee and Mishra 2021).

There have been many episodes of water scarcity in the country over the last decade which have led to negative consequences like the ban of construction activities in some states (such as in Pune in 2014), and the declaration of "day zero" in a state to mark the absolute absence of water in that region (such as in Chennai in 2019). Moreover, water scarcity has also hampered many industries (including the construction industry) in south India. These water scarcity episodes are a result of various factors such as (Manikandan and Ramappa 2012; Ministry of Water Resources 2013):

1) Poor management of water resources
2) Inadequate infrastructure for water storage
3) Less-efficient water usage
4) Regular droughts and floods
5) Increasing population
6) Decreasing per capita water availability
7) Lack of knowledge among people surrounding the urgency to manage water
8) Low economic value placed on water
9) Increased water wastage

2.2 Water Policies in India

The lack of knowledge among people regarding the importance of conserving water and the low economic value placed on it are responsible for the lack of initiatives and frameworks related to water management in India (Ministry of Water Resources 2012). At present, there are two policies related to water management to ensure efficient water use and minimal water wastage while ensuring adequate availability of water to all. These are the Draft National Water Framework Bill 2016 and National Water Mission 2008. These documents outline policies for industrial water management that include the construction industry and construction material manufacturing industries. However, due to weak governance and planning, these regulations and policies are failing to conserve water resources in India (Bharat and Dkhar 2018). Section 2.2.1 and Section 2.2.2 discuss these policies in detail.

2.2.1 Draft National Water Framework Bill 2016

In 1983, the government of India set up the National Water Resources Council with the aim of having an organization that prepares national water plans for the optimum utilization of water resources in the country based on national, regional, and local requirements (Ministry of Water Resources 2013). The National Water Resources Council aims to create a National Water Policy for India and review it from time to time (Ministry of Water Resources 2013). The National Water Policy identifies the need to manage and conserve water by specifying policies and concepts to ensure its adequate availability to all (Ministry of Water Resources 2013; Rathee and Mishra 2021). The first National Water Policy was released in 1987, followed by a revision in 2002, and finally in 2012 (Ministry of Water Resources 2013; Rathee and Mishra 2021). These National Water Policies do not have any legal status and do not lay out mandatory regulations to be adopted, thereby resulting in inefficient water consumption in the country (Ministry of Water Resources 2013; TERI 2018). To overcome this limitation, the National Water Policy 2012 identified the need to create National Water Framework Laws to set up essential guidelines and regulations that provide authority to all concerned governing bodies for water governance in India (Ministry of Water Resources 2012; Ministry of Water Resources 2013). The result was the creation of the Draft National Water Framework Bill 2013 which was updated to the Draft National Water Framework Bill 2016 (Ministry of Water Resources 2016; TERI 2018).

This bill highlights the following principles for protecting, conserving, and regulating water resources in India (Ministry of Water Resources 2013; Ministry of Water Resources 2016):

1) Water efficient systems must be adopted where possible to reduce water consumption and water wastage.
2) The impacts of climate change on local water availability need to be considered when making decisions regarding conducting water consumption activities in an area.
3) A national standard for SWM of different activities and products must be developed, and everyone involved in these activities and product manufacturing must constantly aim at reducing their WF.
4) Local governments must set up binding water quality standards for each activity, and the recycling and reuse of water must be promoted to reduce freshwater consumption.
5) Providing incentives and reducing taxes can help promote efficient water management practices in industries. Moreover, penalties must be applied to industries that do not follow appropriate water conservation measures and cause water wastage.

6) Water consuming industries must not be located in water-stressed and drought prone areas. For industries located in water-stressed areas, they are allowed to withdraw a portion of their makeup water, but they must return their treated effluent to the hydrologic system.
7) Large industries that consume over one million cubic meter of water per year must file an annual water returns document specifying the amount of water consumed to manufacture a unit of their produce, effluent discharge details, amount of water reused and recycled, amount of rainwater harvested, and amount of freshwater consumed. They must also highlight plans to reduce their water footprint and identify the progress that has been made in reducing the same.
8) To ensure urban water management, all industries must prepare a water budget and water security plan that highlights the amount of water required for their operations, the sources of water being used, and water efficiency measures adopted.

Though this bill is a step forward towards efficient water management in India, its practical application to accomplish it is not very clear. For instance, the bill specifies the need to reduce water consumption through the adoption of water efficient systems and benchmarks but fails to regulate the amount of reduction that should be achieved. These benchmarking values are of extreme importance as they motivate people towards accomplishment (please see chapter 5 for further information on this).

2.2.2 National Water Mission 2008

In 2008, the Ministry of Environment, Forest and Climate Change released the National Action Plan on Climate Change that highlighted eight core missions that need to be accomplished to tackle the issues of climate change (Press Information Bureau 2021). One of the missions of the National Action Plan was the National Water Mission (Press Information Bureau 2021). The National Water Mission aims to conserve water, minimize waste, and ensure equitable distribution of water for different sectors of the country (TERI 2018; Press Information Bureau 2021). It aims at planning the economic activities of the country by carefully considering the local availability of water (Bardhan 2011).

The National Water Mission aims to increase water use efficiency in India by 20% (Ministry of Water Resources 2008; Bardhan 2011). It highlights that by following the below principles, water consumption can be reduced (Ministry of Water Resources 2008):

1) Given the challenges surrounding industrial wastewater recycling, incentives must be provided to encourage the reuse and recycling of industrial wastewater. These incentives can be in the form of tax rebates, concessions on import duty of equipment's and machinery used in collecting, treating, and storing this wastewater.
2) To reduce the consumption of freshwater, tariff rates on water must be kept fixed so that industries are forced to identify opportunities for reducing their freshwater consumption by exploring possibilities of water reuse, recycling, or integration of water efficient processes. Moreover, industries must be encouraged to meet 50% of their freshwater requirements with treated wastewater.
3) Water audits for industries must be encouraged and benchmarks for water consumption based on national and international standards must be laid out to force industries to reduce their water consumption.
4) Metering of water can help in efficient water use by identifying all the areas of water consumption and the amount of water consumed. This will help motivate concerned personnel to make decisions regarding reducing these water consumption values.

As compared to the Draft National Water Framework Bill 2016, this framework specifies the benchmarks for water reduction thereby ensuring more successful adaptation. Moreover, this framework requires companies to monitor their water consumption through the installation of water meters, and these are only installed at the water withdrawal site (please see Chapter 5 for further information on this). This framework fails to regulate that water meters are installed at all consumption points to ensure real-time monitoring for more efficient decision making.

When compared to other countries like Dubai that are facing similar water scarcity issues, it can be seen that the government of Dubai has also launched various policies like the United Arab Emirates Vision 2021, The Environment Mission 2030 and The Energy Efficiency and Renewable Strategy 2040 for water management (Saradara et al. 2023). These policies focus on increasing water efficiency and reducing water wastage (Saradara et al. 2023). Moreover, similar to the National Water Mission 2008 in India that specifies increasing water efficiency by 20% in the country, The Energy Efficiency and Renewable Strategy 2040 in Dubai also specifies benchmarks such as reducing water consumption by 20% and increasing reuse by reusing 95% of the treated sewage effluent of the country.

2.3 Life Cycle of Buildings

The National Building Code (NBC) of India by BIS (2016a) defines buildings as "any structure for whatsoever purpose and of whatsoever materials constructed and every part thereof whether used as human habitation or not and includes foundation, plinth, walls, floors, roofs, chimneys, plumbing and building services, fixed platforms, verandah, balcony, cornice or projection, part of the building or anything affixed thereto or any wall enclosing or intended to enclose any land or space and signs and outdoor display structures". It further states that, depending on the intended use of the building, it can be classified into residential or commercial. Residential buildings include those where people live and there are provisions for sleeping such as hotels, hostels, houses, etc. Commercial buildings on the other hand include buildings intended for other activities besides living like education, business, etc. The Domestic Building Standards Technical Handbook by Scottish Government (2019) defines buildings as any permanent or temporary structure that has been erected. While the BIS (2016a) provides a more detailed definition of a building by also specifying its components, and since this study focuses on residential buildings, the following definition can be quoted "a built structure irrespective of its height and materials of construction, as long as it provides sleeping and cooking services for its residents, is called a residential building".

The Building Research Establishment (BRE) (2018) outlines the lifecycle stages of a building as shown in Figure 2.1. This thesis follows the modules of construction, and the stages as specified in this standard. The lifecycle of the building can be divided into four broad stages namely product stage, construction stage, use stage, and end-of-life stage. The product stage includes the extraction of raw materials (A1), their transportation to the material manufacturing site (A2), and the manufacturing of raw materials into final building materials (A3). The construction stage includes the transportation of construction materials to the construction site (A4) and the actual construction process (A5). The use stage of the building includes the use of the building materials (B1), their maintenance (B2), repair (B3), replacement (B4), and refurbishment (B5), and the operational use energy (B6) and water (B7). Finally, the end-of-life stage of the building includes demolition of the building (C1), transportation of the demolished building elements to the waste processing site (C2), processing of the demolished elements (C3), and finally the disposal of demolished elements (C4).

Life Cycle Stage	Product			Construction		Use							End-of-Life			
						Building Fabric					Building Operation					
Module	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4
Stage	Extraction of Raw Materials	Transportation of Raw Materials	Manufacturing of Building Materials	Transportation of Building Materials	Building Construction	Use of Materials	Maintenance of Materials	Repair of Materials	Replacement of Materials	Refurbishment of Materials	Operational Energy Use	Operational Water Use	Demolition of Building	Transportation of Wastes	Wastes Processing	Disposal of Wastes

Figure 2.1: Lifecycle stages of a building (Source: BRE 2018)

Water is a very important resource that is used at all stages of the building lifecycle (Bardhan 2011; Bardhan and Choudhuri 2016; Heravi and Adbolvand 2019; Rahman et al. 2019; Mannan and Al-Ghamdi 2020; Sharma and Chani 2022). United Nations Environment Programme (2006) reports that buildings during their entire lifecycle (module A1-C4) consume 30% of global freshwater while generating 30% of wastewater (Bardhan 2011; Meng et al. 2014; Sharma and Chani 2022). Moreover, the construction of buildings (module A1-A5) consumes

16% of global freshwater (Dixit, Kumar and Haghighi 2022). Part of this water remains embedded in the built structure by being incorporated into the building elements while part of it gets converted to wastewater as a result of the different manufacturing and construction activities. This water that remains embedded and that is converted to wastewater, comprises the “EW” of the building and is analysed in this study.

2.4 Buildings and Embodied Water

Allan (1993) first introduced the concept of EW, also known as virtual water, to determine the amount of water needed to manufacture agricultural products (Meng et al. 2014; Bardhan and Choudhuri 2016; Dixit, Kumar and Haghighi 2022; Sharma and Chani 2022). However, with the building industry being a huge consumer of water and the continuous increase in building construction activities, the amount of water needed to construct these structures gained significant attention and the concept of EW of buildings was introduced (Treloar and Crawford 2004; Bardhan and Choudhuri 2016; Sharma and Chani 2022). The EW of a building comprises of two components namely the DEW and the IEW (Crawford and Treloar 2005; Dixit, Kumar and Haghighi 2022) as shown in Figure 1.1. The DEW is the amount of water needed to construct the building on the construction site (module A5) and the IEW is the amount of water needed to manufacture all the construction materials used in the building (module A1-A4) (Crawford and Treloar 2005; Crawford 2011; Bardhan and Choudhuri 2016; Heravi and Abdolvand 2019; Rahman et al. 2019; Dixit, Kumar and Haghighi 2022). Figure 2.2 shows the water consumed at each stage of the building lifecycle.

Life Cycle Stage	Product			Construction		Use							End-of-Life			
						Building Fabric					Building Operation					
Module	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4
Stage	Extraction of Raw Materials	Transportation of Raw Materials	Manufacturing of Building Materials	Transportation of Building Materials	Building Construction	Use of Materials	Maintenance of Materials	Repair of Materials	Replacement of Materials	Refurbishment of Materials	Operational Energy Use	Operational Water Use	Demolition of Building	Transportation of Wastes	Wastes Processing	Disposal of Wastes
Water Consumption	Indirect Embodied Water			Direct Embodied Water		Operational Water							Demolition Water			

Figure 2.2: Lifecycle stages of a building with water consumption (Source: Author)

2.4.1 Indirect Embodied Water

IEW of a building is the amount of water needed to manufacture all the materials used in the construction of that building throughout their supply chain (module A1-A4) (Crawford and Treloar 2005; Bardhan 2015a; Crawford 2022). Water can be used as an input raw material for the manufacturing of a product (such as cement, bricks and tiles) or for ancillary activities like cooling of the equipment's and cleaning purposes (Choudhuri 2015; Rahman et al. 2019). Besides this, water is also consumed by workers working along the entire material supply chain for various purposes like sanitation and cleaning activities.

The amount of water needed to manufacture a material is expressed in kilolitres (kL) per unit of production of that material (m^2, m^3, ton) and is known as the EWC of that material (Bardhan 2015a). The EW of a material "M" is the EWC of that material (EWC_M) multiplied by its quantity (Q_M) (Bardhan 2015a). The IEW of the building is thus the sum of the EW of all materials, as shown in Equation 1 (Bardhan 2015a).

$$IEW = \sum EW_M = \sum EWC_M \ x \ Q_M \quad \text{(Equation 1)}$$

Bardhan (2011) calculated the IEW of buildings made of cement, steel and bricks, and noted that steel has the highest contribution in the IEW with a value of 97% of the IEW. Modern buildings have a very high WF because the materials used in the construction of these buildings, such as steel, are very water intensive as they require large volumes of water for their manufacturing (Rahman et al. 2019). It is extremely essential for material manufacturing industries to become more conscious about their water consumption patterns and make significant changes to their process to reduce their water consumption and the EWC of the manufactured material (Bardhan 2011).

The choice of the construction materials used, and their quantities greatly impact the WF of the building, and decisions regarding their selection must be taken very judiciously and carefully considering all the sustainability aspects and government initiatives to reduce resource consumption (Bardhan 2011). Using materials that have a low EWC will help reduce the IEW of the building (Choudhuri and Roy 2015). It is essential to identify all the water consuming activities in the material manufacturing process and to determine the possibilities of using water more efficiently (Choudhuri and Roy 2015).

2.4.2 Direct Embodied Water

DEW of a building is the amount of water consumed on the construction site for the actual construction of the building (module A5) (Crawford and Treloar 2005; Bardhan 2015b). Water is used on sites for various construction activities like soil compaction; aggregate washing; preparing concrete, mortar and plaster; and curing concrete, mortar and plaster (Choudhuri 2015; Rahman et al. 2019; Crawford 2022). Besides these, water is also used for ancillary activities like dust suppression, site cleaning and washing equipment’s. (Choudhuri 2015; Rahman et al. 2019; Crawford 2022). Lastly, water is also consumed by the workers working on the construction site for sanitation and housing purposes (Choudhuri 2015; Rahman et al. 2019; Crawford 2022).

The DEW depends on various factors like construction technique employed, local water availability, scale of the construction project, water management practices followed on the construction site, and working style of the construction team (Bardhan 2015b; Rahman et al. 2019). The amount of water needed to carry out an activity is expressed in kL per unit of execution of that activity (m^3,m^2) and is known as the EWC of that activity. The EW of an activity "A" is the EWC of that activity (EWC_A) multiplied by its quantity (Q_A). The DEW of the building is thus the sum of the EW of all the activities, as shown in Equation 2.

$$DEW = \sum EW_A = \sum EWC_A \; x \; Q_A \quad \text{(Equation 2)}$$

Choudhuri (2015) and Heravi and Abdolvand (2019) found that DEW makes up 10% to 20% of the EW. Though the DEW makes up a small portion of the EW of a building (Treloar et al. 2004; McCormack et al. 2007; Choudhuri and Roy 2015), it requires adequate attention to reduce its value, and the application of SWM practices can help reduce this consumption (Choudhuri and Roy 2015).

2.4.3 Embodied Water

The EW of a building is the sum of its IEW and DEW as shown in Equation 3 (Bardhan 2015b). In simpler terms, it is the amount of water invested in a building before it enters its operational stage (Bardhan 2015b). Choudhuri (2015) highlights that when comparing the EW of a building with its operational water, the former is 31.65% of the latter for a building in operation for 50 years. This highlights the huge significance EW has on the total WF of a building (Meng et al. 2014).

$$EW = IEW + DEW \quad \text{(Equation 3)}$$

The EW of a building depends on the materials used and the construction technique employed for the construction of that building (Bardhan 2011). For instance, an RC building will have high DEW when compared to a steel and glass building that would have high IEW (Bardhan 2011). Thus, materials must be selected based on careful considerations of their impacts on the DEW and IEW of the building. Knowledge of the EW of a building can help identify all the water consuming activities and their corresponding water consumption values, to make informed decisions regarding identifying possibilities of water conservation. Without this information, SWM is not possible and the misuse of water during construction activities and material manufacturing processes will continue (Bardhan 2011). This information will also help identify better water management practices to achieve the objectives of the National Water Mission 2008 and the Draft National Water Framework Bill 2016.

2.5 Life Cycle Assessment

An LCA analysis of a product (good, commodity or building) identifies all the resources consumed and wastes produced throughout the product's lifecycle or at certain stages of its lifecycle, thereby analysing its environmental impacts (Bardhan 2011; Crawford, Stephan and Prideaux 2022). This helps assist decision makers to identify opportunities for improving the environmental performance of that product (International Organization for Standardization (ISO) 14040 2006). LCA studies have been widely used to determine the EW of different construction products as shown in studies conducted by Treloar et al. (2004), Crawford (2011), Crawford, Stephan and Prideaux (2019), and Heravi and Abdolvand (2019) to name a few. While the former three followed a hybrid LCA approach, the latter followed a process LCA approach. The process and hybrid LCA approach are discussed in detail below. When determining the EW of a product, the amount of water consumed throughout the product's lifecycle and its associated impacts are determined.

ISO in an international body that specifies national standards for conducting various activities. ISO 14040 (2006) (Environmental management- life cycle assessment- principles and framework) and ISO 14044 (2006) (Environmental management- life cycle assessment- requirements and regulation) are the two standards that specify the guidelines for conducting an LCA. They further state that the guidelines in these standards can be modified to comply with other applications based on its intended use. This has resulted in the formulation of ISO 14046 (2014) (Environmental management- water footprint- principles, requirements and guidelines) which lists the methodologies for conducting a water footprint. The methodology it follows is the same as ISO 14040 (2006) and ISO

14044 (2006), but it differs by focusing exclusively on determining water related environmental impacts.

Table 2.1 summarises the differences between LCA studies as defined by ISO 14040 (2006) and ISO 14044 (2006), and WF assessment studies as defined by ISO 14046 (2014).

Table 2.1: Differences between life cycle assessment studies based on different standards (Source: Author)

Parameter	ISO 14040 (2006)/ ISO 14044 (2006)	ISO 14046 (2014)
Title	Principles and framework/ requirements and guidelines- for conducting LCA analysis	Principles, requirements and guidelines- for conducting water footprint
Principle focus	Outlines the basics for conducting an LCA on a product	Outlines the basics for conducting an LCA on a product that focuses specifically on water consumption during the entire life cycle of the product and its associated environmental impacts. WF studies can be used as a standalone or can be described in terms of the main environmental impact they are quantifying (like water scarcity footprint, water eutrophication footprint, etc)
Basis of analysis	LCA	LCA by impact
Stages	1) Goal and scope definition 2) Life cycle inventory 3) Life cycle impact assessment 4) Interpretation and result	1) Goal and scope Definition 2) Water footprint inventory 3) Water footprint impact assessment 4) Interpretation and result
Identified environmental impacts	All environmental impacts associated with the manufacturing of the product are identified. These impacts include but are not limited to: 1) Freshwater consumption 2) Carbon emissions 3) Eutrophication 4) Acidification	The environmental impacts related to water that result from the product are determined and assessed.
Quantity of water consumed	This analysis technique determines the amount of water consumed (in addition to other resources) by the product during its entire lifecycle	This analysis technique determines the amount of water consumed by the product during its entire lifecycle
Source of water used	This analysis does not assess the source of water consumed.	This analysis focuses on the source of water used

When defining the amount of water consumed to manufacture a product, two terminologies may be used which are "WF" of the product and "EW" of the product. Both these terms are used synonymously to each other (Hoekstra et al. 2011;

Netz and Sundin 2015) but have different meanings in terms of the extent of their measurement (Hoekstra et al. 2011). While EW refers to the amount of water (irrespective of its source) needed to manufacture a product, WF refers to the amount of water required to manufacture a product based on its source, thereby classifying it into blue (freshwater), green (rainwater), and grey (treated wastewater) components (Hoekstra et al. 2011). To ensure consistency of writing, the term "EW" will be used in this thesis. Moreover, the EW calculations will follow the principles listed in ISO 14040 (2006) and its application to this study will be discussed further in Chapter 3.

ISO 14040 (2006) states four stages of conducting a LCA study and these are discussed next.

2.5.1 Goal and Scope Definition

This stage defines the aim of the study, system boundaries, functional units, and parameters to be analysed and formulates the data collection strategy. This is an extremely essential stage as all the other stages depend on the boundaries and scope defined here. For building elements few examples of functional units are mass such as tonnes of cement and volume such as m^3 of concrete. The selection of a system boundary is an important aspect as it defines the goal of the analysis. BRE (2018) defines that the system boundary of a study can be of the following types and is shown in Figure 2.3:

1) Cradle-to-gate: This system boundary covers the extraction of raw materials (module A1), transportation to the manufacturing site (module A2) and manufacturing of building materials (module A3).
2) Cradle-to-gate with options: This system boundary covers all the stages of the cradle-to-gate system boundary (module A1-A3) plus any additional lifecycle stages from module A4-D depending on the requirements of the study. For construction materials normally the transportation to the construction site (module A4) is also considered. If all the stages till the building construction (module A5) are being considered like when

determining the EW of a building, the system boundary defined would be cradle-to-gate with construction.

3) Cradle-to-grave: This system boundary covers the entire lifecycle of a product and thereby includes all the module starting from A1 until D.

Life Cycle Stage	Product			Construction		Use							End-of-Life			
						Building Fabric					Building Operation					
Module	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4
Stage	Extraction of Raw Materials	Transportation of Raw Materials	Manufacturing of Building Materials	Transportation of Building Materials	Building Construction	Use of Materials	Maintenance of Materials	Repair of Materials	Replacement of Materials	Refurbishment of Materials	Operational Energy Use	Operational Water Use	Demolition of Building	Transportation of Wastes	Wastes Processing	Disposal of Wastes
System Boundary	Cradle-to-Gate															
	Cradle-to-Gate with Transportation															
	Cradle-to-Gate with Construction															
	Cradle-to-Grave															

Figure 2.3: Lifecycle stages with system boundary (Source: Author)

Following the definition of EW of a building, the system boundary for this study is defined as cradle-to-gate with construction. The EWC of construction materials is calculated at module A3 and for construction activities at module A5.

2.5.2 Inventory Analysis

This stage identifies all the inputs and outputs associated with the identified system boundary (ISO 14040 2006; ISO 14044 2006). It is a crucial data collection stage because the completeness and accuracy of the collected data depend on it. When calculating the EW, the input parameter considered is water. This can be determined in three ways depending on the source of data collection.

According to Crawford and Treloar (2005), Stephan and Crawford (2014), Heravi and Abdolvand (2019), Dixit and Kumar 2022, and Crawford (2022), these three analysis techniques are:

1) Process analysis: This technique involves breaking down the processes in the identified system boundary into smaller unit processes and identifying the water inputs for each of these units. Data related to the amount of water consumed at each unit is normally collected directly from the source of production or consumption. The data collected from this method is more focused on the product and hence is a commonly adopted technique for EW calculation. Environmental product declarations (EPD) follow this method for the collection of their data and the category "net use of freshwater" refers to the EWC of the product under investigation. The major disadvantage of this analysis is that minor stages in the product's lifecycle are excluded when defining the unit processes. EPDs usually ignore processes that contribute less than 1% of the total life cycle of the product. Process data can be either obtained through data collection from the site or using LCA tools like SimaPro.
2) Input-output analysis: This technique combines the sector wise input-output economic data of a country with the country's national water accounts to create environmentally extended input-output data. In this technique, the product and water prices as available from economic records of the country are used to develop water flows to determine the EW of the product. These national input-output data represent the water intensity of the sector in kL/$1000 of product which refers to the amount of water (in kL) needed to manufacture $1000 worth of products of that sector. This data provides a more comprehensive analysis of the EW of a product as compared to the process analysis, as it covers a larger data collection boundary by including the small activities that remain omitted in the process analysis due to difficulty in collecting that data. Since this technique relies on national economic tables and national water records, it suffers from inaccuracies because of the generalisation of the water requirements for an activity and the added limitation to distinguish between different products in a sector.

3) Hybrid analysis: The hybrid analysis combines the results from the process analysis and input-output analysis to obtain data covering a larger system boundary and subsequently reducing the inaccuracies of using each process individually. Depending on the combination and integration of the two analysis methods different types of hybrid analysis like process-based hybrid analysis and input-output based hybrid analysis are possible.

Most of the past research on EW such as Crawford and Pullen (2011), Meng et al. (2014) and Dixit, Kumar and Haghighi (2022) have relied on the hybrid LCA approach. Few studies like Choudhuri and Bardhan (2018) and Heravi and Abdolvand (2019) have used the process LCA approach. These studies are discussed in detail in Section 2.6.

2.5.3 Impact Assessment

In this stage, all the inputs and outputs identified in the previous stage are divided into impact categories based on their impact on the environment. This stage can provide qualitative or quantitative information to further analyse the results of the life cycle inventory analysis stage (ISO 14040 2006; ISO 14044 2006). For EW calculation, the identified environmental impacts are eutrophication potential and freshwater depletion potential to name a few.

2.5.4 Interpretation

In this stage, the results from the previous two stages are analysed and discussed for the development of recommendations and strategies depending on the scope of the analysis as defined in stage 1. For EW analysis studies, it can help identify the hotspots of a building or product where large amounts of water are consumed and identify alternative products that have a low EWC (Crawford 2022).

Figure 2.4 summarises all the stages of the LCA approach.

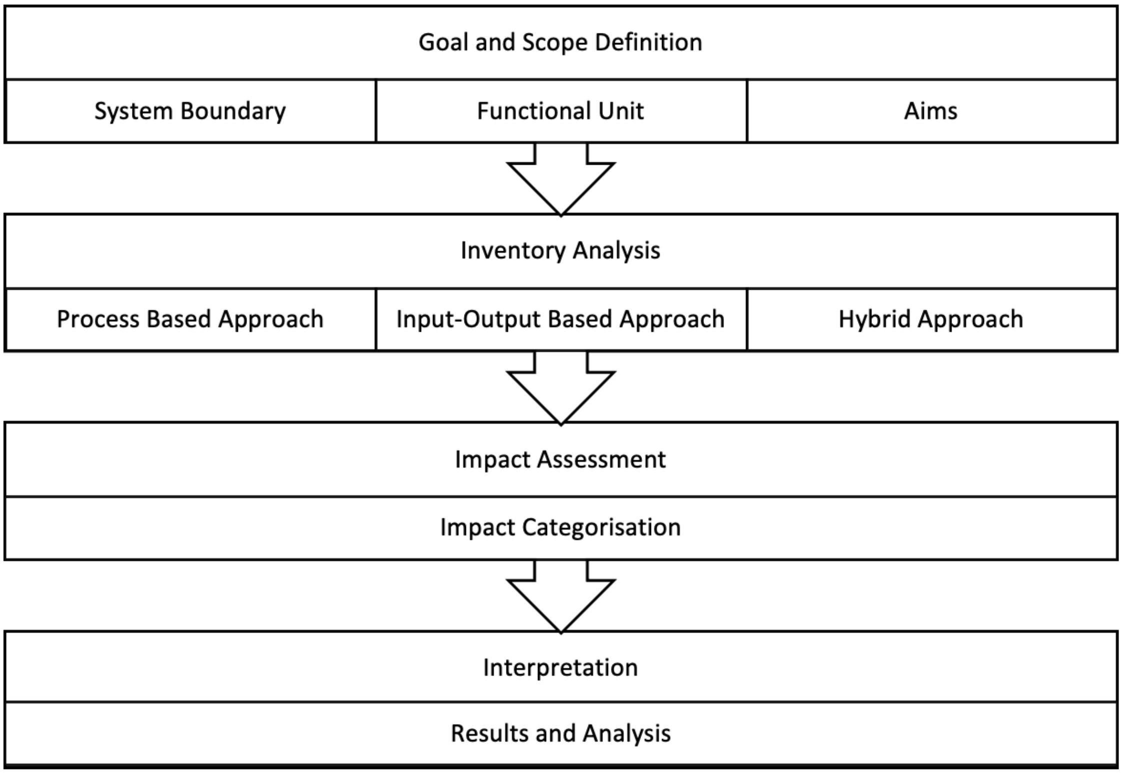

Figure 2.4: Life cycle assessment process (Adapted from: ISO 14040 2006, ISO 14044 2006)

LCA is the most adopted method to determine the EW of different construction products as noted from studies by Treloar et al. (2004), Crawford (2011), Crawford, Stephan and Prideaux (2019), and Heravi and Abdolvand (2019). In the LCA method, the final product can be broken down into smaller products and processes throughout the supply chain of the final product. The amount of water consumed at each stage of the supply chain can then be determined and eventually the EW of the product can be calculated. A similar approach can be applied to building construction, considering a building as a final product. The building can be broken down into all the materials used and construction activities undertaken for its construction. By identifying the amount of water consumed for the manufacturing of each material and execution of each activity, the EW of the building can be calculated. It can thus be seen how an LCA approach can also assist in calculating the EW of a building.

An LCA can be conducted by either following the conventional approach or a manual approach. The conventional approach uses LCA computer software to breakdown the product being analysed into all the stages across its supply chain and then determine the environmental impacts at each stage using LCA databases. A manual approach on the other hand manually breaks down the process into all the stages across its supply chain, and manually collects data related to the environmental impacts at each stage. McCormack et al. (2007) and Dixit, Kumar and Haghighi (2022) are examples of two studies that have adopted the conventional approach to calculate the EW of non-residential buildings in Australia and higher education buildings in USA respectively. This method was adopted since both the countries have a large LCA database of construction materials and activities in their geographical context. Heravi and Abdolvand (2019) on the other hand adopted a manual LCA approach to calculate the EW of six residential buildings in Iran due to the absence of such an extensive LCA database in Iranian context. A similar extensive LCA database in Indian context is also unavailable and hence this study adopts the manual LCA approach. Similar to Heravi and Abdolvand (2019) this study uses document analysis to collect environmental impact data of the materials and activities being analysed.

2.6 Past Studies on Embodied Water

As aforementioned, studies analysing the EW of buildings has been gaining attention around the world. Table 2.2 summarises the main findings from few studies conducted in India and globally.

Table 2.2: Main findings from past embodied water studies (Source: Author)

Study	Location	Main Findings
McCormack et al. (2007)	Australia	This study analysed the EW of seventeen non-residential buildings in Australia using the hybrid LCA technique. It found that the EW of a building depends greatly on its size and can be as high as 20.1 kL/m^2 for a medium-rise office building.
Bardhan (2011)	India	This was the first study carried out in India and it analysed the EW of a multi-storied residential building in east India. IEW calculations focused on only four building materials. To calculate the DEW the amount of water withdrawn from bore wells on the site based on their energy consumption for operating the electrical pumps was used. The resultant EW of the building was found to be 27 kL/m^2.
Meng et al. (2014)	China	This study analysed the EW of six buildings in Beijing using the hybrid LCA technique. Data from the EW intensity database for the Chinese economy was used to calculate the DEW and IEW. The EW of the building was found to be 20.83 kL/m^2.
Choudhuri (2015)	India	This study analysed the EW of a four-star hotel in central India. IEW calculations focused on five building materials. To calculate the DEW, the volume of water delivered by water tanks to the construction site during the entire project duration was calculated. The resultant EW of the hotel was found to be 20.95 kL/m^2.
Bardhan and Choudhuri (2016)	India	This study analysed the EW of two urban buildings located in different parts of India with different water availabilities. For the IEW calculations, five construction materials were used. Whereas, for the DEW the average water used daily was calculated based on information shared by the site staff. The IEW was similar for the two buildings due to standardized data of EWC for the construction materials. However, the DEW was significantly different (almost three times) between the two sites due to differences in their local water availability.
Heravi and Abdolvand (2019)	Iran	This study analysed the EW of six residential buildings in Iran using the process based LCA method and found the EW to be 20.8 kL/m^2. For the IEW calculations, the EWC of common construction materials determined by conducting interviews with people involved in the material manufacturing process were considered. For the DEW calculations, the EWC of construction activities as obtained from the annually updated Commentary of the National Building Price List database was used.
Dixit, Kumar and Haghighi (2022)	USA	This study used an input-output based hybrid LCA technique to calculate the EW of five higher education buildings in USA. This study introduced a third component of EW known as the implied EW (or energy related EW). It noted that the IEW is up to three times higher than the DEW.
Sharma and Chani (2022)	India	This study analysed the EW of four masonry residential houses in north India using the process-based hybrid LCA approach. For the DEW, the amount of water withdrawn from wells and purchased during the building construction was used. For the IEW, twenty-seven materials were considered and their EWC was based on those calculated by Crawford and Treloar (2010), Crawford and Pullen (2011), and Crawford, Stephan and Prideaux (2019).
Dixit and Kumar (2024)	USA	This study used an input-output based hybrid LCA technique to calculate the EW, EE and EC of four university buildings in USA. It noted the rationale for the analysis of all three components (EW, EE and EC) when assessing the environmental impacts of buildings.

Comparing the previous research conducted in India and outside India leads to various striking differences such as:

1) Majority of the studies conducted outside India used a hybrid LCA approach while studies conducted in India relied only on process LCA approach. The main reason for this is the lack of sector wise input-output tables and water accounts in the Indian context.
2) The IEW calculations outside India considered more construction materials than those considered in Indian studies. Majority of the Indian studies considered four to five materials. Sharma and Chani (2022) is the only study in India that used twenty seven materials for IEW calculations. However, the EWC of construction materials considered by Sharma and Chani (2022) were based on those developed by Crawford and Treloar (2010), Crawford and Pullen (2011), and Crawford, Stephan and Prideaux (2019) in Australian context.
3) The most common methodology of calculating the DEW is by calculating the amount of water withdrawn from bore wells and amount of water purchased throughout the construction period. However, a study by Santos, Silva and Cerqueira (2018) used a completely different methodology of calculating the DEW value. It calculated this value by installing a water meter on the construction site and measuring the daily water consumption. Moreover, it mapped the daily water consumption against the project schedule to determine the changes in water consumption trends. However, Santos, Silva and Cerqueira (2018) (similar to all other studies) did not determine the EWC of different construction activities.

As discussed in Section 1.2, and as noted from the differences between Indian and global studies on EW, there is a lack of data related to EWC of construction materials and construction activities in Indian context. This study aims to bridge this gap by calculating these values using a process LCA approach.

2.7 Environmental Product Declaration

EPDs are material specific documents that provide quantified environmental information (inputs in terms of resources and outputs in terms of impacts) about that product (ISO 14025 2006). This environmental information is quantified using the process LCA approach (Crawford 2022). The "net use of freshwater" category in the EPD provides information related to the amount of water needed to manufacture a unit of that product throughout the different stages of its entire lifecycle (Crawford 2022).

ISO 14025 (2006) provides the principles and procedures for developing EPDs. BRE (2018) specifies the product category rules (PCR) to develop EPDs of construction products and are used in conjunction with ISO 14025 (2006) to develop an EPD for construction products. For construction products, module A1-A4 under the "net use of freshwater" category refer to the EWC of the product (Crawford 2022).

2.8 Construction Materials

Water is used for various activities during the manufacturing of construction materials such as:

1) Cleaning the raw materials, equipment's and surfaces
2) Cooling the manufactured material, by-product and equipment's
3) Dust suppression during the mixing and storage of raw materials
4) As a raw material (for example in cement, bricks and tile manufacturing)

Besides these, water is also used by the staff involved in the material manufacturing process throughout the supply chain for various activities like sanitation and cleaning. Water consumed for all these activities constitutes the EWC of the manufactured material. It remains embodied in the material throughout its lifecycle and ultimately impacts the sustainability of the building. Hence, the choice of building materials must be carefully considered and planned during the conceptual stages of the building design to reduce its negative environmental impacts (BIS 2016a).

To increase the sustainability of manufactured construction materials and reduce their environmental impacts, construction material manufacturing industries are trying to make their processes more sustainable by consuming water efficiently (Nezamoleslami and Hosseinian 2020). By analysing all the areas of water consumption, informed decisions can be made regarding their efficient management (Nezamoleslami and Hosseinian 2020).

The increased demand for construction activities has led to an inevitable increased demand for construction materials (Crawford, Stephan and Prideaux 2022) resulting in traditional materials like stone and wood being replaced by concrete and steel to become the most used construction materials (BIS 2016b). Cement, steel, and bricks are the most commonly used construction materials for the construction of residential buildings in India (Sharma and Chani 2022) and this is also observed through the data collection of this study (see Chapter 5 for more information on this). Glass is another material commonly used for architectural finishing in buildings. The following sections identify the uses of these materials for construction projects in India, along with analysing the existing data related to their EWC.

2.8.1 Steel

The construction industry is the largest industrial consumer of steel consuming 50% of the global steel production (Bosman 2016). It is widely used in construction for reinforcement of concrete due to the high tensile strength it provides to the plain concrete structure (The International EPD System 2022b). The steel used for providing these reinforcements is also commonly known as rebar (The International EPD System 2022b). Its low cost of manufacturing makes steel a very commonly used construction material (Nezamoleslami and Hosseinian 2020; Kumar et al. 2021). On the contrary, the amount of water needed to manufacture steel is the highest when compared to manufacturing other construction materials (Nezamoleslami and Hosseinian 2020). There are two types of steel namely unalloyed or carbon steel, and alloyed steel. Unalloyed steel has a low carbon content while alloyed steel is unalloyed steel mixed with other metals (Bosman 2016; Nezamoleslami and Hosseininan 2020). Bosman (2016) states that unalloyed steel accounts for 89% of global steel production and is also the most common type of steel used in the construction industry (Bosman 2016).

In Indian context, the following three documents list the EWC of steel:

1) Central Public Health and Environmental Engineering Organisation (1999) states the EWC to be 200-250 kL/ton. This EWC value is extremely high and outdated. Sharma and Chani (2022) also noted this value to be extremely high suggesting the need for its recalculation.
2) Sharma and Chani (2022) state the EWC to be 98.64 kL/ton. This value is based on the findings of Crawford and Pullen (2011) that calculated this using a hybrid LCA approach in Australian context.
3) The International EPD System (2022b) states the EWC to be 3.55 kL/ton calculated using a process LCA approach.

The first value published by Central Public Health and Environmental Engineering Organisation (1999) is extremely outdated while the second published by Sharma and Chani (2022) is not in Indian context. The EWC value published in The International EPD System (2022b) is the only reliable and valid data available in Indian context.

2.8.2 Cement

In 2021, the construction sector in India accounted for 55% of the country's cement consumption with 75% of it being consumed by the building sector making cement the most used construction material (Kansal et al. 2022; Statista 2023). Cement is a hydraulic inorganic binder that binds different materials like sand, aggregates, and admixtures along with water to produce other construction materials like concrete, plaster, mortar, and bricks (Bosman 2016). A report by the Cement Manufacturer's Association (2021) states that India is the second largest producer of cement after China accounting for 7% of global cement manufacturing (Selvarajan et al. 2017; Kansal et al. 2022). Moreover, the cement industry in India is among the best in the world owing to the up-to-date technology used and the quality of cement produced (Selvarajan et al. 2017). However, Indian cement industries suffer from a limitation because most of the cement manufacturing plants are located in dry and arid regions of the country that are already suffering from water scarcity issues (Selvarajan et al. 2017).

In Indian context, the following three documents list the EWC of cement:

1) Central Pollution Control Board (2009) lists the EWC of ordinary Portland cement (OPC) to be 0.5-1 kL/ton. With advances in cement manufacturing technology over the last decade, this value needs to be re-evaluated.
2) Sharma and Chani (2022) list the EWC to be 8.52 kL/ton. This value was based on the findings of Crawford and Treloar (2010) that calculated this using a hybrid LCA approach in Australian context.
3) The International EPD System (2022a) states the EWC collected from a process LCA approach to be 0.27 kL/ton.

The values noted by Central Pollution Control Board (2009) and The International EPD System (2022a) are outdated. Though The International EPD System (2022b) is a recent publication, the value it reports is based on the water consumption data collected for the year 2018 and is outdated. Moreover, the value noted by Sharma and Chani (2022) is not in Indian context. The lack of EWC data of cement in Indian context highlights the need for the collection of this data and this material was selected for analysis in this study and is discussed in Chapter 4.

2.8.3 Aggregates

Aggregates are the most used material during building construction with their quantity of consumption amounting to almost twelve times the amount of cement consumed (Brito and Kurda 2021). The building construction industry consumes 40% of the world's raw aggregates (Sonebi, Ammar and Diederich 2016; Musenga and Aigbavboa 2019). Aggregates are solid particles that may be mixed with cement to make construction materials like concrete, mortar, and plaster, or maybe used individually as a base layer and filling material (The National Sand, Stone and Gravel Association 2013; Langer 2016; Sonebi, Ammar and Diederich 2016).

In Indian context, only one document by Sharma and Chani (2022) list the EWC of coarse and fine aggregates to be 3.5 kL/m^3. This value was based on the findings of Crawford, Stephan and Prideaux (2019) that calculated these values using a hybrid LCA approach in Australian context. Though Sharma and Chani (2022) conducted an extensive literature review and a robust analysis when selecting this EWC, these values are not representative of Indian context. Besides this document, there are no EPD's published in Indian context highlighting the EWC of aggregates. The lack of EWC data of aggregates in Indian context highlights the need for the collection of this data and this material was selected for analysis in this study and is discussed in Chapter 4.

2.8.4 Concrete

Mack-Vergara (2019) noted that Cementous construction materials (cement, concrete, plaster, and mortar) are the most used and manufactured construction materials. The concrete industry withdraws 9% of the global industrial water (Sharma and Chani 2022). The major raw materials used in concrete which are aggregates and cement, result in the various advantages and disadvantages associated with using concrete. The advantage of using concrete is in terms of cost as aggregates and cement require low manufacturing and thereby low cost of production (Sonebi, Ammar and Diederich 2016). However, the disadvantage of using concrete is that its raw materials are not sustainable in nature as they are derived from non-renewable resources (Brito and Kurda 2021). Another advantage of using concrete is that when freshly prepared, it has a fluid consistency making it easier to transport and pour, and once it hardens it develops excellent durability and mechanical properties (Sonebi, Ammar and Diederich 2016).

In Indian context, there exists one valid published EPD by The International EPD System (2022c) that lists the EWC of different concrete strengths such as M-7.5 and M-40 to be 0.303 kL/m^3 and 0.531 kL/m^3 respectively.

2.8.5 Glass

Glass is a widely used construction material because it is cheap, strong, sustainable, environmentally friendly, and chemically inert (Achintha 2016). Owing to its architectural, environmental, and sustainable benefits, this material can now be used for various other applications for building construction in addition to its earlier applications as windowpanes (Achintha 2016). Glass not only provides architectural finish to the constructed building, but also aids in ensuring daylight penetration along with visual and thermal comfort. The glass used in construction projects is known as flat-float glass due to its float manufacturing process and flat glass output produced. Glass is used in construction projects for purposes like windows, doors, facades and mirrors, and the construction industry in India is its largest consumer (TechSci Research 2023). 60% of glass produced in India is flat glass that is used for construction application (TechSci Research 2023).

In Indian context, the following four documents list the EWC of glass:

1) Choudhuri (2015) list an EWC value of 3.42 kL/m^2 based on the findings of Crawford (2011). Crawford (2011) calculated this value using a hybrid LCA approach in Australian context.
2) Sharma and Chani (2022) note this value to be 4.148 kL/m^2 based on the findings of Crawford and Treloar (2010). Crawford and Treloar (2010) calculated this value using a hybrid LCA approach in Australian context.
3) The International EPD System (2023a) list the EWC of 4mm glass with magnetron coating to be 0.053 kL/m^2.
4) The International EPD System (2023b) list the EWC of 8mm glass with magnetron coating to be 0.091 kL/m^2.

The lack of EWC data of float glass without any coating in Indian context highlights the need for the collection of this data and this material was selected for analysis in this study and is discussed in Chapter 4.

2.8.6 Masonry

Masonry is defined as an assembly of units (clay bricks, concrete blocks, aerated concrete blocks, stones, etc) bound together by mortar (Smith, Bingel and Bown 2016).

In Indian context, the following two documents list the EWC of masonry units:

1) Bardhan (2011) notes the EWC of clay bricks to be 0.71kL/ton and this value was assumed based on the amount of water required to make M-20 grade concrete.
2) Bardhan (2015a) notes the EWC of solid concrete blocks and hollow concrete blocks to be 0.416 kL/m^3 and 0.119 kL/m^3 respectively based on a site visit to a brick manufacturing plant, and by interviewing its site staff and analysing their water consumption records documents.

Since the EWC of clay bricks in Indian context is based on assumptions, it highlights the need for the collection of this data and this material was selected for analysis in this study and is discussed in Chapter 4.

2.9 Activities on Construction Sites

Construction practices followed on building construction sites depend on various factors like location of the building, soil condition, existing norms and standards related to construction practices, working style of the construction team and scale of the construction project (Bardhan 2015b; Rahman et al. 2019; Tirth et al. 2022). Water is consumed to carry out all the activities that are undertaken to construct the building such as (European Bank for Reconstruction and Development 2010; Noh, Lee and Yu 2018):

1) Earthwork activities like excavation and backfilling
2) Making and curing of concrete
3) Laying of masonry walls using mortar and curing them
4) Making the plaster to apply on masonry walls and curing them

Besides the above listed construction related activities, water is also consumed by activities that support these construction activities such as (Choudhuri 2015; Rahman et al. 2019; Crawford 2022):

1) Dust suppression
2) Site cleaning
3) Vehicle cleaning
4) Equipment cleaning

In addition to these activities, water is also consumed by the site staff working on the construction site for various activities like cleaning and sanitation. Past studies have indicated that human activities consume the largest amount of water on construction sites (Bardhan 2011; Choudhuri 2015).

Tirth et al. (2022) states that masonry, plastering, and earthwork activities consume large quantities of water. In addition, a large amount of water is consumed for dust suppression on construction sites. However, none of the past studies conducted in India or globally have recorded the amount of water required for executing different construction activities.

2.10 Embodied Energy and Embodied Carbon

EE and EC are two terminologies used interchangeably, but there are striking differences between the two. While EE refers to the amount of energy consumed during the construction of a building (module A1-A5), EC refers to its associated carbon emissions (George and Jacob 2018; Dixit and Kumar 2022). The amount of energy required can be reduced through the integration of energy efficient technologies while carbon emissions can be reduced by the use of renewable and sustainable energy sources. For example, if wind energy replaces the use of fossil fuels as a source of energy, the energy requirement remains the same, but associated carbon emissions are reduced. George and Jacob (2018) state that EC of a building accounts for 74% of the lifecycle carbon emissions.

EE and EC monitoring and measuring suffer from the same challenges as EW due to the large number of consumption points during the process (Sabnis, Mysore and Anant 2016). Moreover, their calculation also follows the same methodology as EW and has been widely used in the past by Crawford and Treloar (2005), and Dixit and Kumar (2022).

For EE, the amount of energy needed to manufacture a material is expressed in Mega Joules (MJ) per unit of production of that material (kg) and is known as the embodied energy coefficient (EEC) of that material. The EE of a material “M” is the EEC of that material (EEC_M) multiplied by its quantity (Q_M). The EE of the building is thus the sum of the EE of all materials, as shown in Equation 4 (Bardhan 2015b).

$$EE = \sum EE_M = \sum EEC_M \ x \ Q_M \quad \text{(Equation 4)}$$

Similarly, for EC, the amount of carbon released during the manufacturing of a material is expressed in kilograms of carbon dioxide (kg CO_2) per unit of production of that material (kg) and is known as the ECC of that material. The EC of a material “M” is the ECC of that material (ECC_M) multiplied by its quantity (Q_M). The EC of the building is thus the sum of the EC of all materials, as shown in Equation 5 (Bardhan 2015b).

$$EC = \sum EC_M = \sum ECC_M \ x \ Q_M \quad \text{(Equation 5)}$$

Though different studies calculate the EW and EE of construction materials, very few like Dixit and Kumar (2022) compared the calculated EW and EE to determine if any trade-off exists between the two to assist in sustainable decision making when selecting materials for building construction. This correlation between the two is extremely essential because some materials might have a low EE but a high

EW or vice-versa and the selection of such a material wouldn’t result in a truly sustainable structure. Dixit and Kumar (2022) noted a weak correlation between EE and EW and suggested that just considering one of the two will not result in a sustainable building. It is thus extremely essential to analyse whether the two can be offset in any way. Dixit and Kumar (2024) noted the need to measure the EC of buildings along with their EE and EW since buildings are made of many different materials and each material utilises different energy sources for its manufacturing. This study thus aims to determine if a material has a high EW but low EC, or vice-versa, and how the two can be offset.

In the Indian context, the International Finance Corporation (2017) developed an EE and EC global warming potential (GWP) database for construction materials. This is attributed to the huge importance given to energy and carbon management in the Indian construction sector. On the other hand, there exists no database for EWC of construction materials in Indian context due to the low importance given to water management.

2.11 Three Pillars of Sustainability and Sustainable Water Management

Sustainable development relies on three pillars namely the economic, social and environmental aspects (Aboulnaga 2013). The three pillars are interconnected to each other and must be considered for a holistic approach to incorporating sustainability. However, majority of sustainable buildings and constructions focus majorly on the environmental pillar often ignoring the equally important economic and social pillar (Vilcekova, Burdova and Selecka 2018).

Based on definition of sustainable development, SWM can be defined as “managing the present water needs taking into account the requirements of the future generations” (Manikandan and Ramappa 2012). The three pillars of sustainability for integrating SWM in building construction as shown in Figure 2.5 focuses on:

1) Economic pillar: Cost of construction and material manufacturing, cost of sourcing the appropriate quality water, economic benefits of integrating SWM.
2) Social pillar: Educating people on the importance of SWM and its benefits, impact on the quality of material manufactured and building constructed, health impacts on the construction staff and material manufacturers.
3) Environmental pillar: Reduction in fresh potable water consumption, increased water reuse and recycling, reduction in wastewater production.

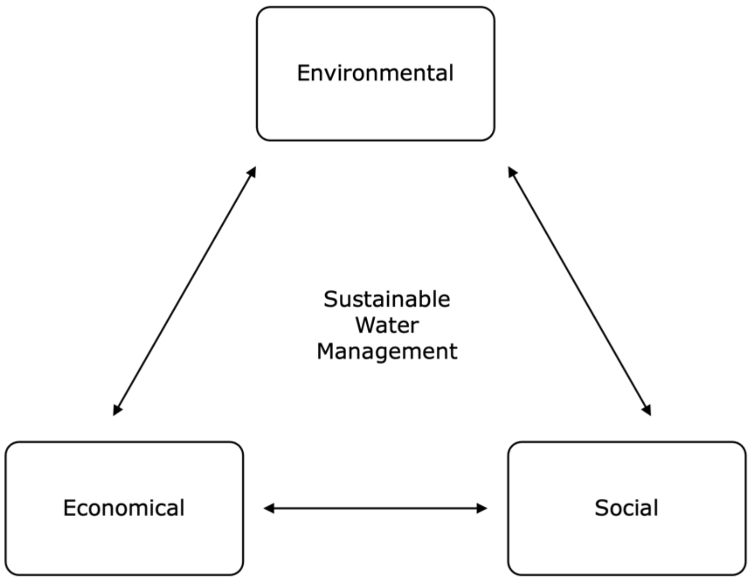

Figure 2.5: Three pillars of sustainability and sustainable water management (Source: Author)

Integrating principles of SWM that focuses on reducing freshwater consumption and increasing wastewater recycling play a crucial role in managing water scarcity issues (Vilcekova, Burdova and Selecka 2018). When integrating SWM in building construction and material manufacturing industries, all the three pillars of sustainability must be equally considered to ensure that water resources are conserved and efficiently managed, along with no negative consequences on the people involved in the project and the final product. Moreover, the aim of the activity must be accomplished economically.

2.12 Water Hierarchy

Waylen, Thornback and Garrett (2011) developed a 6R water hierarchy concept for water conservation and management. Waidyasekara, De Silva and Rameezdeen (2017) note its importance for construction water management. However, it can also be applied for water management during material manufacturing. Waidyasekara, De Silva and Rameezdeen (2017) define the following stages of the 6R water hierarchy and are shown in Figure 2.6:

1) Review : This stage aims at reviewing if water is necessary for carrying out an activity. If the activity can be successfully completed without using water, its use must be avoided. However, being a cheap and easily available resource, it is often used even when not required.
2) Replace : Once the application of water for an activity has been deemed essential, the next stage of the water hierarchy aims at replacing fresh potable water with an alternative water source. The quantity and quality of water available from the alternate source, its supply security, and the minimum level of treatment required so that the alternate water source meets the desired water quality standard for carrying out that activity play an important role in the selection of the alternate water source. An ideal water source is one that requires the least amount of cost and treatment to achieve the desired water quality standards for conducting an activity.
3) Reduce : Once an alternate water source has been identified, this next stage is to reduce the water consumption by increasing water use efficiency. This can be achieved by incorporating water efficient technology and improving housekeeping behaviour.
4) Reuse : Once water has been used to accomplish an activity, the next stage is to identify the possibilities of reusing the wastewater produced. Reuse aims at using the wastewater for another activity without any prior treatment.
5) Recycle : Once water has been used to complete an activity, and if the reuse of the wastewater is not possible, the next stage is to identify possibilities of recycling it. Recycling aims at preliminary wastewater treatment before utilising it for another activity.

6) Remove : If recycle of wastewater is not possible, the last stage is removing the wastewater and its transfer to a wastewater treatment facility.

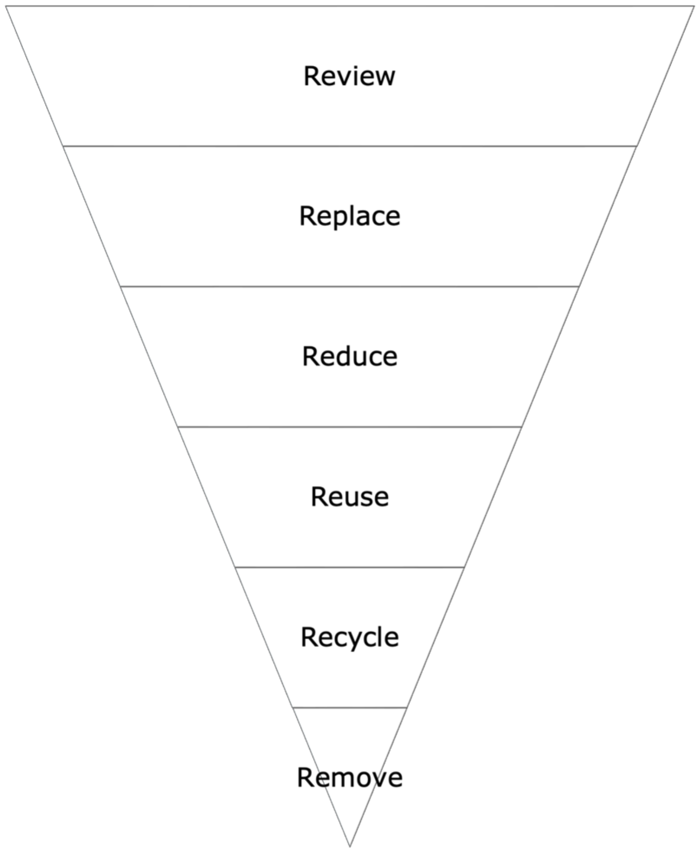

Figure 2.6: 6R water hierarchy (Source: Waidyasekara, De Silva and Rameezdeen 2017)

2.13 Chapter Summary

This chapter defined the urgent need for water management globally and in India with a specific focus on the residential building construction sector (which also includes the construction material manufacturing industries). This chapter also identified the two policies regarding water management currently implemented by the Indian government (Draft National Water Framework Bill 2016 and National Water Mission 2008). It further analysed these policies, identified their limitations in managing water resources and compared it with similar policies in other countries like Dubai. The efficiency of these existing policies in India will be analysed further through semi-structured interviews with construction professionals and construction material manufacturers in Chapter 7. This chapter also described the lifecycle stages of a building based on BRE (2018). It outlined the corresponding stages of the DEW and IEW along with their calculation equations. The different methodologies for conducting an LCA were also described, and the method selected was the LCA approach defined by ISO 14040 (2006) and ISO 14044 (2006). Furthermore, the differences between EW and WF were highlighted and the basis for the selection of EW in this study was defined. This chapter also discussed the commonly used materials and activities undertaken for residential building construction in India along with an analysis of their EWC values in Indian context. This analysis revealed the lack of these EWC data which formed the basis for their collection in Chapter 6. The relationship between EE, EC and EW was further outlined in this chapter which highlighted the need for further studies comparing these components. Two policies related to water management which are the three pillars of sustainability in SWM and the 6R water hierarchy were also defined.

Chapter 3 : A Review of Water Management Frameworks

This chapter reviews the available water management frameworks from different sectors. Each framework is analysed based on the rationale behind its formation, the aim of the framework and its various components. The aim of this review is to identify the similarities between the different existing water management frameworks to inform the creation of the conceptual framework in Chapter 4.

3.1 Different Types of Water Management Frameworks

The quality and quantity of water availability around the world has changed tremendously over the past decade due to various factors like increasing population, urbanisation, industrialisation, food security and climate change (Zarkani and Fadel 2024; Zhou, Han, Zhou 2024). Thus, management of water is of utmost priority and can be facilitated by creation of water management frameworks. The existing water management frameworks in literature can be classified into quantitative water management frameworks, qualitative water management frameworks and hybrid water management frameworks.

Quantitative water management frameworks incorporate modelling and scenario simulations to quantify the impacts of the variables being analysed. Authors like Huang et al. (2024) and Pourmahmoud, Shahdany and Roozbahani (2024) have developed quantitative frameworks to monitor and analyse different parameters for water management. Huang et al. (2024) developed a machine learning based modelling framework for monitoring the quality of river water. Pourmahmoud, Shahdany and Roozbahani (2024) developed a framework to manage agricultural water and assess the risks by quantifying potential failures due to draught induced scenarios. From these studies it can be noted that by modelling different parameters, their impact on water management can be quantified and this can aid in the selection of water management practices. In terms of visual presentation, these quantitative frameworks are represented in a step-by-step arrangement that states the output of the first stage as the input of the next stage.

Qualitative water management frameworks on the other hand list the qualitative steps that can be adopted to implement water management practices. Authors like IPIECA (2021) and Seijger (2023) have used this technique to develop water management frameworks across different sectors. IPIECA (2021) developed a cyclical framework that lists the five key interconnected steps for water management in the oil and gas (O&G) industry. Seijer (2023) on the other hand developed a compass framework that integrates six steps to help identify the changes in societal priorities and the shifts in agricultural water management practices based on different mediating and moderating variables. Both these studies not only listed qualitative steps in a defined order to implement water management practices but also depicted these steps in a visual framework based on the authors preference.

A few studies like Feng et al. (2023) and Zarkani and Fadel (2024) have developed hybrid frameworks that combine both qualitative and quantitative steps for water management. Feng et al. (2023) developed a framework for green water management that integrates game theory modelling. The developed framework highlights that green water management can be improved by balancing the water management practices in the upstream with water compensation in the downstream (qualitative steps of the framework). Moreover, the integration of game theory modelling (quantitative steps of the framework) can help in simulations based on different water management strategies and aid in solving water resource management issues in river basins. Zarkani and Fadel (2024) developed a novel LCA based framework that defines six steps for selecting optimal treatment and management technologies for water produced from offshore O&G operations. The first two steps specify qualitative measures for water management and the last four steps specify quantitative measures that focus on computer simulations and modelling scenarios to quantify the environmental impacts of different treatment technologies. It can thus be noted from Feng et al. (2023) and Zarkani and Fadel (2024) that hybrid water management frameworks not only define the qualitative steps for water management but also include quantitative steps in terms of modelling and simulation to quantify the impacts of the practices being proposed to solve water management issues.

This study aims to develop a framework of efficient water management practices for EW management in the residential building construction sector in India. The framework is intended to consist of qualitative steps that must be undertaken for EW management. It does not focus on simulations and modelling scenarios of water management practices and consumption patterns (quantitative or hybrid frameworks). This is because companies often have limited resources to conduct modelling and computer simulations, whereas adoption of qualitative measures is comparatively easier. As a result, to accomplish the research aim, a qualitative water management framework will be developed in this study (Chapter 4), after analysing the different water management frameworks existing in different sectors across the world. Section 3.2 to Section 3.5 discuss the water management frameworks developed across different sectors. It shows the visual representation of each framework along with an analysis of the key themes in terms of the rationale behind its creation, its key components and the stakeholders the framework is intended for. Section 3.6 highlights the similarities of all the frameworks that were reviewed to identify key themes for the creation of the conceptual framework in Chapter 4.

3.2 Drinking Water Management Framework

Natural and anthropogenic contaminants in drinking water sources have been constantly increasing. The growing presence of these emerging contaminants is a serious concern, and their mitigation requires adequate attention. Moreover, the stringent government regulations surrounding water quality further define the basis for the selection of appropriate treatment technologies for the mitigation of these emerging contaminants.

McLellan et al. (2024) noted that from a holistic standpoint, there is limited understanding regarding the selection of different treatment technologies for the mitigation of emerging contaminants. As a result, McLellan et al. (2024) developed a matrix-based framework to facilitate the selection of appropriate water treatment technologies for different groups of emerging contaminants. The framework is shown in Figure 3.1.

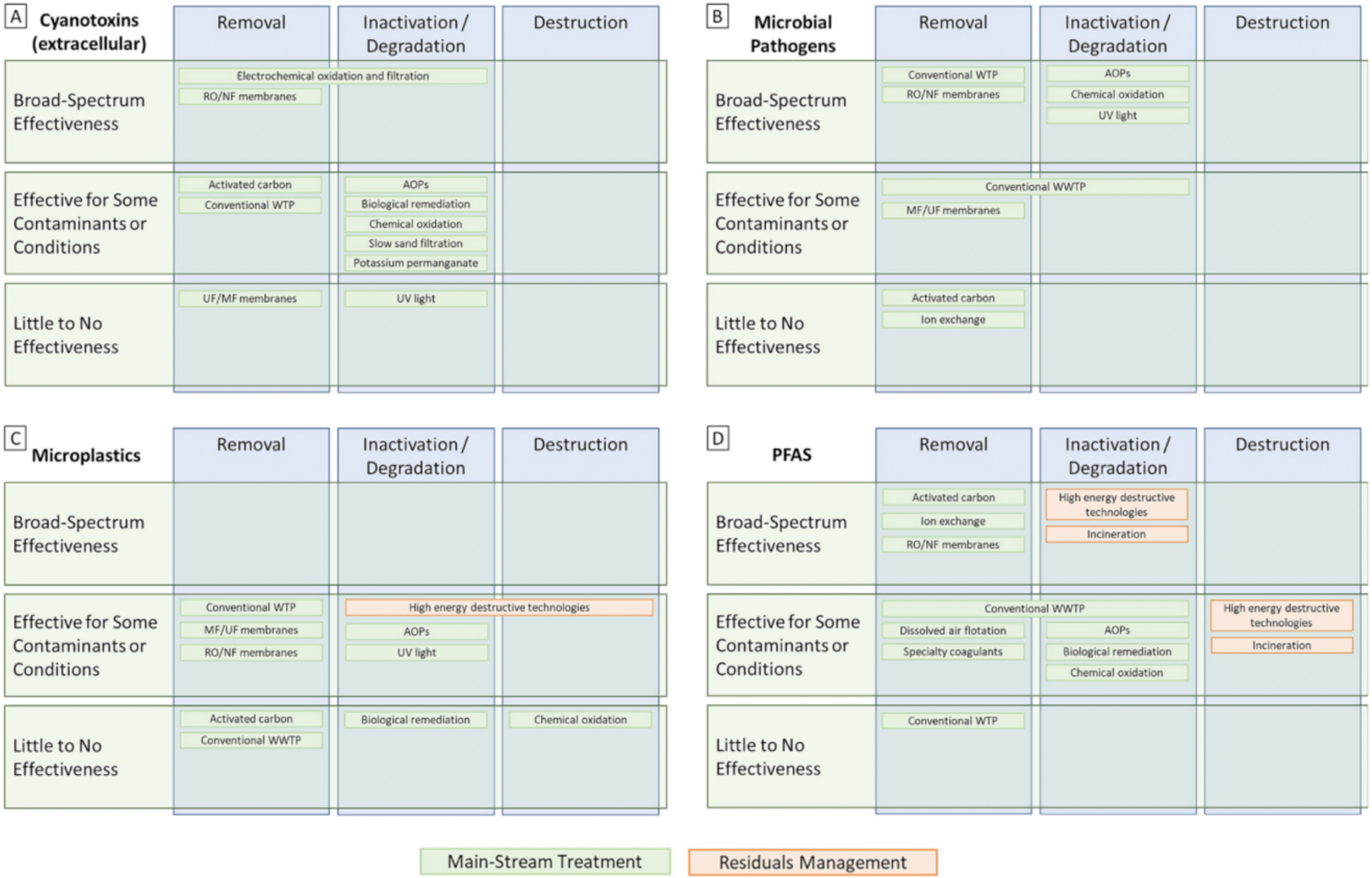

Figure 3.1: Drinking water management framework (Source: McLellan et al. 2024)

For each identified emerging contaminant group (Cyanobacterial Toxins, Microbial Pathogens, Microplastics, Per- and Polyfluoroalkyl- Substances), the suitable treatment technology for its mitigation can be selected based on the degree of treatment required (broad spectrum effectiveness, effective for some contaminants or conditions, little to no effectiveness) and the mechanism of mitigation (removal, inactivation, degradation, destruction). Organising these treatment technologies in a matrix representation not only helps water managers select treatment technologies with overlapping benefits but also helps identify gaps in the treatment technologies that can define the basis for further research.

3.3 Agricultural Water Management Framework

The Agricultural sector is the largest global water consumer accounting for 72% of global freshwater withdrawals (Food and Agriculture Organization of the United Nations 2021). It is also responsible for 56% of the global wastewater discharge (Food and Agriculture Organization of the United Nations 2021). These significant water consumption and wastewater generation values signify the need for agricultural water management (AWM) through creation of frameworks. Bjornlund and Bjornlund (2019) and Seijer (2023) developed two unique frameworks for AWM. Section 3.3.1 and Section 3.3.2 discuss these two frameworks.

3.3.1 Agricultural Water Management Framework Based on Socioeconomic and Biophysical Factors

Socioeconomic factors such as population change, opportunities for advancements and adaptability define the social and economic status of a region. On the other hand, factors that define the biological, chemical and physical conditions of an environment like evaporation, precipitation and soil fertility are known as biophysical factors. Both the socioeconomic and biophysical factors are interlinked with each other and impact the AWM practices adopted in a region. This is because when biophysical factors act as barriers, they are overcome by socioeconomic factors to aid in water management.

Bjornlund and Bjornlund (2019) thus developed a conceptual framework that depicts the influence of socioeconomic and biophysical factors on AWM within a region or society over time. The framework is shown in Figure 3.2. It highlights the relationship between the different socioeconomic and biophysical factors and their impact on the development of AWM in a region. The socioeconomic factors (demographic, technology, society, power source) and biophysical factors (environment, climate, resources) can act as drivers, facilitators, enablers or barriers and they define the development of AWM in a region into six stages. The six stages of AWM are:

1) Stage 1: maximizing the benefits from water in-situ without manipulating the biophysical environment
2) Stage 2: maximizing the benefits from water in-situ by manipulating the biophysical environment
3) Stage 3: canal irrigation – restructuring the biophysical environment
4) Stage 4: conquering biophysical barriers to access water and supply/drain new land near commercial centres
5) Stage 5: Irrigation as part of commodification: industrialization and globalization of trade
6) Stage 6: A paradigm shift in water management

The socioeconomic and biophysical factors were selected based on their relevance in the agricultural sector and their correlation with each other. The six stages of AWM considered were based on the findings of Long (2009). By providing a correlation between the different socioeconomic and biophysical factors, and their impact on AWM, the framework can help decision makers to design future AWM projects that are better adapted to operate and preserve the local environment.

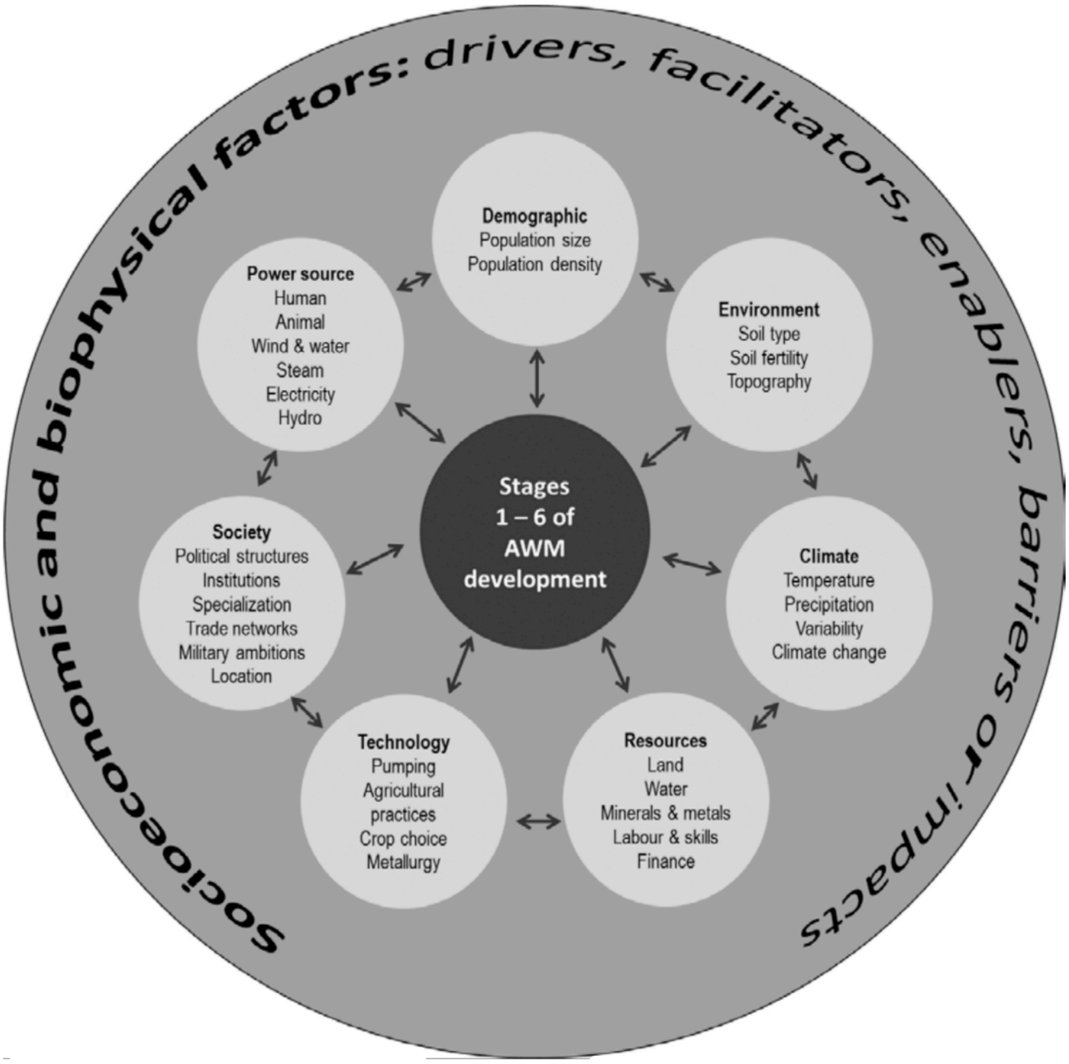

Figure 3.2: Agricultural water management framework (Source: Bjornlund and Bjornlund 2019)

3.3.2 Agricultural Water Management Framework Based on Shift in Societal Priorities

Over the past few years, the issues of climate change and increasing population has resulted in a shift in societal priorities to focus on climate change mitigation and adaptation, and increasing food security. This shift in societal priorities impacts the AWM practices of the society. For instance, the current focus of societies to invest on urban growth as opposed to agricultural intensification in the past, has resulted in redistribution of scarce water resources from the agricultural sector to the urban development sector.

Seijer (2023) thus developed a novel interdisciplinary compass framework that considers the shifts in societal priorities and the corresponding degree of reorientation for AWM. The framework is shown in Figure 3.3. The framework provides a link between the change in societal priorities (like climate change, environmental awareness, etc.) and the corresponding changes in AWM (like changes in crops, water systems, etc.). It focuses on identifying the AWM practices before the shift in societal priorities. It considers the biophysical and social factors that moderate the shift and concludes by identifying the AWM practices after the shift in societal priorities.

The framework can help decision makers and policy makers in the Agricultural sector to identify AWM practices that take into account shifts in societal priorities while considering the impact of different factors on moderating these changes.

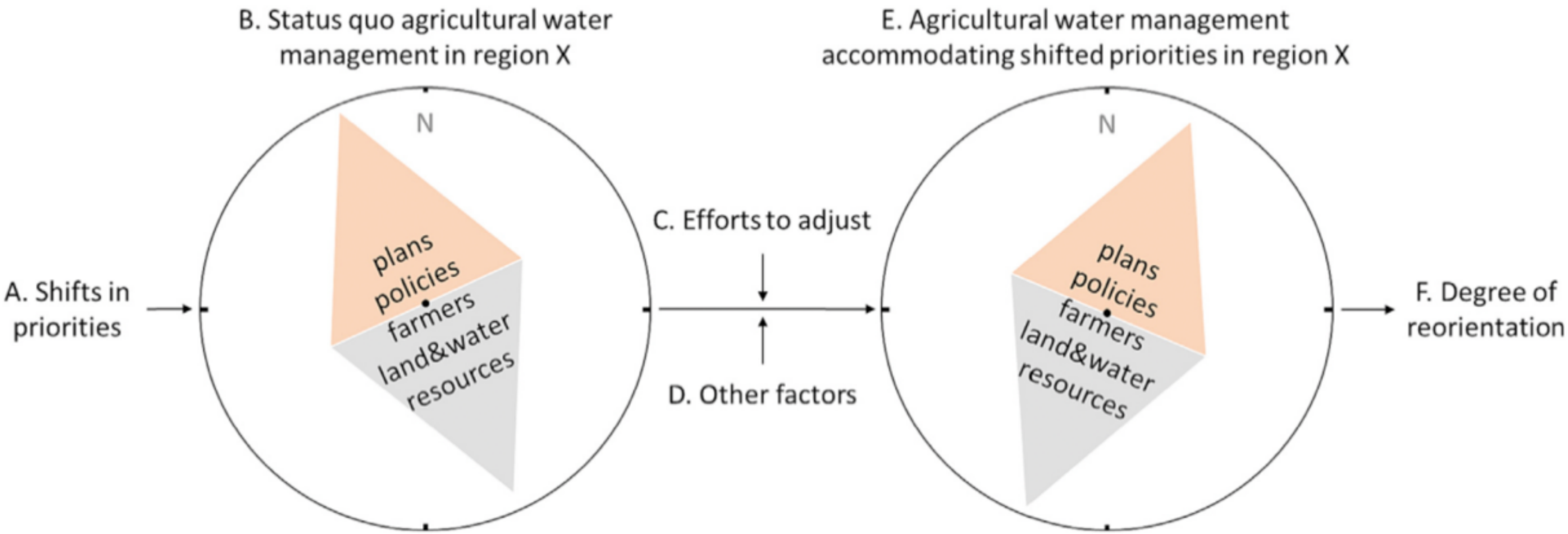

Figure 3.3: Agricultural water management framework (Source: Seijer 2023)

3.4 Industrial Water Management Framework

While industrialisation plays a significant role in the economic development and urban growth of a country, it is also greatly responsible for environmental degradation. Given the huge dependence of the industrial sector on freshwater resources and the potential for integrating water management, Zhou, Han and Zhou (2024) and IPIECA (2021) developed two frameworks for industrial water management (IWM). Section 3.4.1 and Section 3.4.2 discuss these frameworks.

3.4.1 Industrial Water Management Framework Based on Carbon Trading and Water Management

Water and energy are two important resources used widely to sustain urbanisation and industrialisation activities. The industrial sector is responsible for 20% global freshwater withdrawals and the generation of 30% global greenhouse gas emissions. Transitioning industries from being carbon intensive emitters to being low carbon emitters is a crucial step for achieving industrial sustainability. Moreover, the transition in industrial sustainability must also consider the growing worldwide water scarcity and should focus on integrating water management in all decisions. The complex interaction between water consumption and carbon emission defines the need for careful planning and execution for their management.

Zhou, Han and Zhou (2024) thus developed a planning framework that incorporates water management and carbon trading to assist in city-level planning. The framework is shown in Figure 3.4. It focuses on maximising water use efficiency to aid in sustainable economic growth. It also considers the carbon market and focuses on reducing carbon emissions through the integration of carbon cap-and-trade strategies. In the cap-and-trade system, the government sets carbon emissions caps for industries. By trading the unused carbon emissions allowances between industries, new emissions can be controlled and managed. The framework focuses on exploring the potential synergies between carbon trading and water management to achieve overall water management and industrial sustainability. And finally, by defining the link between the government and industries, it depicts the importance of the government in setting up regulations related to water management and carbon emissions.

This framework can be used by industrial decision makers and planners to make adequate decisions regarding the measures and steps that can be taken for achieving water sustainability by taking into consideration carbon emissions and water consumption.

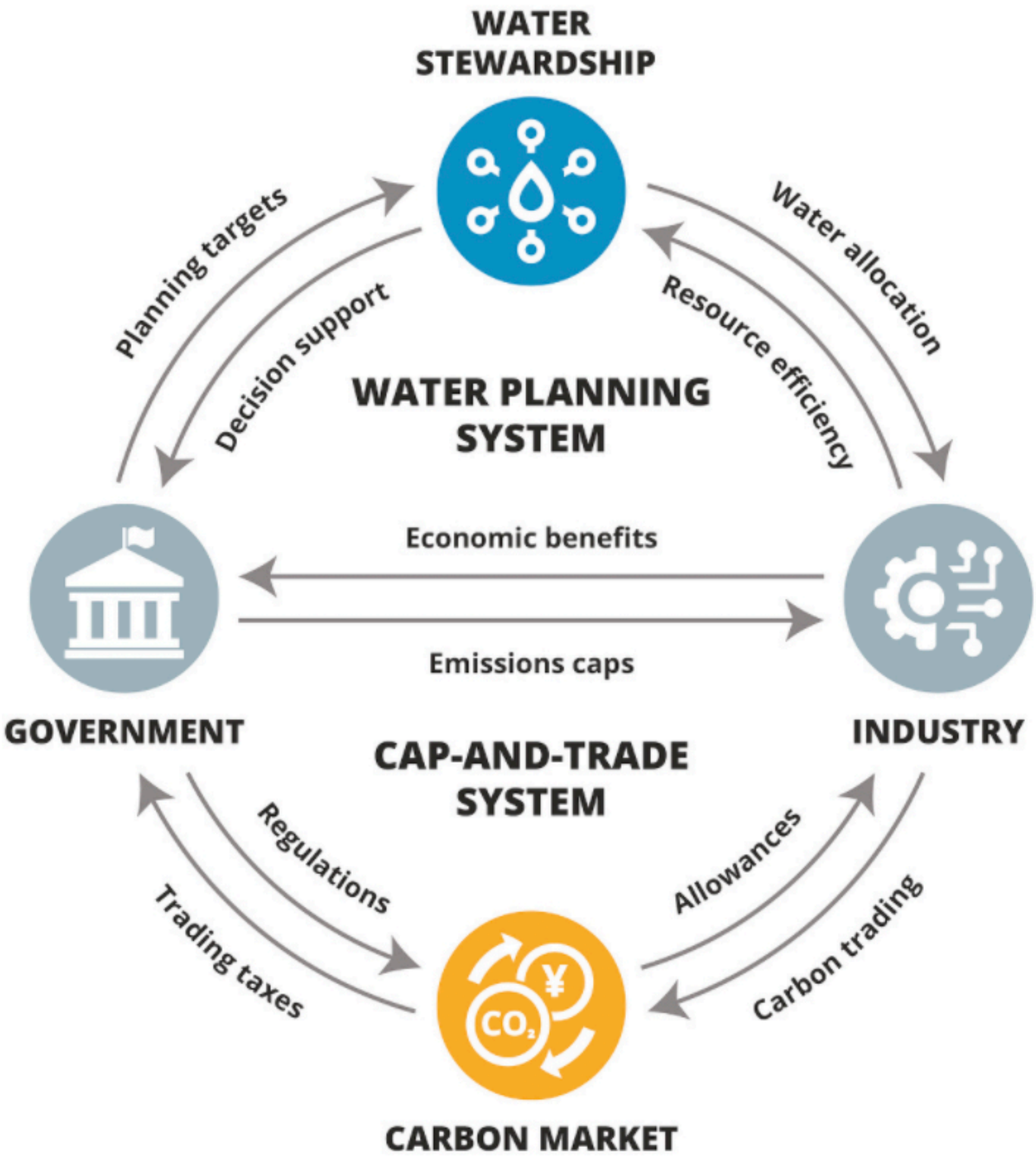

Figure 3.4: Industrial water management framework (Source: Zhou, Han and Zhou 2024)

3.4.2 Industrial Water Management Framework Based on Oil & Gas Operations

Despite the shift from non-renewable energy sources to renewable energy sources, O&G still plays a pivotal role in supplying majority of the global primary energy demand fulfilling 30% of the global energy demands (Zarkani and Fadel 2024). Offshore O&G operations not only consume water for different upstream and downstream activities but are responsible for the creation of large volumes of wastewater known as produced water. The management of this produced water poses as a challenge to the industries due to stringent government regulations regarding its disposal. The efficient management of water throughout the O&G operations can not only help reduce the consumption of water but also reduce the generation of this produced water.

IPIECA (2021) thus developed a cyclical water management framework that can be applied by the O&G industry throughout the life cycle of an asset. The framework is shown in Figure 3.5 and can help the industry to implement sustainable water management practices. The framework is composed of four stages, namely, planning, implementation, evaluation and review. The framework integrates stakeholder and regulatory engagement at the centre signifying the importance of these water management regulations and stakeholder engagements throughout the life cycle. The first stage of planning focuses on water risk assessment and the planning of all water management activities. The second stage focuses on implementation of the identified water management practices and their review. Regular monitoring of these measures helps identify the changes in water and wastewater demands and how they are likely to impact the O&G operations. The evaluation stage focuses on collecting the water data and performing a water risks review. The last stage of review evaluates if the measures taken address the water risks and improve operation while integrating water sustainability practices. The cyclical nature of the framework highlights the use of the review stage on future planning.

This framework can be used by decision makers and planners in the O&G industry to achieve the water efficiency targets specified in SDG 6 regarding increasing efficiency in water use and reducing pollution from wastewater discharge.

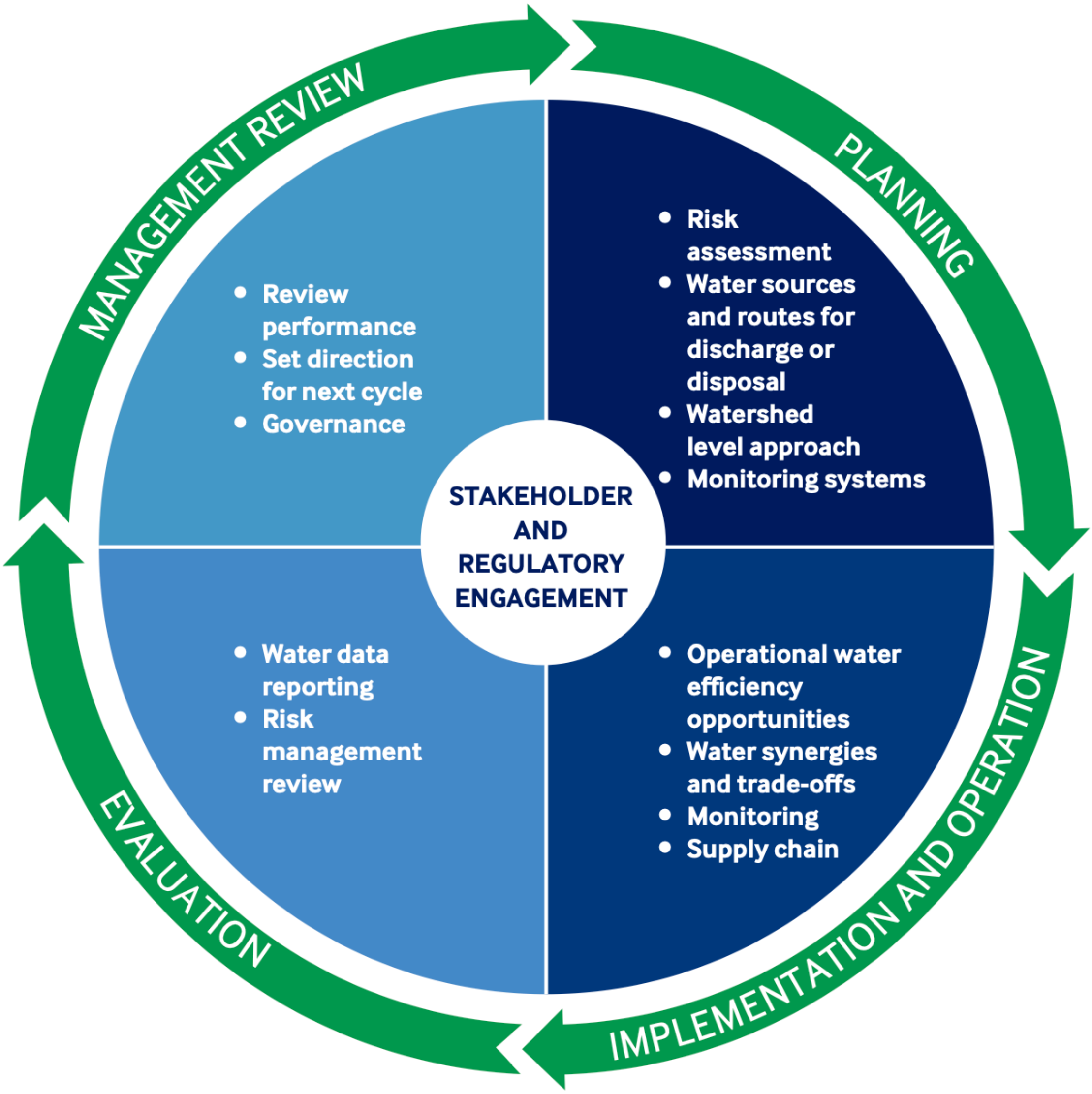

Figure 3.5: Industrial water management framework (Source: IPIECA 2021)

3.5 Building Operational Water Management Framework

The tourism industry has various impacts on the economical, socio-cultural and ecological aspects of a society. Moreover, the tourism industry is only projected to grow in the coming years. The growth in the tourism industry is going to inevitably result in an increase in the number of hotels (Kasim et al. 2014). Hotels are major consumers of water since occupants during their stay in hotels often consume more water than they would at home (Kasim et al. 2014). The application of innovative technologies in hotels can help reduce this water consumption.

However, the adoption of innovative technologies depends on various factors like cost and resources availability.

Kasim et al. (2014) developed a matrix-based framework that integrates the 4R concept (reduce, reuse, recycle and recovery) to aid selection of innovative technologies. The framework is shown in Figure 3.6. Depending on the capabilities of a hotel, the framework can help identify the innovative R technologies that can be adopted. For instance, a large hotel with financial funds to apply in technologies and the presence of existing knowledge can apply the highest level of innovative R which is recycling. On the other hand, a small hotel with less knowledge among staff and low investments in technology can adopt the lowest innovative R of innovative reducing.

The framework helps decision makers in a hotel to decide on the innovative R that can be applied depending on the knowledge and technological capabilities of the hotel. The framework further highlights that either individually or together, knowledge and technology can help identify innovative R technologies for water management.

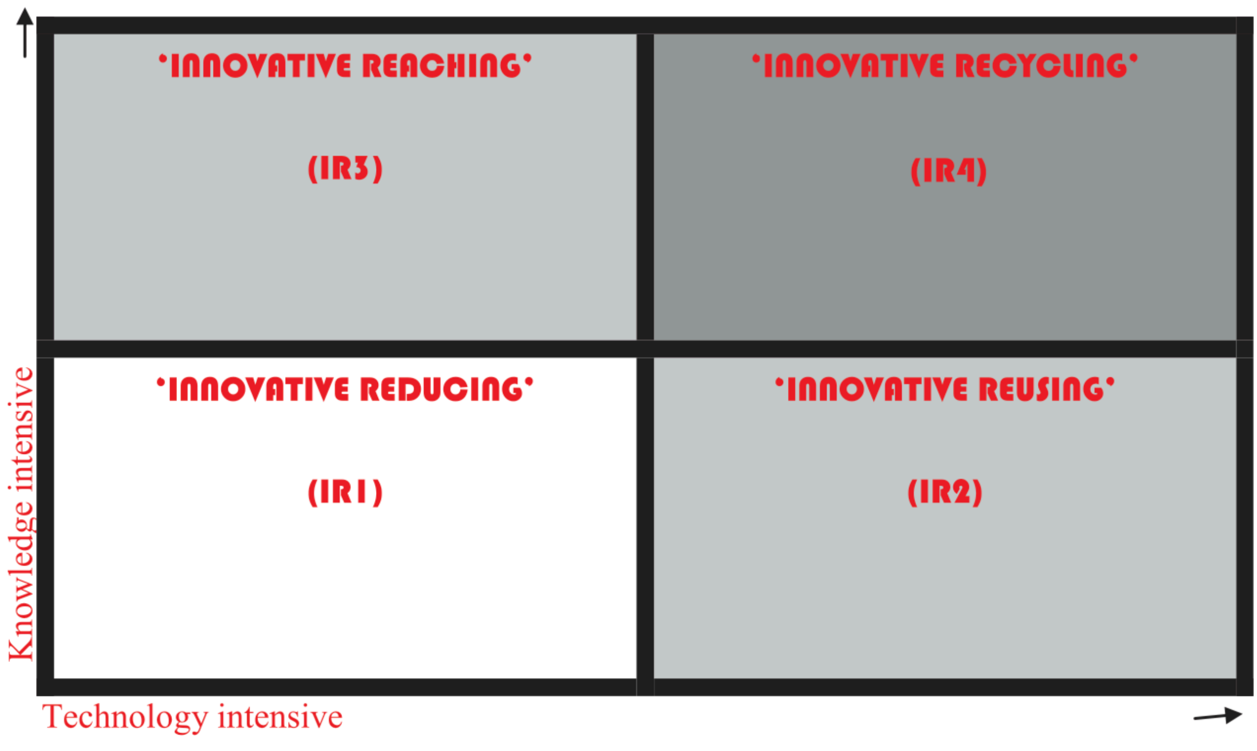

Figure 3.6: Building water management framework (Source: Kasim et al. 2014)

3.6 Comparison Between the Identified Water Management Frameworks

This section compares each identified framework on the themes of visual representation, impact of regulations, impact of technology, awareness, stakeholders' involvement, and adaptability and flexibility of design. Section 3.6.1 to Section 3.6.6 discuss each theme in a separate sub-heading.

3.6.1 Visual Representation

Visually representing a framework assists the reader to observe and understand the framework being presented and explore the relationship between the different variables. The visual representation style adopted depends on the aim of the framework. For instance, for a framework to assist in the selection of a parameter based on two variables, a matrix style is the most suited. This was the reason for Kasim et al. (2014) and McLellan et al. (2024) to select this visual representation style as shown in Figure 3.1 and Figure 3.6. Kasim et al. (2014) developed a framework to select the innovative R technique suitable for a hotel depending on the existing knowledge of the hotel and available technological capabilities. Moreover, McLellan et al. (2024) developed a framework to select suitable treatment technologies for emerging contaminants based on the level of treatment and mechanism of mitigation.

When the framework aims to show a closed loop process wherein the output of the final stage acts as the input for the first stage, a cyclical framework is most suited. This was adopted by IPIECA (2021) when designing a framework for water management in offshore O&G industries as shown in Figure 3.5. The final stage of the framework was the review stage whose inputs feed into the first stage of planning. A closed loop cyclical format of a framework is also suitable when showing the inter-relationship between all the parameters. This was adopted by Bjornlund and Bjornlund (2019) and Zhou, Han and Zhou (2024). Bjornlund and Bjornlund (2019) used this representation style to show the correlation between the different socioeconomic and biophysical factors on the various stages of AWM as shown in Figure 3.2. On the other hand, Zhou, Han and Zhou (2024) used this representation style to show the integration of water stewardship and carbon trading with the government and industries as shown in Figure 3.4.

Seijer (2023) developed a unique looking framework in the shape of a compass as shown in Figure 3.3. This was an ideal visual representation style to depict the shift in priorities and the corresponding degree of reorientation. The change in the arrow keys direction visually depicts this shift and reorientation.

3.6.2 Regulations

Regulations related to water management play a strong role in motivating companies to adopt water management practices and invest in technologies and knowledge that help save water. All the frameworks in some way or the other integrate government and regulations in the produced framework highlighting their importance. IPIECA (2021) placed regulations in the centre of the framework showing their importance at all stages. Kasim et al. (2014) and Zhou, Han and Zhou (2024) stated the huge impact government regulations have in motivating companies to adopt measures to manage the increasingly scarce water resources. They further noted that the provision of incentives to companies for taking measures to incorporate sustainability in their operations further increases the adoption rate of these regulations. Seijer (2023) highlighted how the government regulations and priorities are changing to adapt to various factors like climate change, food security, etc. This suggests how it is important for the government to continuously monitor their regulations and update these in accordance with the current scenario of the region.

The various stringent environmental standards set up by the government also motivate industries to adopt water management practices and invest in suitable technology. For instance, McLellan et al. (2024) noted how the stringent government regulations surrounding drinking water quality forces companies to invest in treatment technologies. McLellan et al. (2024) also state that the identification of these treatment technologies and stringent regulations motivate research to improve the technology in areas where gaps are identified. Zarkani and Fadel (2024) noted how the stringent water quality standards for the disposal of wastewater forces companies to take adequate measures to treat the wastewater before disposal to protect the local flora and fauna, and consider alternatives like reusing and recycling to reduce the amount of wastewater being discharged.

3.6.3 Technology

As discussed in Section 3.6.2, the growing stringent regulations and standards by the government forces companies to invest in technology to manage their water and wastewater. Kasim et al. (2014) and McLellan et al. (2024) developed frameworks to identify technologies for water management. While Kasim et al. (2014) developed a framework to identify water treatment technologies, McLellan et al. (2024) developed a framework to identify innovative water reducing technologies in hotels.

Kasim et al. (2014) states how the technologies adopted by a company largely depend on various factors like the availability of financial funds and existing knowledge. In addition to this, the willingness among the company decision makers regarding adoption of water management practices further impacts their investment in technology. Kasim et al. (2014) further states that the technological decisions taken do not necessarily have to be expensive. For example, adopting innovative reducing technology does not require huge financial investments from the company. Moreover, McLellan et al. (2024) state how the identification of technologies can help identify further areas of research in technology. Zhou, Han and Zhou (2024) state that the incentives provided by governments motivate companies to invest in technologies to reduce their water consumption.

3.6.4 Awareness

Kasim et al. (2014) noted that the investments in technology undertaken by a company greatly depend on the awareness of the decision makers in the company. It largely depends on whether these stakeholders want to invest in the technology and focus on water management. Kasim et al. (2014) further noted how the changes in the attitude of people can help in resource conservation. Seijer (2023) noted along the same lines that awareness related to climate change has resulted in a shift in societal priorities in relation to water management. The awareness among government policy makers is also responsible for the creation of regulations related to water management and all the frameworks (as discussed in Section 3.6.2) give extreme importance to regulations.

3.6.5 Stakeholders

All the frameworks discussed in this Chapter are intended for decision makers in the appropriate sector. Decision makers play a very crucial role in the implementation of water management practices as these are the individuals who decide what practices are going to be implemented. For example, for a hotel these decision makers could be the hotel management and for industries these could be the management team of the company.

Besides these decision makers, policy makers at the government level also play an important role in defining what regulations need to be followed. This is similar to the discussion in Section 3.6.2 that state the importance of the government in setting regulations to define what the companies must undertake.

3.6.6 Adaptability and Flexibility

To be successfully adopted in a region, it is extremely essential for the framework to be suited and adjusted in the local context (Kasim et al. 2014; IPIECA 2021). The framework must consider the geographical location and the impact of various socioeconomical and biophysical factors as these act as barriers as well drivers for water management (Bjornlund and Bjornlund 2019). All the frameworks highlight that a framework developed for a region or industry will not be directly adaptable in another area, but are flexible to be adapted.

3.7 Chapter Summary

This chapter started by defining the different types of water management frameworks (quantitative, qualitative and hybrid) available in literature and the rationale for selecting to review qualitative water management frameworks. It then reviewed the existing water management frameworks across different sectors like drinking water, agriculture, industry and buildings. It introduced each framework based on the rationale behind its formation, its aim and various components. This chapter finally concluded by comparing the similarities between each framework. It identified the huge contribution of government regulations and awareness for water management, along with the need for developing a framework that is flexible and adaptable for the region it is being developed. The learnings from these frameworks will help develop the conceptual framework as discussed further in Chapter 4.

Chapter 4 : Conceptual Framework for Embodied Water Management

This chapter presents the conceptual framework for EW management in India that was constructed based on literature review (Chapter 2) and a review of existing water management frameworks across different sectors (Chapter 3). It also identifies the drivers and challenges for EW management in India that further highlight the need for the conceptual framework.

4.1 Gaps identified from the Existing Water Management Frameworks

A review of different types of frameworks (quantitative, qualitative and hybrid) as discussed in Chapter 3, revealed that the majority of the existing water management frameworks focus on AWM (Bjornlund and Bjornlund 2019; Seijer 2023; Pourmahmoud, Shahdany and Roozbahani 2024). This is due to the huge consumption of water in this sector along with its significant contribution in the economic and social development of a country. Further the frameworks reviewed highlighted the absence of frameworks focused on water management during the construction stage of buildings and manufacturing of construction materials. The lack of such a framework highlights a major gap that the current research seeks to bridge by creating an EW management framework for residential building construction.

As discussed in Chapter 1, the construction sector in India is growing at an astounding rate of 6.6% per annum (Arukala et al. 2020). Building construction sector consumes 16% of global freshwater resources (Dixit, Kumar and Haghighi 2022), with huge possibilities for water conservation and management. The lack of an EW management framework in literature and the urgent need for water management in the construction sector in India define the need for creation of an EW management framework in this context. At this stage, a conceptual framework for EW management in India can be developed based on literature review (Chapter 2) and review of the existing water management frameworks from other sectors (Chapter 3).

4.2 Drivers for Embodied Water Management in India

As of 2023, the population of India was estimated at 1.43 billion which is a 35% increase from 2000 (World Bank Group 2024b). Moreover, its urban population increased from 27.8% of the total population in 2001 to 35.4% of the total population in 2021 (World Bank Group 2024a). If the current trend of population increase in the country continues, by 2050, India will be the most populous country housing 1.70 billion people with more than 50% of this population residing in urban areas (BIS 2016a). The building construction industry is crucial for urban development and with the increasing population and urbanization, the building construction activities are also going to increase.

The building construction industry is very water demanding as it consumes almost 16% of the global freshwater resources (Bardhan and Choudhuri 2016; Dixit, Kumar and Haghighi 2022). Groundwater is a very common source of water for these activities and its overexploitation due to increasing construction activities has resulted in declining groundwater tables across the country (Bardhan 2011). Moreover, since half of the population of India depends on groundwater for its water demand, managing this depleting resource is extremely essential to ensure water security in the country (Bej 2018). The Energy and Resources Institute (2022) notes that India is the largest user of groundwater in the world with an estimated consumption of 251 billion cubic meter per year which is more than quarter of the global groundwater consumption.

Knowledge of water consumption during construction activities (and manufacturing of construction materials) can help identify sustainable water management practices for conserving freshwater resources (Choudhuri 2015) and increasing water efficiency (Bardhan 2011). If EW is not measured and monitored, the rampant misuse of water will continue (Bardhan 2011) along with growing water scarcity episodes in the country.

Sharma and Chani (2022) note that India is dealing with severe water insecurity since it is responsible for 25% global water extraction, 17% global population and 4% global water resources. There have been many episodes of water scarcity in the country over the last decade such as the ban on construction activities in few states (such as in Pune in 2014) and the declaration of "day zero" in a state to mark the absolute absence of water in that region (such as in Chennai in 2019). The growing water scarcity in the country can further be observed in the visual increment in desertification in many Indian regions (Sharma and Chani 2022). Adding to that, the huge imbalance in the demand and supply of water resources in India is going to result in a critical decline in the country's aquifers within 20 years (Bej 2018). The huge water scarcity and water stress in India can also be noted since 600 million people are facing extreme water stress and almost 200,000 people are dying each year due to inadequate access to safe water (National Institution for Transforming India Ayog 2019). Besides the declining water quantity, India is also suffering from poor water quality. The country currently ranks 120 out of 122 in the water quality index and almost 70% of the country's water is contaminated (National Institution for Transforming India Ayog 2019).

4.3 Challenges for Embodied Water Management in India

Due to the growing water scarcity in India, the government has set up various policies and regulations for water conservation such as the Draft National Water Framework Bill 2016 and National Water Mission 2008. However, the majority of these regulations for the construction industry focus on the operational stage of the building while the pre-operational stage that includes the construction stage and manufacturing of building materials is often overlooked (Choudhuri 2015). A report by The Energy and Resources Institute (2018) further noted that due to the weak governance and planning, these regulations and policies are failing to conserve water resources in India. Moreover, construction water management and the implementation of sustainable practices in the construction sector is given very low priority in India (Bardhan 2015). This highlights the lack of awareness among people across all the sectors (government and construction industry) surrounding water management and water scarcity.

All the past EW studies conducted in India such as Bardhan (2011) and Choudhuri (2015) have only considered three to five construction materials when calculating the IEW of building. EWC for three of these materials (cement, steel and clay bricks) was recorded in the Indian context, while the EWC of two materials (aluminium and glass) was based on EWC values in Australian studies as published by Crawford and Pullen (2011). Sharma and Chani (2022) noted that the EWC of construction materials in Indian context is outdated (refer to Section 2.8 for more details) posing a challenge for EW management.

All the past studies on DEW conducted in India, such as Bardhan (2011) and Choudhuri (2015), calculated the values based on estimating the amount of water withdrawn from borewells and water delivered to construction sites by water tankers. None of the studies calculated the EWC of different construction activities. These EWC values for construction activities can help in controlling and monitoring water consumption by acting as baseline water consumption values (Bardhan 2015). Since water consumed on construction sites in India is rarely ever reported, there is an absence of these EWC values in Indian context. This lack of EWC of construction activities further poses as a challenge for EW management in India.

4.4 Conceptual Framework for Embodied Water Management in India

The discussion on all the frameworks presented in Chapter 3 highlight the importance given to government regulations and policies for water management. It shows how these regulations and policies act as starting points for implementation of water management policies. They also help encourage companies to manage and reduce their water consumption. Zhou, Han and Zhou (2024) noted how government regulations and investments provided by them to companies motivate the latter to reduce water consumption and carbon emissions. McLellan et al. (2024) revealed how regulations set up by the government in terms of water quality standards motivate companies to select treatment technologies for their mitigation. IPIECA (2021) further noted how government regulations play a pivotal role throughout the whole life cycle of an asset and how it impacts each stage of a project. This suggests the huge impact government regulations have in being a starting point for implementation of water management practices. Thus, "reviewing policies and practices for EW management" was set as the first step of the conceptual framework.

The three sustainability pillars and the 6R water hierarchy stages as discussed in Section 2.11 and Section 2.12 respectively play a significant role for EW management. The environmental pillar focuses on reducing potable water consumption, increasing reuse and recycling of water, and reducing wastewater being discharged for treatment. The economic pillar focuses on the selection of a cheap and affordable alternate source, and the measures taken to reduce, reuse and recycle must be cost efficient to the company. And finally, the social pillar aims at selecting a water source for an activity that does not negatively impact the activity being undertaken. Besides these, there are two policies in the Indian context that focus on EW management. These are the Draft National Water Framework Bill 2016 and the National Water Mission 2008. The review of these policies and regulations forms the first stage of the conceptual framework.

McLellan et al. (2024) noted how the government has been setting stringent water quality regulations. Similarly, Zarkani and Fadel (2024) state the stringent standards set by the government for the disposal of wastewater from O&G operations. These stringent standards and regulations prevent overconsumption of water by different industries (TERI 2018). As a result, the second stage of the conceptual framework is to "set benchmarks for water consumption" during manufacturing of materials and construction activities using existing EWC values as discussed in Section 2.8 and Section 2.9. The final stage of the conceptual framework is focused on "developing and implementing water management practices". The need for the inclusion of an implementation stage and identifying the water management practices has been proposed by studies like IPIECA (2021) and Seijer (2023).

By considering the drivers and challenges for EW management in India the framework is adaptable to Indian context. By focusing on the existing regulations and policies for water management, along with the existing EWC data, the framework is flexible in its application on both construction sites and material manufacturing industries. Adaptability and flexibility in this framework is extremely essential to ensure its successful application. The importance of a framework being flexible and adaptable was also noted by Kasim et al. (2014) and IPIECA (2021). The conceptual framework is shown in Figure 4.1

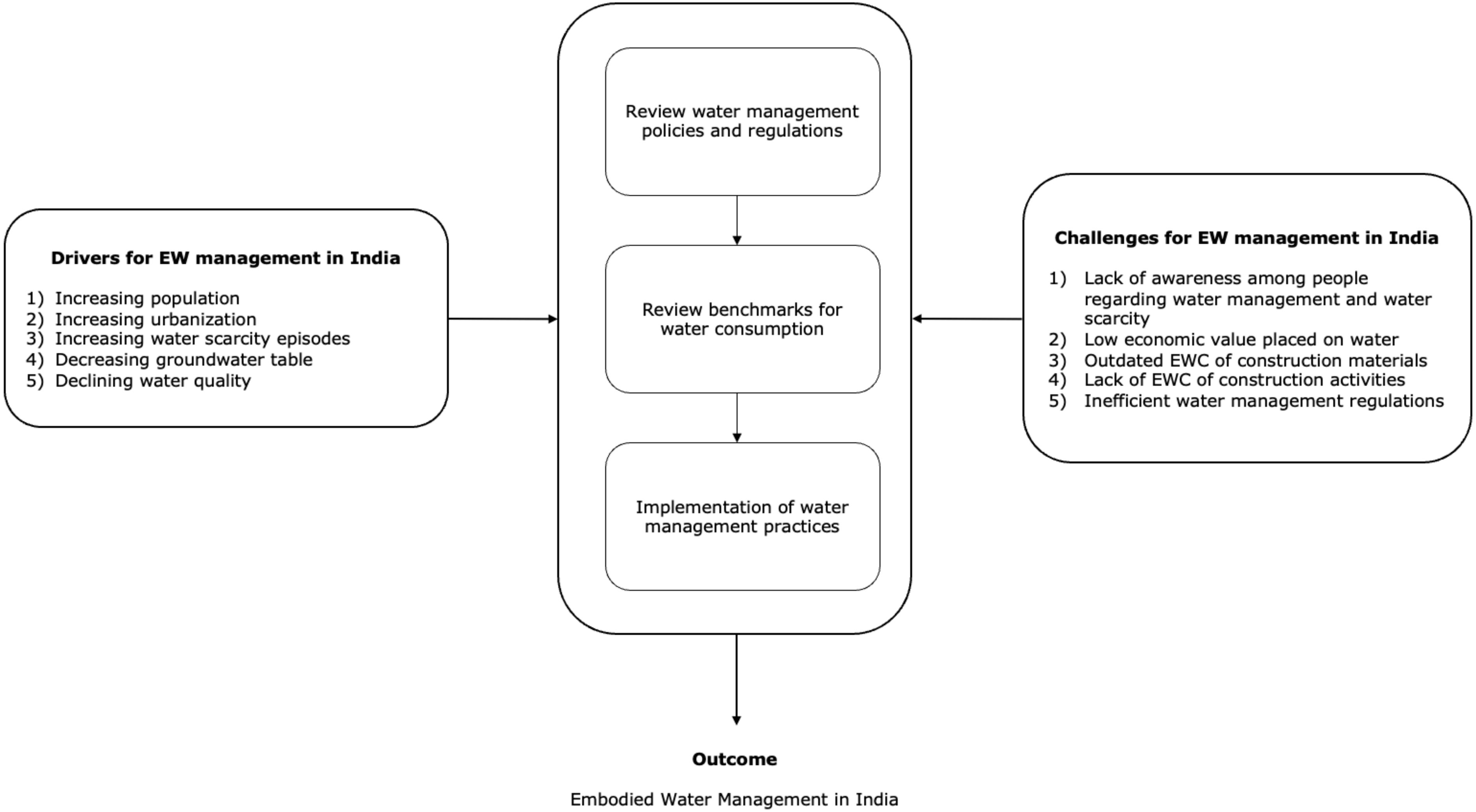

Figure 4.1: Conceptual framework for embodied water management (Source: Author)

4.5 Chapter Summary

This chapter highlighted that increasing population and urbanization along with increasing water scarcity are few of the drivers for EW management in India. It further highlighted that the lack of awareness and regulations in addition to the outdated and non-existent EWC values of construction materials and activities are few of the challenges for EW management in the country. Following this it discussed the similarities and key learnings from the water management frameworks reviewed in Chapter 3 to develop the conceptual framework of EW management in India.

Chapter 5 : Research Methodology

The "research onion" model that was used to develop the research methodology of this study is presented in this chapter. Each layer of the research onion is briefly explained before correlating its application to this study. It starts by explaining the first layer of the research onion which focuses on developing the research philosophy and approach to theory development. Following this the second layer of research design (which includes the methodological choice, research strategy and time horizon) are explained. And lastly, the innermost layer of the research onion (data collection and analysis) is discussed. This chapter concludes by discussing the limitations of the research design and the research ethics of the study.

5.1 Research Methodology Development

The theoretical and contextual factors considered when developing the strategy to conduct research underlines the research methodology of the study (James and Slater 2014; Melnikovas 2018; Saunders, Lewis and Thornhill 2023). It includes the philosophical beliefs and assumptions that play a pivotal role in the development of the research questions and the selection of appropriate research methods (Melnikovas 2018). Dissanayake (2023) states that the research methodology forms an integral part of a research as it assures coherence between the research philosophy, methods, and strategies. However, the development of this methodology is an arduous process as it involves the exploration of various theories. This process however can be simplified by adopting systemized and coherent models that highlight the key steps involved.

One such model is the "research onion" model developed by Saunders, Lewis and Thornhill (2023) as shown in Figure 5.1. It outlines detailed guidelines to develop a coherent, strong, and justifiable research design (Melnikovas 2018; Dissanayake 2023; Saunders, Lewis and Thornhill 2023). It is broadly divided into three stages. The first stage aims at identifying the research philosophy and research approach. The second stage focuses on developing the research design and the final stage outlines the data collection and analysis process that will be adopted to accomplish the research aim and objectives.

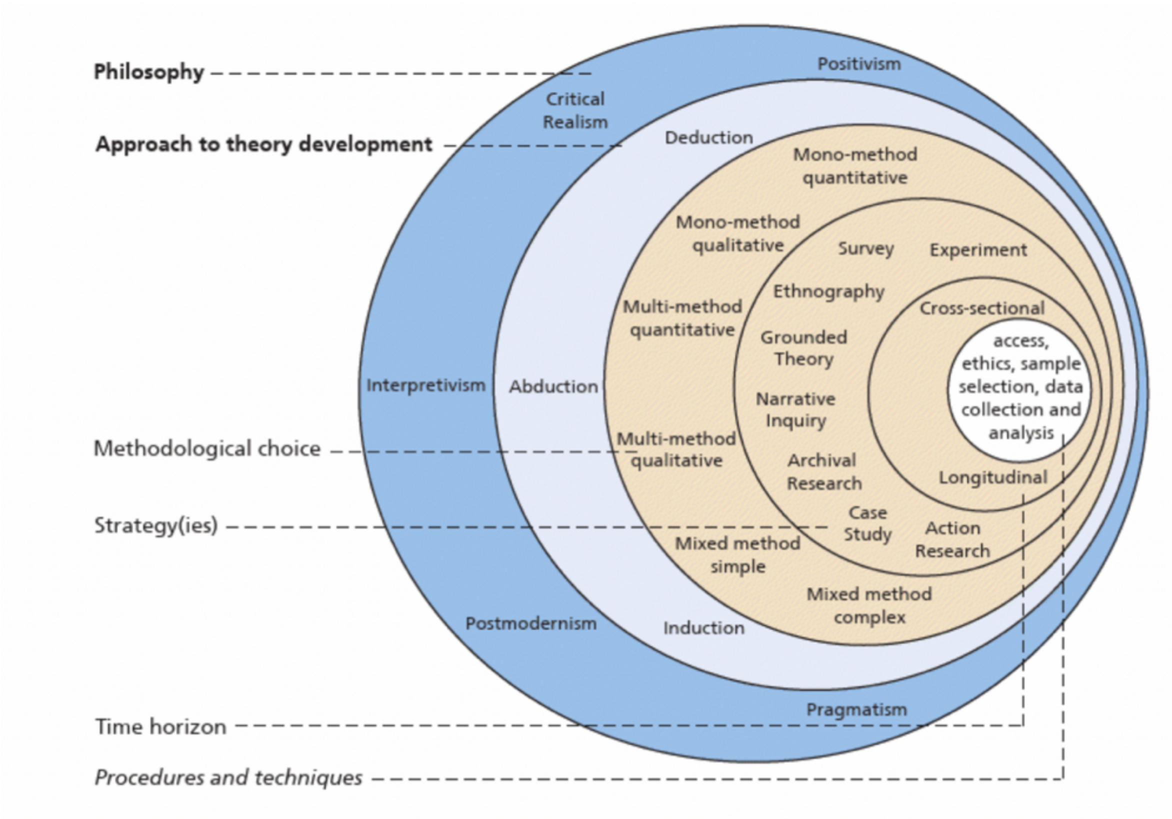

Figure 5.1: Research onion model (Source: Saunders, Lewis and Thornhill 2023, p.131)

This model was initially developed for business and management research, and later was widely used for social science research (Melnikovas 2018). Since this research deals with research management, involves human participants, and investigates the behavioural and social aspects of water management (along with its environmental and economic impacts), the "research onion" model is used as a basis for designing a coherent research methodology in this study. Figure 5.2 shows the research onion model adopted to this study and each layer is discussed in detail in this chapter.

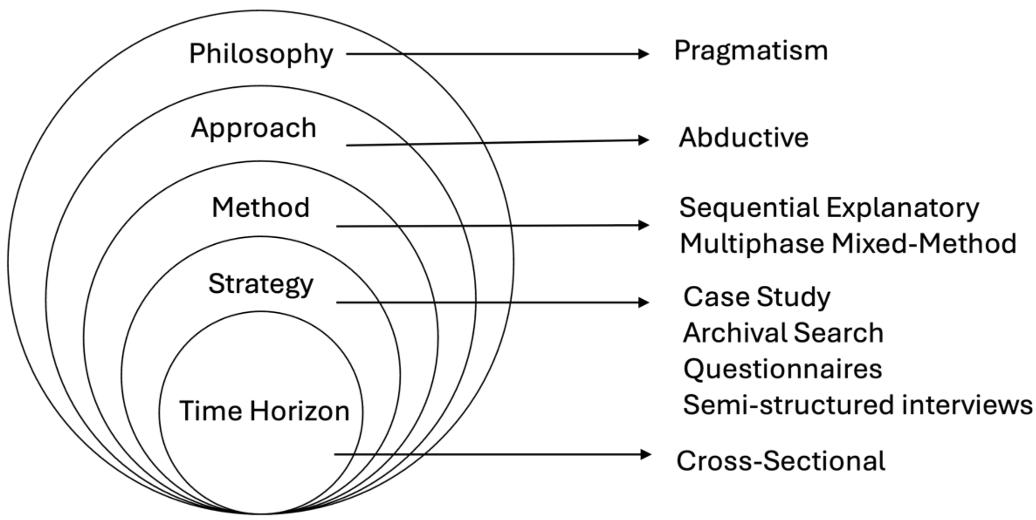

Figure 5.2: Research onion model of this study (Source: Author)

5.2 Research Philosophy

The research philosophy is the outermost layer of the research onion and the first step in developing the research methodology. Saunders, Lewis and Thornhill (2023) define research philosophy as "a system of beliefs and assumptions about what constitutes acceptable, valid and legitimate knowledge; the nature of reality or being; and the role of values and ethics in relation to research".

During the course of a research, the researcher knowingly and unknowingly makes various assumptions that help define the research philosophy (Dissanayake 2023). These assumptions are of the following three types (Corbetta 2003; Dissanayake 2023):

1) Ontological: These are assumptions made regarding the nature of reality. It constitutes elements the researcher considers essential for conducting the research thereby impacting the decision regarding what is being studied and how the subjects are analysed.
2) Epistemological: These are assumptions made about knowledge. It constitutes elements related to what the researcher considers as valid and

legitimate knowledge, and how this knowledge can be transferred. These assumptions thereby impact the type of data being collected.

3) Axiological: These are assumptions made about values and ethics. It determines the way the researcher wants to conduct the research thereby impacting the choice of research methods.

Bryman (2012), Creswell and Creswell (2018), and Saunders, Lewis and Thornhill (2023) define many research philosophies, but note that positivism, interpretivism and pragmatism are the most commonly used philosophies in social science related research. Table 5.1 discusses the differences in the ontological, epistemological, and axiological assumptions of these three philosophies.

Table 5.1: Ontological, epistemological, and axiological assumptions of common social science research philosophies (Adapted from: Corbetta 2003; Bryman 2012; Saunders, Lewis and Thornhill 2023)

Assumption	Positivism	Interpretivism	Pragmatism
Ontological	Positivists believe it is the role of the researcher to test theories and develop law-like generalisations using measurable and quantifiable data.	Interpretivists believe that humans create meanings, and these meanings must be interpreted. They thus believe that the creation of law-like generalisations results in the loss of credible data.	Pragmatists believe that only the concepts that can be supported by action are considered reliable.
Epistemological	They believe that only quantifiable data collected from measurements and observations is considered credible.	They believe that meanings must be interpreted, and this interpretation can lead to the production of new and rich credible information.	They believe that data can be collected and analysed in multiple ways. The most suitable research method depends on the research objectives and the reasons for collecting data.
Axiological	They believe in being neutral and thereby remain detached from the research participants. The values of the researchers therefore do not impact the analysis of the collected data.	The researcher connects with the research participants to interpret their feelings. Thus, the values and beliefs of researcher impacts the interpretation of collected data.	Like interpretivists, the values of the researcher impact the analysis of the collected data.

This study aims at developing a framework of efficient and SWM practices that can be applied during material manufacturing and construction of residential buildings. In doing so it follows a ”pragmatism” philosophy as it aims at developing concepts (in this case a framework) that can help achieve desired outcomes (in this case EW management).The ontological, epistemological, and axiological assumptions that define the pragmatism philosophy for this study are as follows:

1) Ontological: Despite water being a widely used resource, its sustainable management during building construction activities and construction material manufacturing processes is not given appropriate consideration. This is due to lack of government regulations and policies focusing on water conservation, along with limited awareness among people. As discussed in Chapter 2, the reality of water scarcity in India defines the practical need for water management. The rapidly growing residential building construction sector defines the basis for its analysis in this study.
2) Epistemological: This study aims at determining the EWC of commonly used construction materials and construction activities and using these values to calculate the EW of selected residential buildings in India. Moreover, it also collects data related to the factors that impact these water consumption values. These types of data are considered as reliable knowledge for data collection to achieve the aims of this study.
3) Axiological: The researcher believes that water is the most important and life sustaining resource, and its efficient consumption is extremely essential to manage the diminishing water resources. The lack of studies related to SWM for building construction in India, motivated the researcher to pursue further investigation in this topic. The aim of the research as aforementioned focuses on developing a framework of efficient water management practices that can only be accomplished if data related to current water consumption patterns, and factors impacting this water consumption are collected. This can help identify practical solutions to reduce the water consumption values. These data are collected through case studies, questionnaires, semi-structured interviews and archival search.

5.3 Approach to Theory Development

The second step in the research onion model is to determine whether the research undertakes a deductive, inductive, or abductive approach. Table 5.2 discusses the differences between the three approaches.

Table 5.2: Comparison between the deductive, inductive, and abductive approach to theory development (Adapted from: Bryman 2012; Gray 2014; Saunders, Lewis and Thornhill 2023)

Parameter	Deductive	Inductive	Abductive
Logic	A hypothesis is developed that is confirmed or disconfirmed through data collection and analysis.	Data is collected and analysed to produce a theory.	It is a combination of the deductive and inductive approach. A hypothesis is initially developed that is tested through data collection to produce a theory that is further tested.
Type of data collected	Quantitative data collected using a large sample size and following a highly structured methodology that can be adequately replicated.	It aims at understanding the background of the research subjects, thereby focuses on collecting qualitative data using a variety of methods and a small sample size.	It is open and sensitive to the data being collected. It also uses pre-existing data to interpret the collected data.
Underpinning philosophy	Positivism	Interpretivism	Pragmatism
Existing knowledge	Most widely adopted for analysing topics that have large existing data availability as it can aid in the development of the hypothesis.	Most widely adopted for analysing topics where there is limited data availability.	Most widely adopted for analysing topics where there is limited research in the context being researched but a lot of existing research on the topic in general to aid in the modification of existing theories or development of new theories.

This study focuses on EW, a field with limited research. Existing water management frameworks across different sectors (agriculture, urban, etc.) are analysed in Chapter 3 to help develop a conceptual framework for EW management in India (Chapter 4). Following the development of the conceptual framework and identifying gaps in available data, this study collects the required data related to water consumption during construction activities and construction material manufacturing. This data is used to develop the proposed framework for

EW management (Chapter 7). Hence, by using existing knowledge and modifying it to develop new knowledge, this study adopts an “abductive” approach.

5.4 Research Design

The research philosophy and approach help formulate the research aim and questions, which are then converted to a research project through the development of the research design that includes the next three layers of the research onion (Saunders, Lewis and Thornhill 2023). These three layers are the choice of research methods, research strategy and time horizon of conducting the study.

5.4.1 Methodological Choice

James and Slater (2014) and Saunders, Lewis and Thornhill (2023) define research methods as the process of data collection and tools of data analysis. These can be in the form of quantitative methods (that adopt the use of numerical data), qualitative methods (that adopt the use of non-numerical data) or mixed methods (that combine both numerical and non-numerical data) (James and Slater 2014; Creswell and Creswell 2018; Melnikovas 2018; Saunders, Lewis and Thornhill 2023). These methods can either be used individually such as in mono methods or as a combination of more than one method such as in multi-method or mixed methods as shown in Figure 5.3.

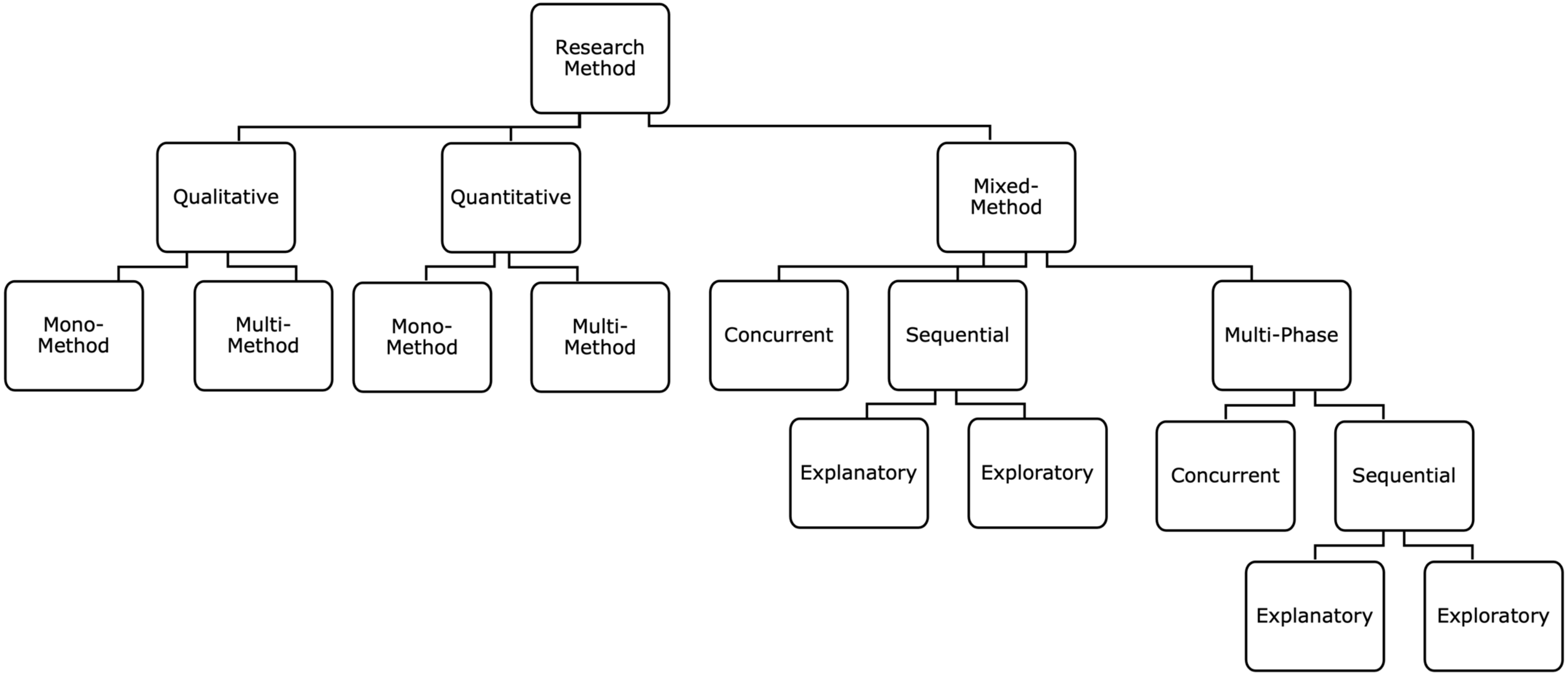

Figure 5.3: Mono, multi and mixed-method designs (Adapted from: Saunders, Lewis and Thornhill 2023)

Multi-method quantitative design combines more than one method of quantitative data collection and analysis, while multi-method qualitative design follows the same process by using qualitative data collection and analysis methods (Creswell and Creswell 2018; Saunders, Lewis and Thornhill 2023).

Mixed method design on the other hand combines both quantitative and qualitative methods in different designs such as (Creswell and Creswell 2018; Saunders, Lewis and Thornhill 2023):

1) Concurrent/ convergent mixed method: Both quantitative and qualitative data are collected and analysed separately in the same single phase of data collection. It differs from a sequential mixed method because both quantitative and qualitative methods collect the same data which are then analysed to confirm or disconfirm their relation to each other.
2) Sequential exploratory mixed method: Qualitative data is collected and analysed in the first phase which is followed by the collection and analysis of quantitative data. This method aims to explore how the quantitative data supports the qualitative data.
3) Sequential explanatory mixed method: Quantitative data is collected and analysed in the first phase which is followed by the collection and analysis of qualitative data. This method aims to explain how the qualitative data supports the quantitative data.
4) Multiphase mixed method: This could be a sequential or concurrent multiphase in which quantitative and qualitative data are collected and analysed at different phases of the research in any order.

Table 5.3 compares the differences between quantitative, qualitative, and mixed methods.

Table 5.3: Comparison between quantitative, qualitative, and mixed methods (Adapted from: Bryman 2012; Naoum 2013; Creswell and Creswell 2018; Saunders, Lewis and Thornhill 2023)

Parameter	**Quantitative**	**Qualitative**	**Mixed**
Type of data being collected and analysed	Numerical	Non-numerical (like words, images, etc.)	Combination of numerical and non-numerical
Logic	It aims to collect data to test a hypothesis and develop theories	It aims to gain in-depth insights into the research subjects and explore their hidden meanings to aid in the development of a framework	Quantitative and qualitative data are collected to combine the benefits of both methods and determine how one method can support the other for the development of theories.
Relationship with the research participant	Independent	Dependent	Combination of the two
Method of data collection	Structured and rigorous methodology that can be replicated	Unstructured or semi-structured methodology that does not need to be replicated but can serve as a basis for the development of another methodology	Combination of the two
Method of data analysis	Statistical and Graphs	Narrative analysis and Grounded theory	Combination of the two
Research strategy	Surveys (like structured interviews, observations and questionnaires) and experiments	Surveys (like semi-structured or unstructured interviews, unstructured questionnaires) and case study	Combination of the two
Research philosophy	Positivism	Interpretivism	Interpretivism Pragmatism
Research approach	Deductive	Inductive	Deductive Inductive Abductive

Yin (2014) states the impact of the research questions on development of the research design in terms of an exploratory, explanatory or descriptive study. Exploratory research design is based around questions starting with "what", while explanatory research design is based around questions starting with "what, how and why" (Yin 2014). Moreover, descriptive studies are based on questions starting with "who and where" (Yin 2014). The research questions underpinning this study focus on identifying "what" factors impact water consumption and "how" they impact it. As a result, this study is explanatory in nature. To accomplish the research aim, it adopts a "<u>sequential explanatory multiphase mixed method</u>" research design as shown in Figure 5.4. A mixed-method research design is suitable as the collection of both quantitative (quantities of material and water consumed) and qualitative (factors impacting water consumption) data are essential to answer the research questions. Moreover, these quantitative and qualitative data are collected in different stages (aligning with a multiphase design) with quantitative data preceding the qualitative data (aligning with a sequential explanatory design). The quantitative data (quantities of material and water consumed) is collected before the qualitative data (factors impacting water consumption) to define the basis for qualitative data collection. Stick (2006) notes that the quantitative data provides a general understanding of the research problem, and the qualitative data explains the statistical results by exploring the participant's views in more detail.

This research design is divided into seven stages. In the first and second stages of the study, quantitative data is collected and analysed which forms the basis for further data collection. This is followed by a sequential explanatory design wherein quantitative data is first collected followed by qualitative data to identify the factors impacting the collected quantitative data. Table 5.4 discusses each stage in this design along with its application to this study and the research objectives accomplished.

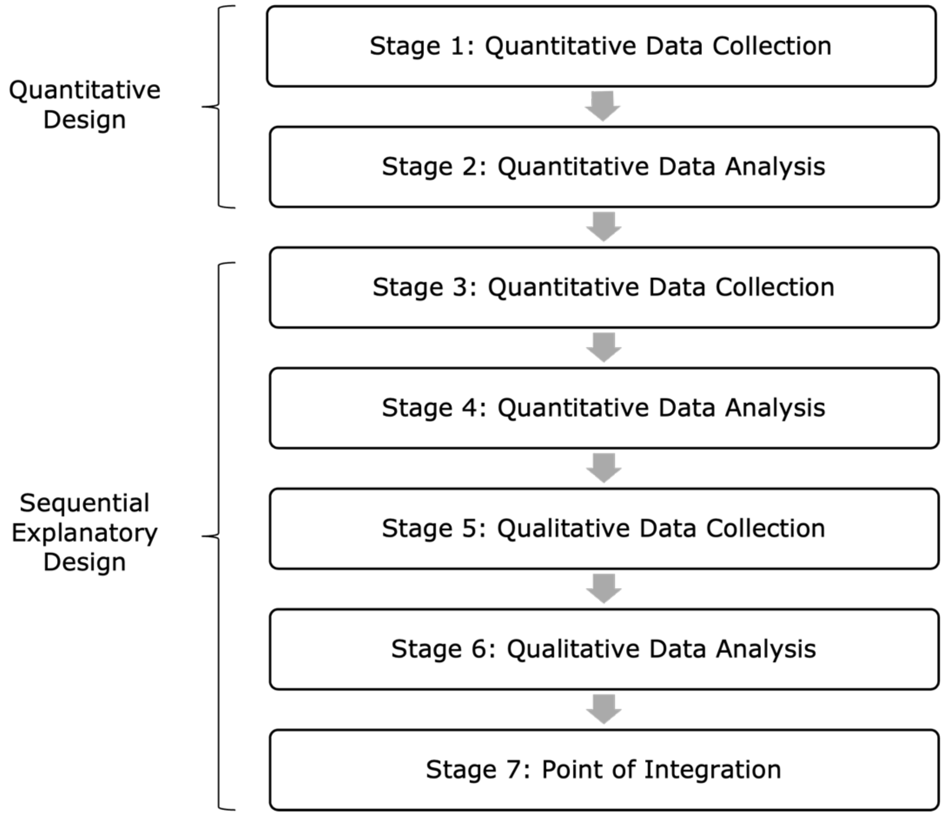

Figure 5.4: Flow chart of research design (Source: Author)

Table 5.4: Description of the seven stages of this study (Source: Author)

Stage	Application to this study	Research objective
Stage 1: Quantitative data collection	Case study residential buildings are selected, and their BOQ's collected.	2
Stage 2: Quantitative data analysis	The BOQ's are analysed to determine the most common construction materials and construction activities. These are analysed further in the sequential explanatory study.	2
Stage 3: Quantitative data collection	Quantitative data related to water consumption during manufacturing of the identified construction materials and construction of the selected case study residential buildings are collected. An archival search is conducted to determine the ECC of construction materials in Indian context. A questionnaire survey is conducted to identify the adoption level of water metering in the Indian construction sector.	3,4 and 5
Stage 4: Quantitative data analysis	The collected water consumption data and BOQ's are used to analyse the EWC of construction materials and construction activities. These EWC data are then used to calculate the EW of case study buildings. The ECC are used to calculate the EC of case study buildings and identify any relationship between EC and EW. The questionnaire is analysed to determine the adoption rate of water metering in India, along with the technique used for water metering and the rationale behind metering (or not metering) the water consumption.	3,4 and 5

Stage 5: Qualitative data collection	Qualitative data on factors influencing EWC values are collected through semi-structured interviews.	6
Stage 6: Qualitative data analysis	The semi-structured interviews collected data on the themes of geographical location, water consumption areas, water management policies and practices, challenges for their adoptions, and recommendations by the interviewee to make the process more sustainable. These were analysed to determine the factors impacting water management and water consumption on construction material manufacturing plants and residential building construction sites.	6
Stage 7: Point of integration of quantitative and qualitative data	Both the quantitative and qualitative data are integrated to develop the proposed framework.	7

5.4.2 Research Strategy

The research strategy refers to the strategy of data collection and analysis (Bryman 2012) and it is the link that connects the methodological choice of the research with its philosophy (Saunders, Lewis and Thornhill 2023). As a result, the selection of an appropriate research strategy is essential to ensure the collection of coherent and reliable data to accomplish the research aims and questions (Saunders, Lewis and Thornhill 2023).

This study adopts the use of "case studies, archival search, online questionnaires and semi-structured interviews" as research strategies. Table 5.5 discusses the reasons for their selection and their corresponding research objectives. Figure 5.5 shows the research methodology design of this study.

Table 5.5: Research strategies of this study (Source: Author)

Research strategy	Rationale of selection	Research objective
Case studies	Case studies allow in-depth inquiry into the research subject (also known as case) in its real-life setting (Saunders, Lewis and Thornhill 2023). By using this strategy, the case can be analysed in great depth and extensive insights about it can be collected. The selection of residential buildings in India as case studies can help analyse these buildings in-depth to determine all the materials that were used and activities that were undertaken for their construction, along with their respective quantities. Moreover, using case studies has practical relevance as it provides real-world examples (in this case how the building is constructed, what materials are used, what activities are undertaken, and their quantities) to help inform practice and policy (in this case the development of EW management framework).	2, 3 and 4
Archival search	An archival search can help broaden the data that is being collected for a study while being cost and time effective for the researcher. For a study like this that focuses on determining the EWC of construction materials and activities through primary data collection, primary identification of ECC is outside the scope of study. Using an archival search to collect this ECC data helps ensure that the data being collected is of high standard and is reliable (Brenna 2023). For this study, online databases produced by the government and industry that list the environmental performance of construction materials are ideal secondary sources to identify ECC of construction materials in Indian context.	4
Online questionnaire	Questionnaires are an ideal research strategy to collect data that is generalisable as it is obtained from a large sample (Naoum 2013). Since this study aims to gain broad and generalisable information related to water metering on construction sites, questionnaires are an ideal research strategy. Moreover, these questionnaires are circulated online since this is a cost and time efficient option when the research participants are not in the same location as the researcher.	5
Semi-structured interviews	Naoum (2013) states the benefits of using semi-structured interviews to gain in-depth information regarding a topic. Since this study aims to gain in-depth insight into the factors that impact water consumption, water management practices adopted, and challenges encountered, semi-structured interviews are an ideal research strategy. Following a semi-structured format, provides flexibility in asking specific questions related to the identified themes while also allowing the opportunity to ask follow-up questions to better understand the initial answers. These interviews help collect deep and detailed information regarding the research topic.	6

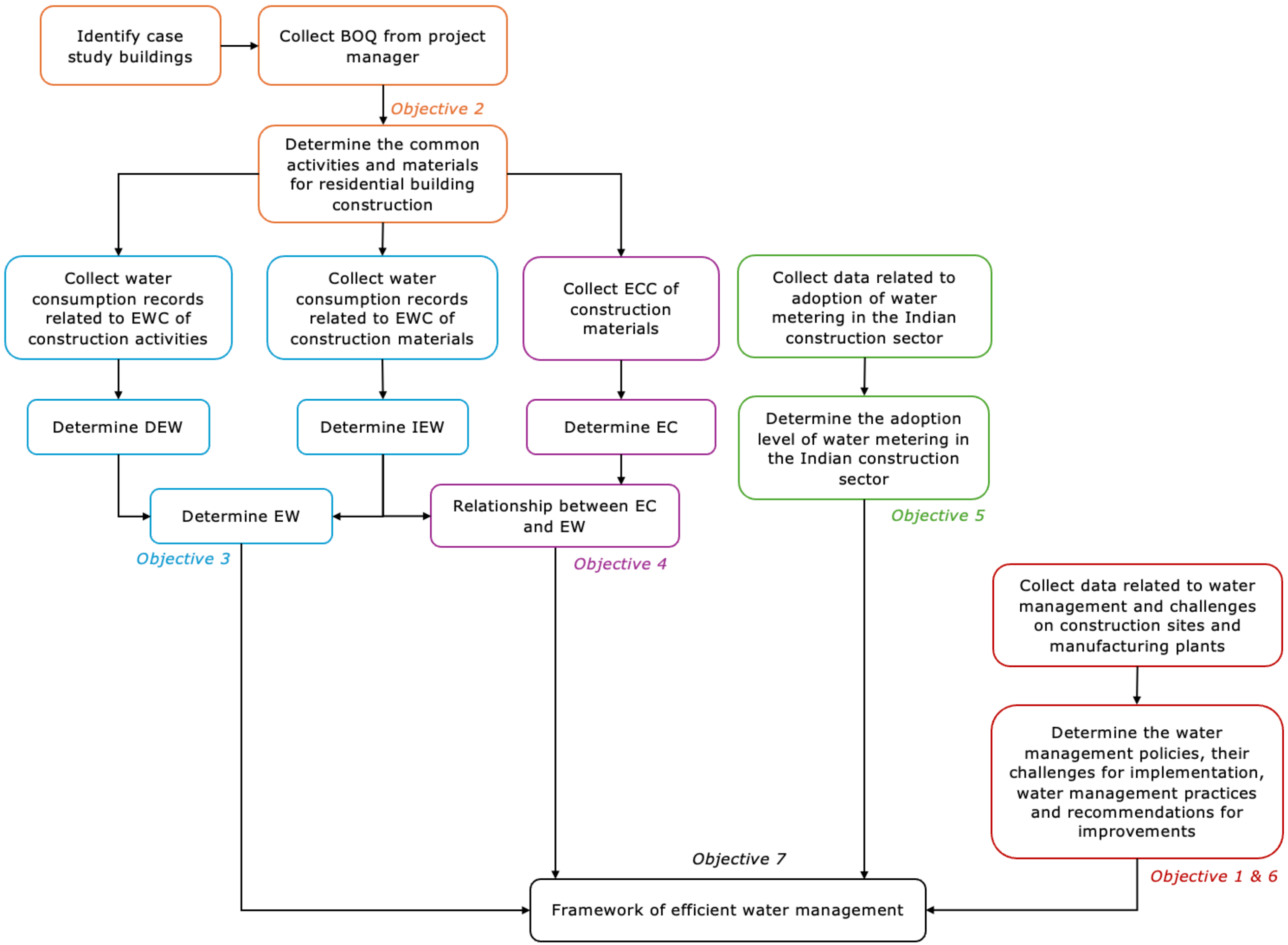

Figure 5.5: Research methodology of study (Source: Author)

5.4.3 Time Horizon

The third and final layer of the second stage of the research onion is the definition of the time horizon of the study. The time horizon of the study depends on the research questions and is crucial to define the scope of the research as it defines the time frame of data collection (Saunders, Lewis and Thornhill 2023). A study can be defined as a cross-sectional (or snapshot) study if the research topic collects data for a particular time frame (Saunders, Lewis and Thornhill 2023). On the other hand, it may be classified as a longitudinal (or diary) study if it collects data over a long-time frame (Saunders, Lewis and Thornhill 2023).

This study collects data related to EWC of construction materials and construction activities through document analysis that recorded these values at the time of data collection. This corresponds to a snapshot of the data thereby contributing to a "cross-sectional" time horizon research design. Thus, the EW of selected case study buildings was also a snapshot calculation. This is corroborated by Bryman (2012) that states survey research like this study are conducted in a cross-sectional design.

5.5 Data Collection

The final layer of the research onion is the data collection and analysis layer. Section 5.5 discusses the data collection procedure while section 5.6 discusses the data analysis process.

The two types of data collected for research are primary data and secondary data (Hox and Boeije 2005). Primary data refers to first-hand data collected by the researcher using either one or a combination of more than one research strategy (Hox and Boeije 2005). Secondary data on the other hand refers to data collected by the researcher upon reviewing existing publications and has no connection with its collection in the first place (Hox and Boeije 2005; Bryman 2012). Section 5.5.2 discusses the primary data collection while section 5.5.3 discusses the secondary data collection. Prior to commencing the data collection, it is essential to identify what data is required to answer the research questions, and the appropriate sources from which this data can be collected. Section 5.5.1 discusses this.

5.5.1 Data Required

Identifying the required data and the sources of its collection are very crucial steps for successfully achieving the research aim and objectives (Bryman 2010). It is extremely essential to correctly and carefully define all the data that needs to be collected as the collected data directly impacts the data analysis and the successful accomplishment of the research objectives. Table 5.6 summarises the data required and its source of collection for accomplishing each research objective.

Table 5.6: Data required and data collection method to accomplish research objectives (Source: Author)

Research objective	Data required	Data collection method
Objective 1: To identify water management policies and practices adopted on construction sites and material manufacturing plants worldwide and in India.	1) Qualitative – Existing water management policies and regulations. 2) Qualitative – Challenges to implement these regulations.	1) Literature review 2) Interviews with selected construction professionals and materials manufacturers.
Objective 2: To identify the commonly used construction materials and construction activities undertaken for residential building construction in India.	1) Quantitative - BOQ of case study buildings.	1) BOQs obtained from project consultant of the case study buildings
Objective 3: To calculate the EW (DEW & IEW) of residential construction projects in India.	1) Quantitative - BOQ of case study buildings. 2) Quantitative - Water consumption records of selected material manufacturing. 3) Quantitative - site water consumption records of case study buildings.	1) Interviews with material manufacturers to collect water consumption records documents. 2) Interviews with project consultant of the case study buildings to collect site water consumption records documents and building BOQ.
Objective 4: To investigate the relationship between EW and EC of the selected construction materials.	1) Quantitative – ECC of construction materials	1) Archival search of existing ECC database in the Indian context
Objective 5: To investigate the adoption level of water metering on construction sites in India.	1) Quantitative – Adoption of water metering on construction sites. 2) Quantitative –Technique for water metering. 3) Quantitative – Reasons for metering (or not metering) the water consumption.	1) Questionnaire filled out by construction professionals.

Objective 6: To analyse how to improve the efficiency of water management practices followed on building construction sites and construction material manufacturing process in India.	1) Qualitative –Water management practices followed. 2) Qualitative – factors impacting water consumption and water management.	1) Interviews with construction professionals and material manufacturers.
Objective 7: To develop and validate a framework for efficient water management practices that focuses on maximising water efficiency and minimizing water consumption in the residential building construction sector in India.	1) Qualitative – Challenges for implementation of water management practices and regulations. 2) Quantitative – EWC of construction materials and construction activities 3) Quantitative – EC of construction materials and its relationship with IEW.	1) Interviews with construction professionals and material manufacturers. 2) Documents collected from construction professionals and material manufacturers. 3) Archival search of ECC of construction materials. 4) Questionnaire filled out by construction professionals.

5.5.2 Primary Data Collection

Primary data for this study was collected through case studies, questionnaires and semi-structured interviews, discussed in Sections 5.5.2.2, 5.5.2.3 and 5.5.2.4, respectively. The selection of an appropriate sample size is essential to ensure that adequate data is collected for comprehensible analysis. The sample size selection process is defined in Section 5.5.2.1. The validity of collected data is another extremely important consideration in defining the suitability of the collected data. Section 5.5.2.5 discusses the data validation process for this study.

5.5.2.1 Sample Size

It is not always possible to collect data from an entire population (research subjects like objects, people, etc.) to answer the research questions (Saunders, Lewis and Thornhill 2023). Selection of a sample from a large population can help overcome the time and access restrictions of collecting data while also ensuring the entire process of data collection and analysis is manageable (Saunders, Lewis and Thornhill 2023). Naoum (2013) defines a sample as “a specimen or part of a whole (population) which is drawn to show what the rest is like”.

Patton (2015) states the selection of a sample size based on the research questions and resources availability in terms of cost and time. The selection of an appropriate sample is of utmost importance to ensure that the data collected is representative of the entire population. The sample size can be selected using a probability sampling or non-probability sampling process depending on the research questions (Saunders, Lewis and Thornhill 2023). Probability sampling is used when the aim of the research is to make statistical inferences from a large group of research subjects (Saunders, Lewis and Thornhill 2023). However, when the aim of the research is to gain insights that are richer than statistical inferences from a small group of research subjects, non-probability sampling is adopted (Saunders, Lewis and Thornhill 2023).

This study adopts a mixed sampling design as outlined by Saunders, Lewis and Thornhill (2023). Probability sampling was adopted to identify the questionnaire respondents as the aim of these questionnaires is to make statistical inferences from a large group of research subjects regarding the adoption level of water metering on construction sites in India. On the other hand, non-probability sampling was adopted to identify the semi-structured interview respondents as these interviews aimed to gain an in-depth understanding of the water consumption patterns, water management policies and water management practices followed during building construction and material manufacturing.

There are various types of probability sampling methods to determine the appropriate sample size and participants. This study adopted the use of "systematic random sampling" technique as this technique is suitable for small and large sample sizes as opposed to simple random sampling being suitable for only large sample sizes (Saunders, Lewis and Thornhill 2023). To identify appropriate respondents for the questionnaire, a Google and LinkedIn search was conducted to identify construction professionals working in India. The questionnaire was distributed to 250 construction professionals. A response rate of 18% (46 responses) with varying professional backgrounds (project managers, contractors, civil engineers and architects) was received. To adhere to the ethical requirements of Robert Gordon University (RGU), each questionnaire respondent was assured of anonymity by issuing an anonymity letter shown in Appendix C.

There are various types of non-probability sampling methods to determine the appropriate sample size and participants. This study adopts the use of a "snowball sampling" technique based on Bryman (2012) and Saunders, Lewis and Thornhill (2023). Bryman (2012) defines snowball sampling as a process of convenience sampling in which the researcher makes initial contact with a small group of experts in the field of study, who then help the researcher establish contact with other people. Given the difficulty in contacting the target audience and receiving responses from them, the researcher adopted this technique.

To identify interviewees for construction activities, four construction professionals were identified through a Google and LinkedIn search. These four interviewees helped identify the other three interviewees also working in the construction sector in India. The interviewees were selected based on their experience of working on residential building construction projects specially those made of RC. Moreover, to ensure robust data collection, construction professionals belonging to different backgrounds (project contractors, project managers, civil engineers and architects) were selected. To identify interviewees from construction material manufacturing companies, different manufacturing companies were searched on google and key personnel working in those companies were identified and contacted through LinkedIn. At the end of the interview, the interviewees were asked for their contacts (in either the same material industry or another), who were further contacted for data collection. Following this approach, two interviewees each for cement, glass and sand were selected, while one interviewee each for tiles and bricks was selected. The interviewees were selected based on their involvement and knowledge of the material manufacturing process. The interviewees had different designations such as plant head, managing director of the company, head of sustainability and technical services, but had a knowledge of the water management in the process. To adhere to the ethical requirements of RGU, each interviewee was issued a confidentiality letter shown in Appendix D.

Saunders (2012) notes that for a homogeneous group, four to twelve research participants form a good sample size for semi-structured interviews. Saunders and Townsend (2016) state that in some cases of qualitative interviews, depending on the research questions, one interviewee sample may be sufficient to provide adequate data (Saunders, Lewis and Thornhill 2023). Bryman (2012) states that there is no definitive answer to an ideal sample size as this number depends on various factors like cost and time constraints and available access to research participants. Guest, Bunce and Johnson (2006) and Corrigan and Onwuegbuzie (2023) further add that an ideal sample size could be achieved when a saturation level in terms of the responses has been received. The saturation level is achieved when the analysis of new data that has been collected does not result in the generation of any new themes or provide new information (Corrigan and Onwuegbuzie 2023). To minimize any bias associated with the selection of the sample, it was assured that the sample was diverse with interviewees and questionnaire respondents belonging to different professional backgrounds as discussed above.

Saunders, Lewis and Thornhill (2023) argue that when using case studies, a sample of one or two case studies could be sufficient to collect data to thoroughly analyse the cases and derive conclusions. Moreover, data collection through case studies is often accompanied by another data collection strategy like semi-structured interviews (Saunders, Lewis and Thornhill 2023) as in this study. Data through these interviews can be collected from all participants of these cases or a sample of the population (Saunders, Lewis and Thornhill 2023). In this study, a sample of case study population was interviewed for data collection.

Table 5.7 summarises the sample size selected for each research strategy.

Table 5.7: Research strategy and sample size (Source: Author)

Research strategy	**Sample size**	**Research objective**
Residential buildings case study	2	2,3 and 4
Construction professional questionnaire respondents	46	5
Semi-structured interview participants for residential building construction	7	6
Semi-structured interview participants from construction material manufacturing company	8	6

5.5.2.2 Case Studies

Case study research is an in-depth investigation of a case (group, organisation, process, etc.) in its real-life background (Bryman 2012; Cook and Kamalodeen 2023). It explores the relationship (if any) between different variables in the case to gain valuable and intensive insights that can be used to understand a phenomenon or generate a theory (Creswell and Creswell 2018; Saunders, Lewis and Thornhill 2023). Moreover, Cook and Kamalodeen (2023) state its application for collecting both quantitative and qualitative data in mixed-method research like this study.

Using residential buildings constructed in India as case studies, provides the ability to analyse them in detail. These case study buildings are analysed to identify the commonly used construction materials and construction activities undertaken for residential building construction in India. Following this, the EWC of these materials and activities is determined to calculate the EW of these buildings. Moreover, the EC and IEW of these case study buildings is also compared to identify any relationship between EC and EW.

5.5.2.3 Quantitative Data Collection

Saunders, Lewis and Thornhill (2023) state that two types of quantitative data may be collected. These are categorical and numerical data. Categorical data refers to data that is composed of text which can be divided into categories depending on the characteristics of the data. Numerical data as the name suggests refers to data that is collected in numerical form as quantities. Naoum (2013) states that this data can be collected by using open-ended or closed ended questions. Both these types of data are collected in this study.

The following three numeric quantitative data are collected to calculate the EW of the case study buildings:

1) BOQs of the identified case study buildings.
2) Water consumption records during the case study buildings construction.
3) Water consumption records during the manufacturing of selected construction materials.

These numeric quantitative data are collected through documents obtained from the project consultants involved in the construction of the case study buildings and selected material manufacturers.

Additionally, the following two categorical quantitative data are collected:

1) Adoption level of water metering on construction sites in India.
2) Water metering technique adopted and reason for its adoption.

These categorical quantitative data are collected by conducting a web-based self-completed questionnaire that was distributed among construction professionals working in India. Given the ease of distribution of web-based questionnaires, this mode of questionnaire distribution was selected. Majority of the questions were open-ended questions requiring short answer responses, while a few questions were closed-ended to collect responses based on the pre-determined codes. The questionnaire consisted of three sections. Table 5.8 summarises the theme of each section and the rationale for its selection, while Table 5.9 presents the questions asked with reference to the research questions of this study.

Table 5.8: Themes for questionnaire along with their rationale for selection (Source: Author)

Theme	Rationale for selection
Water metering	The aim of this theme was to identify if the construction professionals' meter the water consumption on their construction site.
Don't meter water consumption	Under this theme, the researcher aimed at collecting information regarding why the respondents don't meter their water consumption.
Meter water consumption	Under this theme, the researcher aimed at collecting information related to the frequency of water metering, the technique adopted and the motivation behind its adoption.

Table 5.9: Questionnaire themes and questions (Source: Author)

Themes	Questionnaire questions	Research questions
Water metering	1) Do you meter the water consumption on your construction site?* ▪ Yes ▪ No	5.1
Don't meter water consumption	1) Why don't you meter the water consumption?	5.2
Meter water consumption	1) How often do you meter the water consumption? ▪ 1 in every 20 projects ▪ 1 in every 10 projects ▪ 1 in every 5 projects ▪ 1 in every 3 projects ▪ 1 in every 2 projects ▪ 1 in every 1 project 2) How do you meter the water consumption? 3) What kind of data do you collect? 4) Why do you meter the water consumption?	5.1 and 5.2

*Compulsory question

5.5.2.4 Qualitative Data Collection

Semi-structured interviews are used as a method of qualitative data collection in this study. Interviews are conversations between two or more people in which the interviewer (in this case the researcher) asks the interviewee (in this case the research participant) unambiguous and concise questions related to different variables to understand the interviewee's point of view and opinion in relation to the research topic (Naoum 2013; Creswell and Creswell 2018; Saunders, Lewis and Thornhill 2023).

Naoum (2013) highlights the significance of using semi-structured interviews for an explanatory type of research as this study. These interviews are used to collect qualitative data related to the factors impacting water consumption on construction sites and during construction material manufacturing, the water management policies, the water management practices followed, and the challenges encountered.

All the interviewees were based in India and hence online platform MS Teams™ was selected as the medium for the interviews. The interviews were conducted on a one-to-one basis to collect in-depth information from the interviewees without any biases from another interviewee. A combination of both open-ended and specific questions was asked. Specific questions were asked to collect information related to the pre-determined themes. These were followed by open-ended questions to provide the interviewee with the opportunity to elaborate on those. The following two qualitative data are collected:

1) Government and company policies surrounding water management on construction sites and construction material manufacturing industries, and the challenges faced for its adoption.
2) Water management practices followed on construction sites and during construction material manufacturing, and the challenges faced for its adoption.

All the interviewees are asked questions on pre-determined themes. The rationale for the selection of each theme is discussed in Table 5.10, while Table 5.11

presents the questions asked with reference to the research questions of this study.

Table 5.10: Themes for semi-structured interviews along with their rationale for selection (Source: Author)

Theme	Rationale for selection	Source
Geographical location	This theme aims to understand the impact of location on the water consumption for different processes (during construction activities and material manufacturing), and the reasons for this difference.	Bardhan (2015b); Bardhan and Choudhuri (2016); Rahman et al. (2019)
Water consumption in the process	The aim of this theme is to understand the major activities that consume water during the process (building construction and material manufacturing). The researcher wanted to explore all the ancillary water consuming activities that cannot be discovered through a literature search. Another aim of this theme was to determine the commonly used water sources and the reasons for their selection.	Thornback et al. (2015); Author
Water management policies	The aim of this theme was to understand the different government and company policies that exist with respect to water management. The researcher also wanted to investigate the effectiveness of these policies and the challenges the company faces (if any) during the adoption of these policies.	Thornback et al. (2015); Waidyasekara, De Silva and Rameezdeen (2016); Waidyasekara, De Silva and Rameezdeen (2017)
Water management practices	Under this theme, the researcher wanted to understand how the above policies impact water management practices and the challenges the company faces in adopting these practices.	Thornback et al. (2015); Waidyasekara, De Silva and Rameezdeen (2017)
Recommendations	Under this theme, the researcher wanted to ask the interviewees for their suggestions as to how the whole process (building construction and material manufacturing) can be made more sustainable by increasing water efficiency.	Author

Table 5.11: Semi-structured interview themes and questions (Source: Author)

Themes	Interview questions	Research questions
Geographical location and climate	<u>Construction materials</u> 1) What locations in India are the manufacturing plants located? 2) If in different parts of India, are there differences in material manufacturing process and water consumption?	6.2
	<u>Construction activities</u> 1) Which locations in India have you worked? 2) If in different parts of India, are there differences in the amount of water consumed, and the reasons behind it?	6.2
Water consumption in the process	<u>Both groups</u> 1) What are the major water consuming activities? 2) What source of water is used and why? 3) How do you measure the amount of water consumed and what are the challenges in doing so?	6.1
Water management policies	<u>Both groups</u> 1) What are the government regulations with respect to water management and water consumption? 2) Does your company have any policies for water management? 3) How effective are these regulations and policies? 4) What challenges do you face in order to adopt these regulations and policies?	1.2, 1.3, 6.2
Water management practices	<u>Both groups</u> 1) What measures do you take to reduce water consumption? 2) What are the challenges of adopting these practices? 3) How do you manage wastewater?	6.1
Recommendations	<u>Both groups</u> 1) What can be done to make the process more sustainable by reducing the amount of water consumption without impacting the quality of the product?	6.2, 7.1, 7.2

5.5.2.5 Data Validation

Data validation is an essential step to ensure the validity (the extent to which the data collection process measures what it is intended to measure) and reliability (the extent to which the data collection process yields consistent findings) or trustworthiness (reliability of the data collection process) and authenticity (validity of the data collection process) of the collected data. Bryman (2012) and Saunders, Lewis and Thornhill (2023) thus define data validation as a process of verifying the data collection process, its analysis and interpretation to ensure the credibility of the collected data. This can be done through participant validation (Bryman 2012; Saunders, Lewis and Thornhill 2023).

This study uses participant validation to verify and test the developed framework, while also validating the data collected from the semi-structured interviews. The proposed framework was sent to four interviewee respondents (two construction professionals and two material manufacturers) for their feedback regarding its feasibility of application and possible areas of improvement. The feedback obtained was used to modify the framework to ensure suitability for the Indian context. Moreover, the main findings from the semi-structured interviews were also discussed with these interviewees as a means of collecting their feedback and validating the collected data.

Creswell and Creswell (2018) state that the validity of an explanatory mixed method research can be increased by using the same set of participants for both the quantitative and qualitative data collection. As a result, the same material manufacturers were used to collect quantitative data related to water consumption during material manufacturing, and qualitative data related to water management practices. Similarly, the construction professional that provided quantitative data related to site water consumption records was also interviewed for the collection of qualitative data related to water management practices.

5.5.3 Secondary Data Collection

Secondary data collection is an essential component of every research as time and access restrictions often limit the amount of primary data that can be collected. These secondary data could be collected from white literature (sources that have been peer-reviewed) like articles in academic or professional journals and books; or grey literature (sources that have not been peer-reviewed) like conference proceedings, government reports and documents (Saunders, Lewis and Thornhill 2023).

Secondary data related to the ECC of construction materials was collected through an archival search of government and industry produced online databases listing the environmental performance of construction materials. The International Finance Corporation of the World Bank Group (2017) lists the EC in terms of the GWP for different construction materials in Indian context. This database is used for calculating the EC of construction materials for the case study buildings.

5.6 Data Analysis

Appropriate analysis of data is essential to generate efficient interpretations. The quality and reliability of these interpretations largely depend on how the data has been explored and analysed (Bryman 2012). This section discusses the analysis process for the quantitative and qualitative data collected.

5.6.1 Quantitative Data Analysis

Section 5.6.1.1. discusses the analysis of the collected numerical quantitative data to calculate the EW and EC of the case study buildings. Section 5.6.1.2 discusses the questionnaire analysis technique adopted.

5.6.1.1 Case Study Residential Building Analysis

The quantitative data collected in terms of the BOQ and site water consumption records of the case study buildings, and EWC of construction materials are used to analyse the EW of case study buildings using a process LCA. This has previously been done by Heravi and Abdolvand (2019) to determine the EW of buildings and construction materials in Iran. Bardhan (2015b) also applied this concept to determine the EW of concrete masonry units in India. Moreover, the ECC collected through an archival search are also used to calculate the EC of the case study buildings.

The four stages of an LCA analysis as described by ISO 14040 (2006) and its application to this study are as follows:

Stage 1: Goal and scope definition

This stage defined the aim of the study, system boundaries, functional units, parameters to be analysed and the data collection strategy.

The following scope has been defined for this study:

1) Aim: To determine the EW of two medium high-rise residential buildings in the height range of 45m to 65m in two different locations in India, and comparing its EC with its IEW.
2) System boundary: Cradle-to-gate boundary that includes stages A1-A5 of the building life cycle defined by BRE (2018) as shown in Figure 2.1.
3) Functional unit: kL/m^2 , kL/m^3, kL/ton and kgCO2 eq/kg
4) Parameter to be analysed: water consumption, EC equivalent
5) Data collection strategy: Document analysis and archival search

Stage 2: Life cycle inventory

In this stage only the inputs associated with the system boundary are determined. Considering the building as the system boundary, the inputs are all the construction materials used and construction activities undertaken during the building construction. The BOQ of the case study buildings was used to collect this data. The BOQ specifies broad activities that were broken down into smaller activities thereby determining the materials used, activities undertaken and the quantity for each. For instance, the BOQ specifies an activity under the heading of plain cement concrete. This main heading was broken down to generate materials like cement, sand and aggregate, and activities like concrete making and curing. The EWC of all the materials and activities was obtained from documents collected as discussed in section 5.5.2.3. The ECC was collected from an archival search as discussed in section 5.5.3.

Stage 3: Life cycle impact assessment

In this stage, the environmental impacts of the building were determined by calculating its DEW, IEW and EC as follows:

1) Calculation of DEW

The EW of a construction activity "A" is calculated by multiplying the EWC of that activity (EWC_A) with the quantity of that activity (Q_A). The sum of the EW of all activities results in the DEW of the building as shown in equation 6.

$$DEW = \sum EW_A = \sum EWC_A \, x \, Q_A \quad \text{(Equation 6)}$$

2) Calculation of IEW

The EW of a material "M" is calculated by multiplying the EWC of that material (EWC_M) with the quantity of that material (Q_M). The sum of the EW of all materials results in the IEW of the building as shown in equation 7.

$$IEW = \sum EW_M = \sum EWC_M \, x \, Q_M \quad \text{(Equation 7)}$$

3) Calculating the EC

The EC of a material is calculated by multiplying the ECC of that material (ECC_M) with the quantity of that material (Q_M). The sum of the EC of all materials results in the EC of the building as shown in equation 8

$$EC = \sum EC_M = \sum ECC_M \; x \; Q_M \quad \text{(Equation 8)}$$

Stage 4: Interpretation

In this stage the EW of the building is calculated as shown in equation 9.

$$EW = DEW + IEW \qquad \text{(Equation 9)}$$

In addition to this, the EC of the case study buildings is compared with its IEW to compare any relationship between materials in terms of their EC and EW.

Figure 5.6 summarises the LCA application to this study.

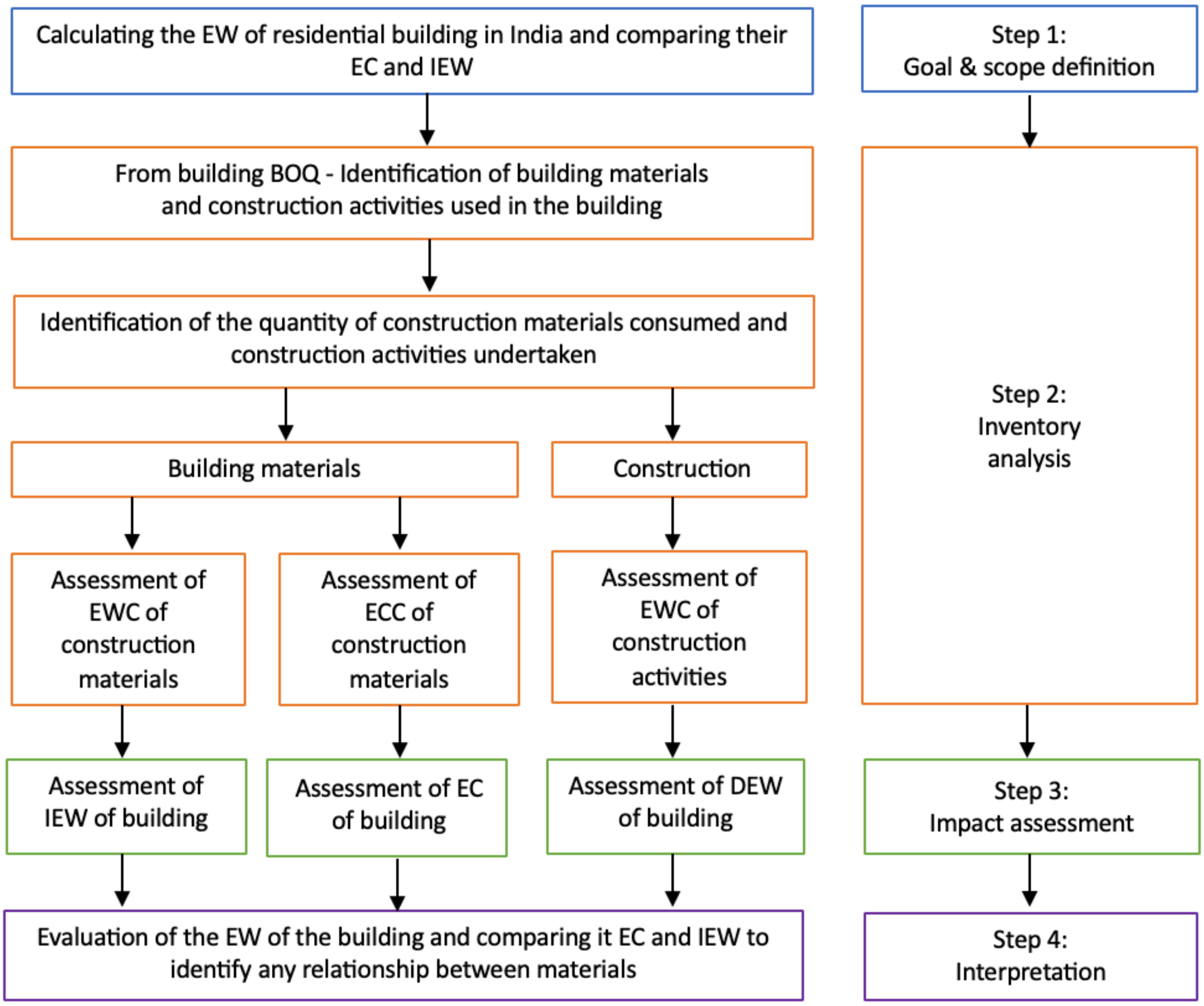

Figure 5.6: Lifecycle analysis application to this study (Adapted from: Heravi and Abdolvand 2019)

5.6.1.2 Questionnaire Analysis

The questionnaire was created and analysed on google forms. There were a total of six questions consisting of both closed ended and open-ended questions. The closed ended questions were automatically divided into the selected codes and analysed directly by the google forms analytics. For the other open-ended questions, the short answer responses received were manually coded and analysed by creating a codebook.

The different steps for creating a codebook as defined by Saunders, Lewis and Thornhill (2023) are as follows:

Stage 1: Defining categories and sub-categories

In this stage, the collected data under each variable (or question) is examined and divided into categories. These categories are further divided into sub-categories if needed. For instance, a variable in this study is technique of water metering, and the categories created are water meter and water tankers.

Stage 2: Allocate numeric codes

Once all the categories and sub-categories have been identified, these are allocated numeric codes. For instance, water meter is coded as 11-13 while water tanker is coded 16.

Stage 3: Note the responses

The responses received for each category (or subcategory) are noted against the code to create the codebook. Finally, the frequency of each response is noted. For instance, for the category of water meter at a code number of 12, one response was received that stated the installation of water meter at the groundwater extraction pump.

5.6.2 Qualitative Data Analysis

The qualitative data collected is analysed simultaneously during and after the data collection (Saunders, Lewis and Thornhill 2023). Simultaneously analysing the data during the data collection process, helps identify any crucial themes that the researcher might have initially missed out on, and confirm the themes being analysed to guide through and assist with the remainder of the data collection process (Saunders, Lewis and Thornhill 2023).

The qualitative data collected from the semi-structured interviews was analysed using the "thematic analysis" process. Clarke and Braun (2017) define thematic analysis as "a method for identifying, analysing and interpreting patterns of meanings (themes) within qualitative data". It is a flexible approach to logically and orderly analyse data to produce rich interpretations (Clarke and Braun 2017).

Creswell and Creswell (2018) define four stages for the analysis of qualitative data collected through interviews. These four stages and their application to this study are as follows:

Stage 1: Data familiarisation

In this stage, the collected verbal data is converted into word-processed text through a process known as transcription. This helps the researcher to get familiarised with the collected data and identify any apparent themes and patterns that may appear.

All the interviews conducted on MS Teams™ were recorded and their transcripts were automatically prepared using the built-in features of the application. These automated transcripts were then analysed in conjunction with the recording to aid in the creation of accurate transcripts and summarised findings of the interviews. The summarised findings of the interviews are listed in Appendix E. Moreover, during the interview, the researcher made a handwritten note of all the crucial points that the interviewees spoke about which were used in the creation of the summarised findings.

Stage 2: Data coding

Once the interviews were transcribed, long sentences were summarised in a single word or short phrase to enable easy handling of data. The process of labelling the collected data with codes (or shorts phrases) is known as data coding. The number of codes generated for a study depends on the extent of data exploration required and research questions.

Examples of a few codes created for analysis are concreting, dust suppression, groundwater and rainwater.

Stage 3: Theme generation, development, and review

Once codes have been generated and assigned to the data, similar codes were combined into groups known as themes. Grouping codes into themes helps condense the data even further thereby ensuring ease of analysis. The themes represent patterns that aid in answering the research questions.

For example, codes like concreting and dust suppressions are grouped under the theme of water consuming activities, while codes like groundwater and rainwater are grouped under the theme of water source.

Stage 4: Theme refining, defining, and naming

Once similar codes have been combined into themes, themes were revisited to ensure that all the codes within the theme correlate to each other and that all the themes are meaningful. This step could result in the formation of new themes, or the transfer of codes between different themes based on the findings of the researcher. This is an essential step as it helps in determining relationships between codes and themes to make adequate interpretations.

5.7 Limitations of Designed Research Methodology

Although adopting the sequential explanatory multiphase mixed method research design has advantages in terms of collecting both quantitative (quantities of material and water consumed) and qualitative (factors impacting water consumption) data, it also has limitations associated with its adoption. The major limitations of this design are the time and planning required in collecting both the quantitative and qualitative data. Moreover, since the results of the analysis of the first stage define the data collection for the next stage, rigorous planning is required, and any delays in the collection and analysis of initial data will impact the next stages (Terrell 2012).

Case study as a research strategy is valuable since it aids in collection of in-depth data regarding the case in its real-life setting. However, collection of this in-depth data during a limited time period is not always possible for a large sample size.

Moreover, data related to BOQ's of the case study buildings is confidential to an organisation and participants might not be willing to share that. Due to this challenge, the researcher was only able to identify two case study residential buildings. The small sample size of the case study limits the possibility to make generalizable assumptions of the data being collected.

The application of archival search strategy in this study helps in broadening the data collected; by enabling collection of data whose primary collection is outside the scope of this research. However, the limitation of archival search is availability or completeness of data in the given time period. The only available ECC data collected in Indian context was reported in 2017 without reporting the exact parameter being considered (the document considered lists the ECC in terms of GWP rather than only the ECC). Although this difference in data availability does not impact the accomplishment of the research objective (Objective 4), it highlights a major limitation of archival search in terms of the completeness of the available data.

The use of online questionnaires helps achieve the research objective to collect generalizable data related to the adoption level of water metering on construction sites in India by targeting a large sample size. However, the use of these online questionnaires has certain limitations. One such limitation is receiving a low response rate as people might ignore the invitation to take part in the questionnaire survey (Saunders, Lewis and Thornhill 2023). The online questionnaire was sent to 250 construction professionals in India but only 46 responses were received. Although this response rate of 18% is low, Saunders, Lewis and Thornhill (2023) state this to be the likely response rate when using online questionnaires. Another limitation of using online questionnaires could be in terms of the quality of responses received, as the respondents might misinterpret the questions being asked or answer the questions to align with societal norms. The latter is largely applicable to the questions related to water metering. The societal pressure to portray sustainability adoption may result in positive responses even though water metering might not have actually been adopted.

The use of semi-structured interviews helps collect in-depth data related to water management and its challenges, while providing the researcher with the flexibility to ask both structured and follow-up questions. However, one major limitation of this strategy is the potential of researcher's bias that may influence the direction of the interview (Saunders, Lewis and Thornhill 2023). Another limitation of semi-structured interviews is the identification of research participants willing to participate and share confidential information. The latter is applicable to this study, considering that water consumption and management issues might be confidential to an organisation and participants may not be willing to participate in interviews to discuss that.

For the validation of the proposed framework, this study adopts the participant validation process outlined by Bryman (2012) and Saunders, Lewis and Thornhill (2023). Using the same participants for the semi-structured interviews and validation process, can assist in validation of findings. However, the chances of participant's bias might act as a limitation of this validation process.

For the data analysis, this study adopts an LCA approach. A conventional LCA approach uses LCA computer software to breakdown the product being analysed into all the stages across its life cycle and then determine the environmental impacts at each stage using LCA databases. However, this study adopts a manual LCA approach which does not use computer software and databases. It manually breaks down the product (in this case a building) into all the materials used and activities undertaken for its construction. Then it collects data related to water consumed for the manufacturing of each material and undertaking each activity through document analysis. The limitation of this manual CA approach is that it is not a widely adopted LCA approach with only one use by Heravi and Abdolvand (2019).

5.8 Research Ethics

Research ethics refers to the considerations taken by the researcher during the research to ensure the rights of the research participants and all those affected by the research are not harmed (Cameron and Herrmann 2023). The ethical concerns of research are very high when it focuses on living participants.

Since this research deals with human participants, the following ethical principles were considered:

1) The researcher respected the rights and dignity of the research participants and provided them with all the necessary information related to the need for data collection and the use of collected data. The semi-structured interview participants were also informed of their right to withdraw from the interview at any given point during the interview.
2) To ensure confidentiality to the research participants and to guarantee the academic use of the collected data, a confidentiality letter stating the same was issued to all semi-structured interview participants. On the other hand, the questionnaire respondents were assured of anonymity prior to the start of the questionnaire data collection.
3) This research deals with collecting information related to BOQ, water consumption records, and company policies and practices related to water management. Since this information is sensitive and private to an organisation, the research participants were assured of anonymity and consent was obtained prior to their collection.
4) All interviews were recorded to help with transcribing the information during data analysis. Before beginning the recording, permission was taken from the research participants.
5) To ensure the anonymity of the selected case studies, the name of the residential buildings being analysed, and the manufacturing companies of the construction material were not disclosed in this study.

5.9 Chapter Summary

This chapter presented the "research onion" model and its application to this study. All levels of the research onion were initially described, and the principle selected for each level along with its rationale defined. This study adopts the "pragmatism" philosophy and uses the "abductive" approach. It further adopts the "sequential explanatory multiphase mixed method" research design. The design is divided into seven stages and each stage was defined. Case studies (residential buildings), archival search (EC database in Indian context), questionnaires (with construction professionals) and semi-structured interviews (with construction professionals and construction material manufacturers) were selected as research strategies to achieve the study objectives. This chapter also discussed the "systematic random sampling" and "snowball sampling" technique along with their application to the study in identifying the research sample. It also defined the themes and questions asked in the questionnaires and semi-structured interviews, the process of conducting these and the method for data analysis. It also discussed the limitations of the designed research methodology (the research method, research strategies and data analysis process). This chapter concluded by discussing the ethical considerations of the research.

Chapter 6 : Data Collection

This chapter discusses the data collected in stage 1 (quantitative data collection), stage 3 (quantitative data collection) and stage 5 (qualitative data collection) of this sequential explanatory multiphase mixed method study as shown in Figure 6.1. The analysis of these collected data (denoted by stage 2, 4, 6 and 7) are discussed in Chapter 7.

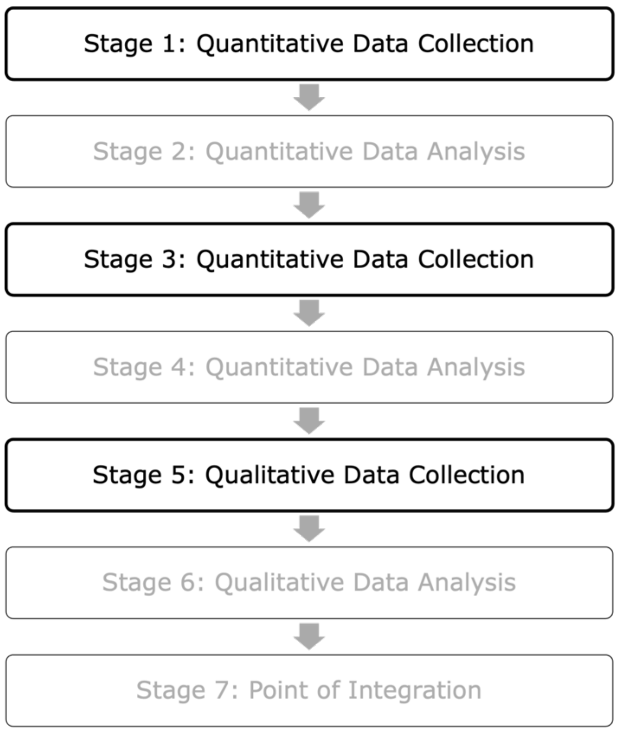

Figure 6.1: Stages discussed in this chapter (Source: Author)

6.1 Stage 1 Quantitative Data Collection

In the first stage of this study, two residential buildings constructed in India were selected as case study buildings for analysis and their BOQ's were collected as shown in Figure 6.2. This stage collected data required to accomplish objective 2 of this study.

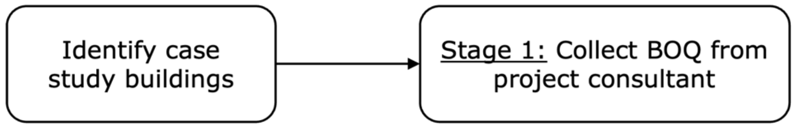

Figure 6.2: Stage 1 of the sequential explanatory multiphase mixed method (Source: Author)

The two case study buildings selected are in two separate regions of the country with similar climatic conditions and local water availability. Table 6.1 presents the characteristics of the case study buildings.

Table 6.1: Characteristics of the two case study buildings (Source: Author)

Name	Location	Total floor area	Number of floors	Type of construction
Case study 1	Delhi	11,335 m^2	11	Reinforced Concrete (RC) with clay bricks
Case study 2	Jaipur	5,900 m^2	5	RC with clay bricks

For Delhi, a residential building of ten to fifteen stories is a common height of construction, whereas for Jaipur, the common hight is between five to ten stories. Moreover, Census (2011) states that RC frame buildings with clay masonry wall is the most common building typology in India constituting 45% of the residential building stock in the country. Thus, residential buildings of these characteristics were selected for analysis. In terms of government regulations, groundwater extraction is banned in Delhi, however, there is no such regulation in effect for Jaipur.

Construction BOQ's of the two case study buildings discussed in Table 6.1 were collected from the project consultant involved on these projects. Table 6.2 summarises few rows from the BOQ of case study 1. Similar data is collected for both the case study buildings and Appendix F shows this data. Figure 6.3 to Figure 6.6 show few stages of the construction for case study 1. While Figure 6.3 shows the common construction typology of RC frame buildings with clay masonry walls, Figure 6.4 and Figure 6.5 show the construction of the building, and Figure 6.6 shows the laying of a column.

Table 6.2: Bill of quantities of case study 1 (Source: Author)

S No.	Particulars	Unit	Quantity
A.	Earthwork		
3.	Filling with available excavated earth (excluding rock) in trenches, plinth side of foundation, etc. in layers. In depth, consolidating each deposited layer by ramming and watering including.	m^3	677.14
C.	Reinforced concrete work		
8.	Providing and laying reinforced cement concrete in raft, wall footings and column footings, excluding the cost of centring, shuttering and reinforcement steel (As per design mix). M-25 grade concrete (RMC Mix) including cement	m^3	622
10.1	Providing and laying reinforced cement concrete works at all height in suspended floors, roofs, landings, beams, lintels, stair slab, counter slabs, etc. but excluding the cost of centring, shuttering, cement and reinforcement steel in (as per design mix) M-25 grade concrete (In-situ mix)	m^3	415.33
D.	Masonry work		
13	Providing and fixing red 9" brick masonry for superstructure with bricks of class designation 75 in cement mortar 1 cement : 6 coarse sand at all floors	m^3	391.25

Figure 6.3: RC Frame with clay brick construction (Photograph: Construction Interviewee 2)

Figure 6.4: Construction of case study 1 (Photograph: Construction Interviewee 2)

Figure 6.5: Construction of case study 1 (Photograph: Construction Interviewee 2)

Figure 6.6: Laying a column in case study 1 (Photograph: Construction Interviewee 2)

In stage 2 of this study, which is the quantitative data analysis, the collected BOQ's were analysed to determine all the construction materials used and construction activities undertaken on the building construction site and are discussed further in Section 7.1. Data related to the EWC of these identified activities and materials was collected in stage 3 of this study as discussed in Section 6.2.

6.2 Stage 3 Quantitative Data Collection

Four groups of data sets were collected in this stage:

1) The first group is numerical quantitative data related to the water consumed at the manufacturing plant for the construction materials identified in stage 2 of this study through documents collected from the material

manufacturers. This collected data is required to accomplish objective 3 of this study.

2) The second group of data collected is numerical quantitative data related to the water consumed on the construction site of the selected case study residential buildings through documents collected from the project consultant. This collected data is required to accomplish objective 3 of this study.
3) The third group of data collected is numerical quantitative data related to the ECC of the selected construction materials through an archival search. This collected data is required to accomplish objective 4 of this study.
4) The fourth group of data collected is descriptive categorical quantitative data related to the adoption level of water metering on construction sites in India collected through online questionnaires. This collected data is required to accomplish objective 5 of this study.

The data collected in this stage is shown in Figure 6.7.

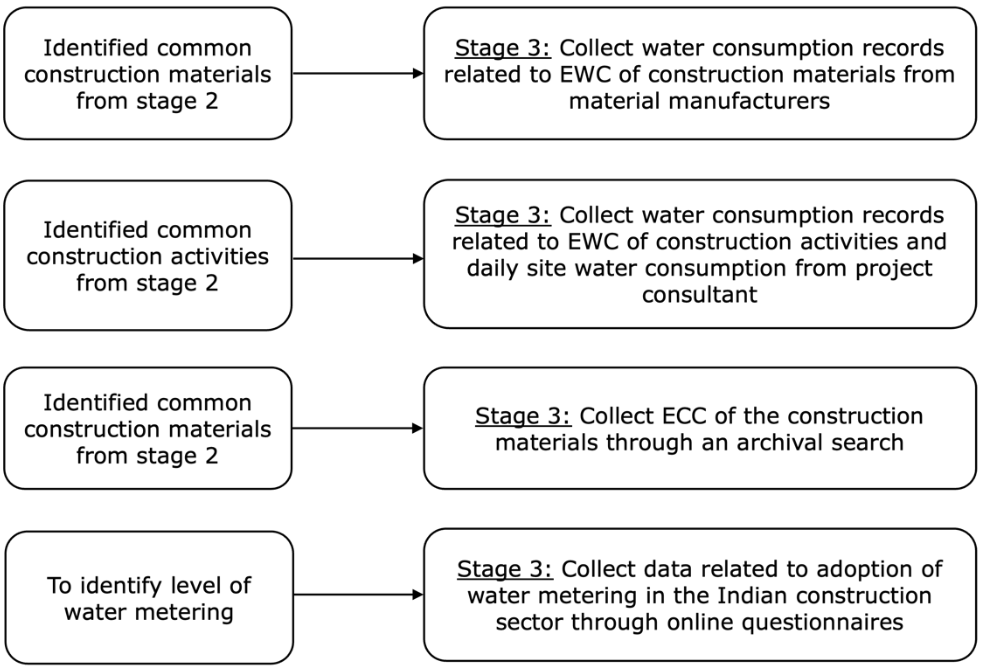

Figure 6.7: Stage 3 of the sequential explanatory multiphase mixed method (Source: Author)

6.2.1 Embodied Water Coefficient of Construction Materials

The analysis of the case study residential buildings revealed that cement, sand and stone account for almost 80% of the material stock of residential buildings. Other materials like steel and clay bricks account for almost 12% of the building material stock, while tiles constitute 1.47% (see Section 7.1 for more information on this analysis). As discussed in Chapter 2, there is no EWC data for sand, stone and tiles in Indian context. Though an EWC of cement is available, the value it reports is outdated. Similarly, though an EWC of clay bricks exists, this value is based on assumptions. Steel is the only material with a recorded EWC in Indian context. As a result, at this stage, the following materials were selected for further analysis and their EWC data was collected:

1) Cement
2) Aggregates (sand and stone)
3) Bricks
4) Tiles

Glass is a commonly used material for architectural finishing in buildings. Due to the challenges associated with obtaining fully completed construction BOQ's, none of the BOQ's specify the quantity of this material. Due to the widespread application of this material in residential projects in India and the absence of its EWC data in Indian context as discussed in Chapter 2, this material was also selected for analysis and data related to its EWC was collected.

This study adopted the methodology followed by Heravi and Abdolvand (2019) wherein the process LCA approach that relies on collecting data through interviews and document analysis was used. To determine the EWC of selected construction materials, documents recording the amount of water consumed on the manufacturing plant were collected from material manufacturers. This document reported the amount of water (in kL) consumed to manufacture a unit (ton,m^2) of material and was recorded using water meters installed at the plant. Due to the various stages in the material supply chain, and the challenges associated with collecting water consumed during mining of raw materials (module A1), and the transportation of raw materials and manufactured materials (module A2 and A4), only the water consumed at the manufacturing plant for the manufacturing of building materials (module A3) was collected. Figure 6.8 shows the IEW stages, and the stage considered for EWC data collection.

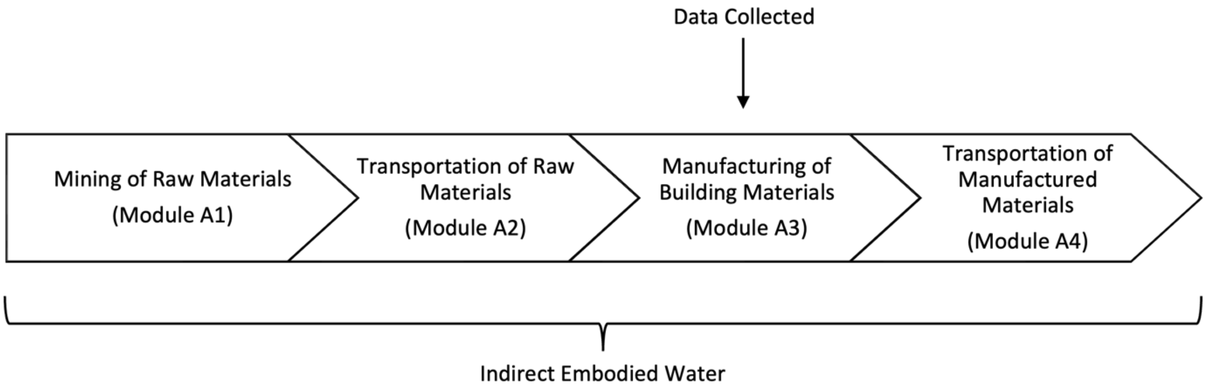

Figure 6.8: Indirect embodied water data collection stage (Source: Author)

Table 6.3 summarises the data related to the EWC of materials that was collected through water consumption records documents collected from material manufacturers.

Table 6.3: Collected data related to embodied water coefficient of construction materials (Source: Author)

Material	Data collected
OPC	0.15-0.20 kL/ton
Clear float glass	0.3-0.35 kL/ton
Manufactured construction sand	0.12-0.14 kL/ton
Manufactured industrial sand	0.23-0.25 kL/ton
Ceramic tiles	0.02-0.03 kL/m^2
Clay bricks	0.4-0.5 kL/ton

6.2.2 Embodied Water Coefficient of Construction Activities

The analysis of the case study buildings' BOQs state that the following activities are undertaken on a construction site:

1) Earthwork activities like excavation and backfilling

2) Concreting work (plain concrete and reinforced concrete) which includes mixing and curing the concrete.
3) Masonry work
4) Plaster work
5) Flooring
6) Waterproofing and terracing

As noted in Chapter 2, none of the past studies (either in India or globally) have recorded the EWC of construction activities. Thus, this study aims at determining the EWC of common construction activities. To determine the EWC of construction activities, documents recording the site water consumption records were required.

For case study 1, the water consumption records document collected from the project consultant listed the amount of water (in kL) required to conduct a unit of an activity (in m^2 or m^3). The project consultant noted that this value was calculated by the site staff by conducting a small pilot experiment of that activity on the construction site. The Indian government specifies a minimum water requirement for site staff that stay on a construction site for 24 hours to be 40 litre/person/day. Based on 20 site staff that stay on the site as obtained from the project consultant, the water for human consumption can be assumed to be 800 litres per day. Table 6.4 summarises this collected EWC data.

Table 6.4: Collected data related to embodied water coefficient of construction activities for case study 1 (Source: Author)

Activity	**EWC**
Human consumption	0.8 kL/day
Excavation	0.04 kL/m^3
Backfilling	0.15 kL/m^3
PC mixing	0.15 kL/m^3
PC curing	0.022 kL/m^3
Off-site RC mixing	0.19 kL/m^3
RC curing	0.17 kL/m^3
Masonry	0.12 kL/m^3
Masonry curing	0.4 kL/m^3
Cement plaster	0.0045 kL/m^2
Cement plaster curing	0.025 kL/m^2
Tile fixing	0.007 kL/m^2

For case study 2, the document collected reported the daily water consumption (in L) on the construction site. For this building, the project consultant installed a water meter on the project site. The opening and closing water meter readings were taken daily. These values were recorded in an excel sheet with further explanation on the activities that were undertaken that day. The site water records were taken after all earthwork activities (site clearing, excavation and backfilling) had been completed and the foundation was laid. Table 6.5 summarises data from a few days over the entire course of collected data. Appendix G shows the data collected for the entire course of construction.

Table 6.5: Collected data related to site water consumption records for case study 2 (Source: Author)

Date	Opening reading	Closing reading	Consumption (L)	Usage
31/08/2019	135,302.00	136,706.00	1,404.00	Slab casting, labour
01/09/2019	136,706.00	137,908.00	1,202.00	Slab curing, labour
02/09/2019	137,908.00	140,102.00	2,194.00	Slab curing, labour
11/01/2020	302,343.00	303,494.00	1,151.00	Curing, concreting
12/01/2020	303,494.00	305,006.00	1,512.00	Curing, concreting
17/07/2020	648.092.00	655,429.00	7,337.00	Masonry, labour, curing, concreting
18/07/2020	655,429.00	661,368.00	5,939.00	Masonry, labour, curing, concreting
17/10/2020	1,096,209.00	1,102,019.00	5,810.00	masonry, curing, tile fixing
18/10/2020	1,102,019.00	1,109,158.00	7,139.00	Masonry, curing, tile fixing
23/12/2020	1,233,209.00	1,234,231.00	1,022.00	Plastering, curing, tile fixing
24/12/2020	1,234,231.00	1,235,810.00	1,579.00	Plastering, curing, tile fixing

A construction site is an uncontrolled environment with many activities being conducted in different places. As a result, numerous individual activities are undertaken on a single day that cannot be all recorded. Thus, the site staff only recorded the major activity conducted on that day. Moreover, due to the difficulties in measuring the exact amount of water consumed for each activity, only the daily site water consumption value was recorded. As a result, for the water recording of a single day, more than one major activity was undertaken.

Due to the different methods adopted by the site staff in collecting the site water data the collected data from both the case studies (Table 6.4 and Table 6.5) were in different units (kL/unit for case study 1 while L for case study 2). The data collected from case study 1 (in kL/unit) can be directly used for the EW calculation of the building. However, for case study 2, the data collected (in L) needs to be converted to EWC units (kL/unit) before calculating the EW of the building. The water consumption data collected as shown in Table 6.5 was analysed along with the case study building BOQ to calculate the EWC of different construction activities. Table 7.3 shows this calculation. These values along with the EWC values of the construction materials collected in Section 6.2.1 were analysed in stage 4 of this study to calculate the EW of case study buildings and are discussed further in Section 7.2.

6.2.3 Embodied Carbon Coefficient of Construction Materials

The International Finance Corporation of the World Bank Group (2017) published an ECC database in terms of the GWP for construction materials in Indian context. This data is shown in Table 6.6. This data is used to analyse the EC-GWP of the case study buildings and identify any relationship between the EC and EW of different construction materials. An identification of the relationship can assist to make informed choices regarding the selection of construction materials with limited negative environmental impacts.

Table 6.6: Collected data related to embodied carbon of construction materials (Source: Author)

Material	**EC-GWP (kgCO2 eq/kg)**
Cement	0.91
Sand	0.0090
Stone	0.0090
Clay bricks	0.39
Steel	2.6
Ceramic tiles	0.68

6.2.4 Questionnaire on Water Metering on Construction Sites

A self-completed web-based questionnaire was created on Google Forms and analysed by creating a codebook as mentioned in Section 5.6.1.2. The sample population consisted of construction professionals working in India. The respondents were selected using a systematic random sampling as discussed in Section 5.5.2.1. A total of 46 responses were received. Table 6.7 summarises the demographic information of the questionnaire respondents.

Table 6.7: Demographics of questionnaire respondents (Source: Author)

Demographics		**% of Total**
Professional background	Architect	28.9
	Civil engineer	31.6
	Contractor	13.2
	Project manager	10.5
Years of experience	1 to 9 years	41.2
	10 to 19 years	9.7
	20 to 29 years	19.4
	30 to 39 years	22.6
	40 to 49 years	6.5

Majority of the respondents had between 1 to 9 years of experience with majority of their area of expertise being architects. This was followed by respondents having between 30 to 39 years of experience with majority of them belonging to the category of civil engineers. The questions asked in the questionnaire are shown in Table 5.9 and the answers obtained are analysed in Section 7.2.6.

6.3 Stage 5 Qualitative Data Collection

In this stage, semi-structured interviews were conducted with construction professionals working on different construction projects in India along with the project consultant working on the selected case study residential building construction sites as shown in Figure 6.9. In addition to these, semi-structured interviews are also conducted with material manufacturers of the selected construction materials. Both the interviewee groups were asked similar questions as shown in Table 5.11 to collect data to achieve objective 6.

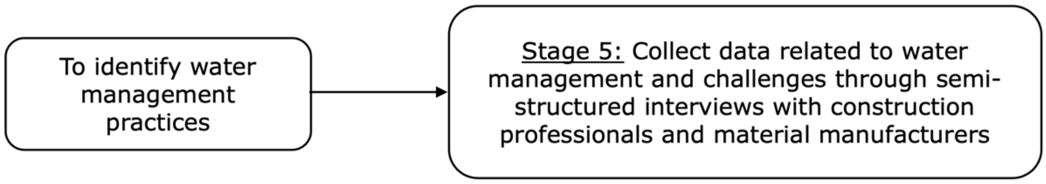

Figure 6.9: Stage 5 of the sequential explanatory multiphase mixed method (Source: Author)

The same manufacturers that were contacted for collecting data related to the EWC of construction materials were interviewed for the collection of qualitative data. This as stated by Creswell and Creswell (2018) assures the reliability of the collected data. The demographic information of each interviewee is summarised in Table 6.8.

Table 6.8: Demographics of material manufacturers interviewees (Source: Author)

Interviewee No.	Job title	Years of experience
Cement interviewee 1	Head of sustainability	15 years
Cement interviewee 2	General manager	25 years
Glass interviewee 1	Managing director	25 years
Glass interviewee 2	Head of technical services (same company as glass interviewee 1)	15 years
Construction and industrial sand interviewee 1	Technical services department (sand manufacturing plant of the same company as glass interviewee 1)	10 years
Construction and industrial sand interviewee 2	Head of environment, head and safety (sand manufacturing plant of the same company as cement interviewee 1)	20 years
Tiles interviewee 1	Plant head	12 years
Bricks interviewee 1	Managing director	20 years

For construction professionals, seven interviews were conducted with different personnel working in the construction sector in India. Similar approach to finding the construction material manufacturers interviewees, a snowball sampling technique, was adopted after finding the first four interviewees. This method helped identify the latter three interviewees. The demographic information of each interviewee is summarised in Table 6.9. Construction interviewee 2 is the project consultant working on the two case study residential buildings.

Table 6.9: Demographics of construction professional interviewees (Source: Author)

Interviewee No.	Job title	Years of experience
Construction interviewee 1	General manager	25 years
Construction interviewee 2	Senior consultant	30 years
Construction interviewee 3	Project manager	25 years
Construction interviewee 4	Civil engineer	20 years
Construction interviewee 5	Civil engineer	20 years
Construction interviewee 6	Architect	10 years
Construction interviewee 7	Architect	10 years

6.4 Chapter Summary

This chapter presented the data collected in stage 1 and 3 (quantitative data collection) and stage 5 (qualitative data collection) of this sequential explanatory multiphase mixed method study. Two case study residential were identified in stage 1 of the study that were analysed to determine the commonly used construction materials and construction activities undertaken for residential building construction in India. In stage 3 data related to the EWC of identified construction materials and construction activities was collected, in addition to the site water consumption records of the two case study buildings. This chapter also outlined the demographical information of the questionnaire and semi-structured interview respondents.

Chapter 7 : Data Analysis

The analysis of the data collected in the Chapter 6 is presented in this chapter. It discusses the data analysed in stage 2 (quantitative data collection), stage 4 (quantitative data collection) and stage 6 (quantitative data collection) of this sequential explanatory multiphase mixed method study. The outcome of each stage is defined along with its correlation to the proposed framework that was developed in stage 7 (point of integration of quantitative and qualitative data) of this sequential explanatory multiphase mixed method study. Figure 7.1 shows the stages discussed in this chapter.

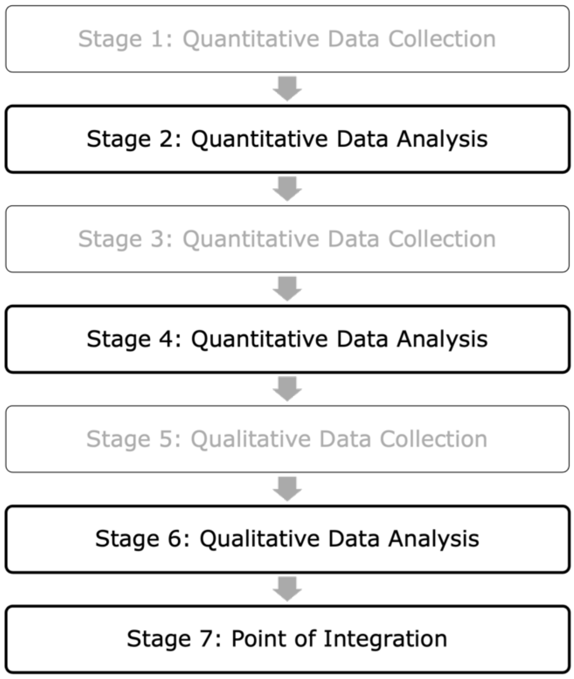

Figure 7.1: Stages analysed in this chapter (Source: Author)

7.1 Stage 2 Quantitative Data Analysis

The BOQ's of the two case study residential buildings collected in stage 1 (Section 6.1) were analysed in this stage to determine the commonly used construction materials (Section 7.1.1) and construction activities undertaken (Section 7.1.2) for residential building construction in India as shown in Figure 7.2. This stage helps achieve objective 2 of the study.

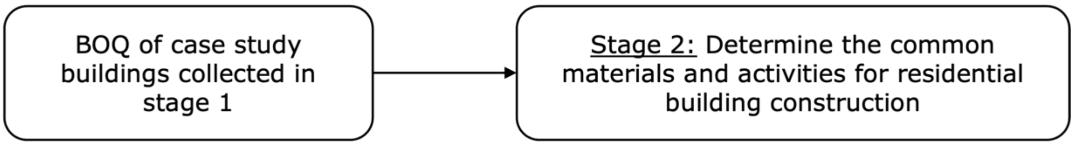

Figure 7.2: Stage 2 of the sequential explanatory multiphase mixed method (Source: Author)

7.1.1 Commonly Used Construction Materials for Residential Building Construction in India

Each component of the BOQ was broken down to determine all the materials used and their quantities consumed to construct that component using the following standards as guidelines:

1) IS 2250: Code of practice for preparation and use of masonry mortars by BIS (2000)
2) IS 1443: Code of practice for laying and finishing of cement concrete flooring tiles by BIS (2001)
3) IS 12212: Code of practice for brickworks by BIS (2005)
4) IS 456: Plain and reinforced concrete- code of practice by BIS (2007a)
5) IS 13757: Burnt clay fly ash building bricks- specification by BIS (2007b)
6) IS 875 Part 1: Code of practice for design loads (other than earthquakes) for buildings and structures- part 1: dead loads- unit weights of building materials and stored materials by BIS (2010)
7) IS 4990: Plywood for concrete shuttering work- specification by BIS (2011)
8) IS 269: Specification for OPC- grade 33 by BIS (2013)
9) IS 10262: Concrete mix proportioning by BIS (2019)

In addition to these guidelines, the following assumptions were made during the calculations as obtained from BIS (2019):

1) Dry specific gravity of OPC = 3.15*
2) Saturated surface dry specific gravity of fine aggregates (sand) = 2.65**

3) Saturated surface dry specific gravity of coarse aggregates (stone)= 2.74**
4) Specific gravity of fly ash= 2.2*
5) Specific gravity of water = 1*
6) Density of water = 1000 kg/m^3
7) 50mm slump
8) 1 kg waterproofing compound per 50kg cement

*Specific gravity is a dimensionless value and presents the ratio between the true density (density of a substance independent of voids) of a substance to the density of a reference substance (usually water). Since cement is available in dry powdered form and the presence of any moisture can impact its workability, its dry specific gravity is considered which is its dry true density (3,150 kg/m^3) divided by the density of water (1,000 kg/m^3).

**Aggregates exist in a dry state naturally. However, when mixed with water their pores absorb moisture. If dry aggregates are used to make concrete, the amount of water required to make the concrete needs to be adjusted taking into consideration the absorption of water by the aggregates. On the other hand, if aggregates in their saturated surface dry state (when the pores are already saturated with water) are considered, they do not absorb any water that is added while making the concrete. The amount of water thus required is only for making the concrete. For ease of calculation, aggregates are considered in the saturated surface dry state and their corresponding specific gravity is considered.

The calculations to breakdown each component of the BOQ's for the two case studies is discussed in Appendix B. Table 7.1 summarises proportion of each material in the total building material stock used for the construction of the two case studies.

Table 7.1: Proportion of each material in the total material stock of the building (Source: Author)

Material	Case study 1	Case study 2
	% in total stock	**% in total stock**
OPC	11.5	13.92
Sand	34.73	34.03
Stone	31.8	36.35
Clay bricks	9.68	8.96
Steel	3.45	3.49
Plywood	2.11	1.71
Waterproofing compound	0.001	0.0058
Ceramic tiles	1.4	1.54
Fly ash	5.32	-

An RC frame building with clay masonry wall is the most common type of residential building construction in India constituting 45% of the residential building stock (Census India 2011). The most common materials used for the construction of these buildings as determined from the two case study buildings are aggregates (sand and stone), cement and clay bricks accounting for 68.46%, 12.71% and 9.32% respectively. Cement and aggregates are not only used for making concrete but are also used for making plaster and mortar which are essential materials required when working with clay masonry.

Steel is another essential material used as reinforcement for concrete and makes up around 3.47% of the material stock. Formwork is used when working with concrete that is cured on site as these two case studies. BIS (2002) specifies plywood as common material for formwork and as noted from the case studies it accounts to 1.91% of the material stock. Ceramic tiles are another common material used for flooring purposes in residential buildings and make up 1.47% of the material stock.

Modern construction is transitioning to replace clay bricks with autoclaved aerated concrete (AAC) bricks (BIS 2016a) however this replacement is only widespread in large projects due to the high upfront cost of these bricks compared to clay bricks as was noted by the semi-structured interviews with construction professionals (see Section 7.3.1 for more information). Moreover, modern construction techniques are also incorporating the use of fly ash while making concrete to reduce the amount of cement required (BIS 2016a). However, this is not a very widespread practice and can also be noted from the case studies since only one out of the four case studies used this material.

The identified commonly used construction materials were further analysed in stage 3 of this study to collect their EWC as discussed in Section 6.2.

7.1.2 Common Construction Activities Undertaken for Residential Building Construction in India

Each component of the BOQ was broken down to identify all the water consuming activities that were undertaken to execute the component activity. Since both the case study buildings are made of the same materials (RC frame with clay masonry), the construction methodology adopted is the same and discussed below.

Prior to the start of construction, earthwork activities (excavation and backfilling) are carried out to prepare the construction site. Water is required for dust suppression and compaction. This is followed by concrete work. Two types of concrete (plain and reinforced) are used for building construction. Plain concrete (PC) is used in small quantities only at the ground slab level and is always made on-site. RC on the other hand is used for majority of the concreting work that is often accomplished using Ready-Mix Concrete (RMC) that has been mixed off-site. Only small portions of RC are mixed on-site. On the contrary, in traditional construction, all RC was made on-site. However, over the last decade, these have been replaced by RMC (see section 7.3.1 for more information). Once all the concrete has been poured, it is cured to achieve the desired strength and workability.

When using clay brick for masonry or half-brick masonry, these bricks need to be made moist before applying the mortar. This is done to prevent the bricks from extracting the water from the mortar and reducing its workability. Upon laying these bricks, they need to be cured, plastered, and cured again. AAC bricks do not require such large volumes of water as these bricks do not need to be moistened prior to application and only need to be layered with gypsum plaster requiring no further curing. However, due to their high cost as aforementioned, these bricks are only used on high-rise and large-scale projects.

Brick bat coba waterproofing is a common traditional type of waterproofing treatment applied on flat terraces in India. In this method broken or cut bricks are laid on the terrace and followed by a layer of waterproofing material. This method is efficient because it reuses all the bricks that are not suitable for use in the masonry construction.

Ceramic tiles are the most common type of tiles used in the finished buildings with applications in the rooms, kitchen, and toilets. However, their application on site consumes water as these need to be placed on a bed of mortar and joined using cement grout. In addition to that, prior to laying the mortar bed, the floor needs to be cleaned and made moist with water.

It can thus be seen that though the BOQ specifies only one major activity, these can be broken down into many smaller activities that all consume water. Table 7.2 breaks down all the water consuming activities undertaken to execute each component of the BOQ.

Table 7.2: Water consuming activities for all case study buildings (Source: Author)

Component from the BOQ	**Water consuming activities for its execution**
Excavation	1) Dust suppression 2) Compacting the sides of the excavated trench
Backfilling	1) Compacting each layer of soil as it is backfilled in the trenches
PC & RC work	1) Making the concrete 2) Curing the concrete
Clay brick masonry & half-clay brick masonry	1) Making the cement mortar 2) Wetting the bricks prior to laying the mortar 3) Curing of the wall
Cement plaster	1) Making the plaster 2) Curing the plaster
Brick bat coba waterproofing on terrace	1) Cleaning the surface 2) Making the cement slurry 3) Making broken bricks cement concrete 4) Curing the broken bricks cement concrete 5) Making the cement mortar 6) Curing the cement mortar
Tiles	1) Cleaning the surface 2) Pouring water before the application of cement mortar 3) Making the grout

Besides the activities listed in Table 7.2, water is consumed on the construction site for miscellaneous activities like dust suppression and cleaning of vehicles and equipment's. Besides these, water is also consumed by the site staff working on the construction site for different activities like cleaning and sanitation. Though these activities are not listed in the BOQ, water is consumed for their execution. In stage 3, the site water consumption records of these case study buildings was collected and in stage 4 the EWC of each activity listed in Table 7.2 was determined as discussed further in Section 7.2. The EWC of human consumption (water consumed by the site staff for various activities like cleaning and sanitation) was determined using the government standards and number of site staff. However, the EWC of ancillary activities like dust suppression and cleaning of equipment's was not determined due to unavailability of water consumed for their execution from the collected site water consumption records.

7.2 Stage 4 Quantitative Data Analysis

The analysis in stage 2 as discussed above revealed the commonly used construction materials and construction activities undertaken to construct residential buildings. Data related to the EWC of these materials and activities was collected in stage 3 as discussed in Section 6.2 and the collected data are analysed in this stage as shown in Figure 7.3.

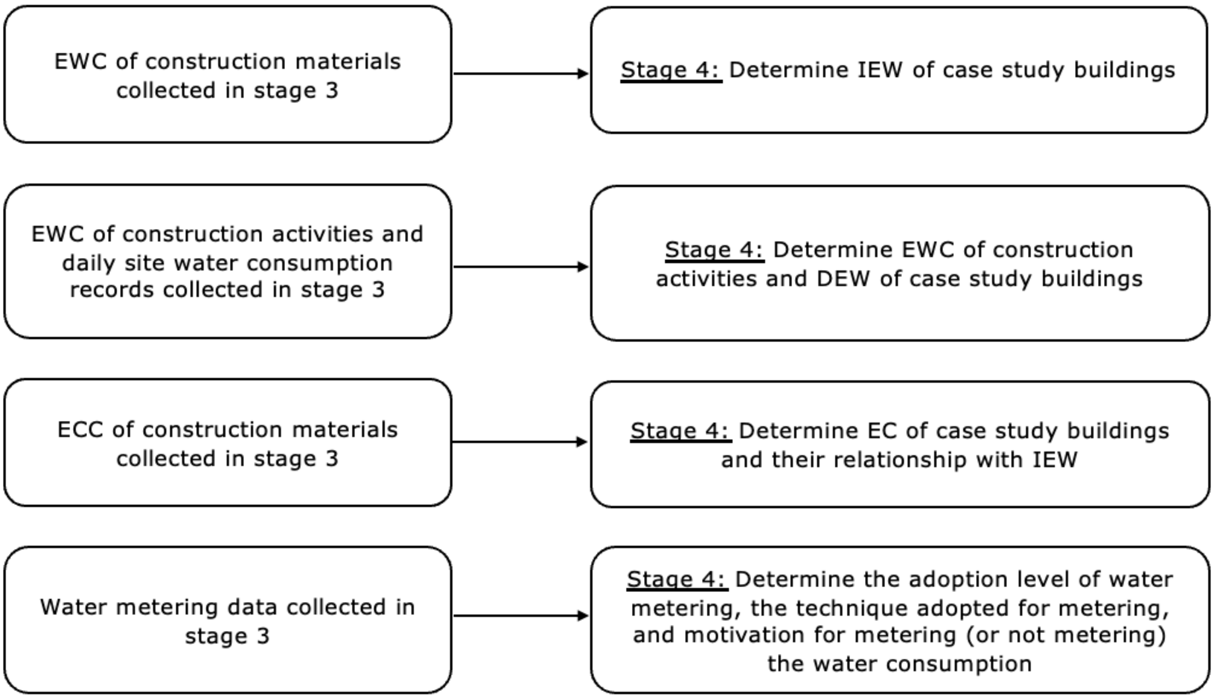

Figure 7.3: Stage 4 of the sequential explanatory multiphase mixed method (Source: Author)

This stage started by analysing the site water consumption records collected from both the case study buildings to calculate the EWC of construction activities (Section 7.2.1). These calculated EWC values along with the quantity of executing an activity as obtained from its BOQ, were used to determine DEW of the case study buildings (Section 7.2.2). For the construction materials, data related to amount of water consumed in the manufacturing plant to manufacture that material was collected (Table 6.3). This collected EWC data was analysed along with the quantities of materials as calculated in stage 2 to determine the IEW of the building (Section 7.2.3). The DEW and IEW values calculated were further analysed to calculate the EW of case study buildings (Section 7.2.4). This analysis helped achieve objective 3. The collected EWC values and calculated EW aid in setting benchmarks for efficient water consumption that plays an integral role in the proposed framework discussed further in Section 7.4.

Moreover, at this stage, the EC of the case study buildings was also calculated based on the EC-GWP database published by International Finance Corporation of the World Bank Group (2017). These EC and EW values were further analysed to determine any relationship between the two to aid in the selection of appropriate materials. This analysis helped achieve objective 4. Decision making based on these two components is essential to select materials (and activities) with the lowest environmental impact and plays a crucial role in the proposed framework.

Lastly, this stage concluded by analysing the questionnaire that was conducted (Section 7.2.6). The aim of the questionnaire was to identify the adoption level of water metering on construction sites in India, the technique adopted and the rationale for water metering. This analysis helped achieve objective 5.

7.2.1 Embodied Water Coefficient of Common Construction Activities

As discussed in Section 6.2.2, the water consumption records data collected from the project consultant for case study 1 reported the EWC of common construction activities (in kL/m^2, kL/m^3). However, for case study 2, the data collected reported the daily site water consumption (in litres) along with the major activities undertaken that day throughout the course of construction as shown in Table 6.5. This data was analysed along with the building BOQ to calculate the EWC of different construction activities (in kL/m^2, kL/m^3) and is discussed below.

Since various activities were undertaken on a single day, and the collected document does not specify the proportion of water for each activity, discussions were conducted with the project consultant to logically divide this water between each activity. The following assumptions are considered based on these discussions:

1) Water consumption by labour = 800 litres per day (based on the Indian government water requirement of 40 litres/person/day, and 20 site staff that stay on the site 24 hours)
2) Total project duration = 656 days
3) Curing of concrete, masonry and plaster, consume very large amounts of water as high as 50% of the water consumed that day.

4) Water can be divided equally for making in-situ concrete, mortar, plaster along with tile fixing on days where more than one of these activities are conducted.
5) For example: for the day when masonry, curing and tile fixing were conducted, 50% water was consumed for curing, and the rest 50% was divided equally between the other activities.

Table 7.3: Calculation to determine embodied water coefficient of construction activities for case study 2 (Source: Author)

Activity	**Water consumption (litres)***	**Quantity (unit)****	**EWC (l/unit)**
PC mixing	49,185.6	307.41 m^3	160 l/m^3
PC curing	5,533.38	307.41 m^3	18 l/m^3
On-site RC mixing	84,727.32	415.33 m^3	204 l/m^3
Off-site RC mixing	345,670	1,678 m^3	206 l/m^3
RC curing	293,066.2	2,093.33 m^3	140 l/m^3
Masonry	74,419.4	676.54 m^3	110 l/m^3
Masonry curing	209,727.4	676.54 m^3	310 l/m^3
Cement plaster	30,740.88	7,685.22 m^2	4 l/m^2
Cement plaster curing	153,704.4	7,685.22 m^2	20 l/m^2
Tile fixing	33,928	4,241 m^2	8 l/m^2

*From collected site water consumption records (Table 6.5)
** From building BOQ

7.2.2 Direct Embodied Water

Once the EWC of construction activities for both case studies was obtained, these were analysed along with the quantity of executing that activity (as obtained from the BOQ) to calculate the DEW of the case study buildings. For plastering and tile fixing, the BOQ specifies their quantities in m^2 as opposed to all the other activities that are reported in m^3. For ease of calculation, the EWC of activities was recorded in the corresponding units of the BOQ.

7.2.2.1 Case Study 1

For case study 1, data related to the amount of water (in kL) consumed to execute a unit of activity (in m^2, m^3) was collected as shown in Table 6.4. These EWC values along with the BOQ of the building are used to calculate the DEW of the building as discussed in Table 7.4.

Table 7.4: Calculation to determine direct embodied water of case study 1 (Source: Author)

Activity	**Quantity (Unit)* Q_A**	**EWC (kL/Unit)** EWC_A**	EW_A **(kL)** $Q_A \; x \; EWC_A$	**% DEW**
Human consumption	1200 days	0.8 kL/day	960	24.35
Excavation	9,000 m^3	0.04 kL/m^3	360	9.13
Backfilling	2,160 m^3	0.15 kL/m^3	324	8.22
PC mixing	81 m^3	0.15 kL/m^3	12.15	0.31
PC curing	81 m^3	0.022 kL/m^3	1.782	0.045
RC curing	4,842.88 m^3	0.17 kL/m^3	823.29	20.88
Masonry	2,173.19 m^3	0.12 kL/m^3	260.78	6.61
Masonry curing	2,173.19 m^3	0.4 kL/m^3	869.28	22.05
Cement plaster	9,275 m^2	0.0045 kL/m^2	41.74	1.06
Cement plaster curing	9,275 m^2	0.025 kL/m^2	231.88	5.88
Tile fixing	8,260 m^2	0.007 kL/m^2	57.82	1.47
Total water consumption on site			3,942.722	
Total floor area			11,335 m^2	
DEW		**3,942.722 / 11,335**	**0.35 kL/m^2**	

* From building BOQ
** From Table 6.4

7.2.2.2 Case Study 2

For case study 2, the data related to the amount of water (in litres) consumed to execute a unit of activity (in m^2, m^3) was calculated in Table 7.3. As mentioned in Section 6.2.2, the site water consumption records only reported the water consumption once all earthwork activities were completed. Thus, there was no record of the water consumption for excavation and backfilling activities. As noted from Table 7.4, these activities constitute up to 20% of the DEW and their inclusion in case study 2 is essential to calculate its DEW. Thus, discussions were conducted with the project consultant working on both the construction sites. Discussions revealed that case study 2 is located in a region with fine soil as compared to the site for case study 1. Hence, more water is required for earthwork activities on the former site. Based on the project consultant's observations during the earthwork activities on both the sites, the water consumed for earthwork activities on the site of case study 2 can be assumed to be 20% higher than that for case study 1. These EWC values along with the BOQ of the building are used to calculate the DEW of the building as discussed in Table 7.5.

Table 7.5: Calculation to determine direct embodied water of case study 2 (Source: Author)

Activity	**Quantity (Unit)* Q_A**	**EWC (kL/Unit)** EWC_A**	EW_A **(kL)** $Q_A \; x \; EWC_A$	**% DEW**
Human Consumption	656 days	0.8 kL/day	524.8	28.1
Excavation	5,952 m^3	0.048 kL/m^3	285.7	15.3
Backfilling	677 m^3	0.18 kL/m^3	121.89	6.53
PC mixing	307.41 m^3	0.16 kL/m^3	49.19	2.63
PC curing	307.41 m^3	0.018 kL/m^3	5.53	0.3
On-site RC mixing	415.33 m^3	0.204 kL/m^3	84.73	4.54
RC curing	2,093.33 m^3	0.14 kL/m^3	293.07	15.69
Masonry	676.54 m^3	0.11 kL/m^3	74.42	3.99
Masonry curing	676.54 m^3	0.31 kL/m^3	209.73	11.23
Cement plaster	7,685 m^2	0.004 kL/m^2	30.75	1.65
Cement plaster curing	7,685 m^2	0.02 kL/m^2	153.7	8.23
Tile fixing	4,241 m^2	0.008 kL/m^2	33.93	1.82
Total water consumption on site			1,867.42	
Total floor area			5,900 m^2	
DEW		**1,867.42 / 5,900**	**0.32 kL/m^2**	

* From building BOQ
** From Table 7.3

7.2.2.3 Discussion of Direct Embodied Water for Case Study 1 & 2

For both the case studies the workers stayed on site for 24 hours and there were provisions for housing, sanitation, and cooking. As a result, as noted from Table 7.4 and Table 7.5, this component constitutes a major portion (almost 26%) of the total water consumed on the construction site. This was also noted by Bardhan (2011) and Choudhuri (2015) that state human consumption activities to be the largest water consuming activities on the construction site.

The amount of water consumed for earthwork activities as mentioned above depends on the type of soil of the location. The finer the soil the more it becomes air borne, and hence more water is required to suppress it. This also results in more water required for compaction. However, since case study 2 did not have any water consumption records to collect the actual water consumption difference, the 20% difference as mentioned above was assumed based on the observation of the project consultant who has worked on construction sites with different types of soil. Moreover, the weather of a location also impacts the water required for these activities, as less water is required during rainy weather, while more is required during windy conditions. However, since the construction of both the buildings was during similar weather conditions, data related to this external factor was not calculated.

As noted from the DEW calculations of both the case studies, the DEW of case study 2 is around 10% lower than that for case study 1. This is attributed to the water management practices followed during the construction of case study 2. The following water management practices were adopted on case study 2:

1) Freshly poured concrete was covered with moist gunny bags to reduce the evaporation of water. This lowered evaporation rate decreases the amount of water required for curing and results in a lower EWC of curing. Figure 7.4 shows how the concrete column was cured.
2) A cleaning platform was created where all cleaning activities were undertaken. The wastewater collected from the cleaning activities was stored in a sedimentation tank and reused for further cleaning. This reduced the amount of potable water consumed for ancillary activities.

Figure 7.4: Water management practices followed during column curing during construction of case study 2 (Photograph: Construction Interviewee 2)

The scattered and unorganised nature of construction sites makes it challenging to record the water consumed for ancillary like dust suppression and cleaning purposes. As a result, the EWC of these activities could not be determined.

Choudhuri (2015) calculated the DEW of a four-star rated hotel in north India by calculating the number of water tankers that arrived on site throughout the construction duration along with the volume of each tanker and noted the DEW to be 1.97 kL/m^2. Another study conducted in Iran by Heravi and Abdolvand (2019) used the Commentary of National Building Price List to calculate the average DEW of six residential buildings to be 3.22 kL/m^2. A study conducted by Santos et al. (2018) measured the DEW of a building constructed in Brazil by installing a water meter on the construction site and noted this value to be 0.83 kL/m^2. The DEW of this study was also calculated following the same methodology as Santos et al. (2018) of installing water meters and noted the average DEW of the two case study buildings to be 0.335 kL/m^2. The latter two studies note a considerably lower DEW as compared to the former two studies by Choudhuri (2015) and Heravi and Abdolvand (2019). This is based on the methodology adopted to calculate the DEW. Choudhuri (2015) and Heravi and Abdolvand (2019) based their values on approximate calculations while this study and Santos et al. (2018) based the values on exact water consumption data collected on-site which is a more reliable method to calculate the DEW as it measures the exact water consumption on site.

7.2.3 Indirect Embodied Water

Data related to the EWC of common construction materials (kL/ton, kL/m^2) was collected from the material manufacturers and shown in Table 6.3. These EWC values along with the quantities of material (obtained from analysing the BOQ of the building as discussed in Section 7.1) are used to calculate the IEW of the case study buildings. The EPD's list the environmental performance of all the materials (except ceramic tiles) in units of ton (as opposed to m^2 for ceramic tiles). As a result, for uniformity of calculation, the EWC of the materials was collected in the corresponding units of EPD's.

7.2.3.1 Case Study 1

Based on the data collected related to EWC of construction materials and the quantities of each material consumed in the building, the IEW of case study 1 was calculated as shown in Table 7.6.

Table 7.6: Calculation to determine indirect embodied water of case study 1 (Source: Author)

Material	**Quantity (Unit)* Q_M**	**EWC (kL/Unit)** EWC_M**	EW_M **(kL)** $Q_M \; x \; EWC_M$	**% IEW**
Cement	2,031.85 ton	0.2 kL/ton	406.37	7.63
Sand	6,136.66 ton	0.14 kL/ton	859.13	16.14
Stone	5,619.22 ton	0.14 kL/ton	786.69	14.79
Clay bricks	1,710.31 ton	0.5 kL/ton	855.15	16.07
Steel	610.12 ton	3.55 kL/ton	2,165.91	40.71
Ceramic tiles	8,218.91 m^2	0.03 kL/m^2	246.57	4.63
Total			5,319.83	
Total floor area			11,335 m^2	
IEW		**5,319.83 / 11,335**	**0.47 kL/m^2**	

* From building BOQ analysis in Section 7.1.1
** From Table 6.3

The BOQ of the building revealed that the concrete used for this case study was ready-mixed. Thus, this concrete was mixed off-site but was placed and cured on site. As a result, the RC curing element was considered in the DEW (Table 7.4), whereas the RC mixing elements was considered in the IEW as shown in Table 7.7.

Table 7.7: Off-site reinforced concrete calculations for case study 1 (Source: Author)

Activity	**Quantity (Unit)*** **Q_M**	**EWC (kL/Unit)**** **EWC_M**	EW_M **(kL)** $Q_M\ x\ EWC_M$
Off-site RC mixing	4,842.88 m^3	0.19	920.15
Total floor area			11,335 m^2
IEW		920.15 / 11,335	**0.081 kL/m²**

* From building B0Q
** From Table 6.4

Hence, the total IEW of case study 1 is 0.47 kL/m^2 + 0.081 kL/m^2 = **0.551 kL/m²**

7.2.3.2 Case Study 2

Based on the data collected related to EWC of construction materials and the quantities of each material consumed in the building, the IEW of case study 2 was calculated as shown in Table 7.8.

Table 7.8: Calculation to determine indirect embodied water of case study 2 (Source: Author)

Material	**Quantity (Unit)*** **Q_M**	**EWC (kL/Unit)**** **EWC_M**	EW_M **(kL)** $Q_M\ x\ EWC_M$	**% IEW**
Cement	1,140.98 ton	0.2 kL/ton	228.2	8.97
Sand	2,789.73 ton	0.14 kL/ton	390.56	15.35
Stone	2,980.13 ton	0.14 kL/ton	417.22	16.4
Clay bricks	734.78 ton	0.5 kL/ton	367.39	14.44
Steel	285.78 ton	3.55 kL/ton	1,014.52	39.87
Ceramic tiles	4,219.90 m^2	0.03 kL/m^2	126.6	4.98
Total			2,544.48	
Total floor area			5,900 m^2	
IEW		**2,544.48 / 5,900**	**0.43 kL/m²**	

* From building BOQ analysis in Section 7.1.1
** From Table 6.3

Similar to case study 1, the BOQ of the case study 2 revealed that majority of the concrete used for its construction was also ready-mixed. Thus, its mixing was included in the IEW. The BOQ also revealed that a small portion of RC that was made in-situ, and hence its casting was included in the DEW (Table 7.5).

Table 7.9: Off-site reinforced concrete calculations for case study 2 (Source: Author)

Activity	**Quantity (Unit)*** **Q_M**	**EWC (kL/Unit)**** **EWC_M**	EW_M **(kL)** $Q_M \, x \, EWC_M$
Off-site RC mixing	1,678 m^3	0. 206	345.67
Total floor area			5,900 m^2
IEW		345.67 / 5,900	**0.059 kL/m^2**

* From building B0Q
** From Table 7.3

Hence, the total IEW of case study 2 is 0.43 kL/m^2 + 0.059 kL/m^2 = **0.489 kL/m^2**

<u>7.2.3.3 Discussion of Indirect Embodied Water for Case Study 1 & 2</u>

It can be noted from Table 7.6 and Table 7.8, that the quantity of steel used is very low compared to other materials like cement, aggregates and bricks, however, its EWC is significantly larger than all the other materials. As a result, the overall impact steel has on the IEW of the building is the highest at almost 40%. Moreover, it can also be observed that though aggregates have the lowest EWC, they are used in the largest quantity and hence contribute significantly to the IEW of the building. It can thus be concluded that, the EWC of a material and its quantity of consumption both influence the IEW.

Besides this, it was also observed that the average IEW of this study (0.52 kL/m^2) is significantly lower than another study conducted in Iran by Hearvi and Abdolvand (2019) that calculated the IEW to be 16.91 kL/m^2. Table 7.10 compares the IEW calculation for both the studies. Though both studies followed the process LCA approach, this study only determined the EWC of the materials based on the water consumed at the manufacturing plant (Module A3). However, Hearvi and Abdolvand (2019) determined the EWC based on water consumed to manufacture the material throughout its supply chain (Module A1-A4). As noted from Table

7.10, this difference results in minor difference in the calculated EWC of the material.

Another reason for this IEW difference is the EWC of steel. Heravi and Abdolvand (2019) reported an EWC of steel that was considerably higher than this study. For this study, the EWC of steel was collected from a published EPD in Indian context (The International EPD System 2022b), and the steel was used as a reinforcement. However, Heravi and Abdolvand (2019) collected the EWC data through interviews. Moreover, in the case study building analysed by Heravi and Abdolvand (2019), steel was used as both reinforcement and as a frame for the façade. As a result, the EWC value considered in the latter study was higher. These differences in steel EWC considered are largely responsible for the significant difference in IEW of these two studies. This significant difference in steel EWC is also responsible for the large contribution (68%) of steel in the IEW from Heravi and Abdolvand (2019) as opposed to this study that noted the contribution to be around 40%.

Table 7.10: Comparison of indirect embodied water calculations between this study and Heravi and Abdolvand (2019) (Source: Author)

Description	**This study**	**Heravi and Abdolvand (2019)**
Location	India	Iran
Method of data collection for EWC of material	Process LCA (Only module A3)	Process LCA (Module A1-A3)
Number of materials considered for IEW calculations	6	8
Major materials considered and their EWC	1) Cement = 0.2 kL/ton 2) Sand = 0.14 kL/ton 3) Stone = 0.14 kL/ton 4) Clay bricks = 0.5 kL/ton 5) <u>Steel = 3.55 kL/ton</u> 6) Ceramic tiles = 0.03 kL/m^2	1) Cement = 0.315 kL/ton 2) Sand = 0.35 kL/ton 3) Stone = 0.35 kL/ton 4) Bricks = 0.76 kL/ton 5) <u>Steel = 84 kL/ton</u> 6) Tiles = 0.05 kL/m^2
IEW (kL/m^2)	0.52	16.91

7.2.4 Embodied Water

The DEW and IEW components are added up to calculate the EW of the case study buildings. As discussed in Section 7.2.3, the IEW is composed of two components, the water required to make all the materials, and the water required to make the RC off-site.

7.2.4.1 Case Study 1

EW = 0.35 kL/m^2 + 0.551 kL/m^2 = **0.901 kL/m^2**

7.2.4.2 Case Study 2

EW = 0.32 kL/m^2 + 0.489 kL/m^2 = **0.809 kL/m^2**

7.2.4.3 Discussion of Embodied Water for Case Study 1 & 2

Table 7.11 compares the proportion of each component (DEW and IEW) in the EW of that building.

Table 7.11: Case study 1 VS case study 2 (Source: Author)

	% DEW	**% IEW**
Case study 1	38.85	61.15
Case study 2	39.56	60.44

Past studies like Bardhan (2011) and Heravi and Abdolvand (2019) note that the DEW constitutes 8% and 16% of the EW respectively. This study found that DEW constitutes around 40% of the EW, and both the DEW and IEW components require equal attention for EW management.

7.2.5 Embodied Carbon and Embodied Water of the Studied Construction Materials

Data related to the EC-GWP in Indian context of different construction materials was collected from the International Finance Corporation of the World Bank Group (2017) database. These collected EC-GWP coefficients are used to determine the EC-GWP of the case study buildings. The calculated EC-GWP of each material is compared with its EW to identify any relationship between the two to aid in the selection of construction materials with limited environmental impacts.

7.2.5.1 Case Study 1

Based on the data collected related to ECC of construction materials and the quantities of each material consumed in the building, the EC of case study 1 was calculated as shown in Table 7.12.

Table 7.12: Calculation to determine embodied carbon of case study 1 and its comparison with indirect embodied water (Source: Author)

Material	**Quantity (kg)* Q_M**	**EC-GWP (kgCO2 eq/kg)** ECC_M**	**EC-GWP (kgCO2 eq)** $Q_M \, x \, ECC_M$	**% EC-GWP**	**% IEW *** **
Cement	2,031,852	0.91	1,848,985.32	42.25	7.63
Sand	6,136,656.46	0.0090	55,229.91	1.26	16.14
Stone	5,619,219	0.0090	50,572.97	1.16	14.79
Clay bricks	1,710,306.40	0.39	667,019.5	15.24	16.07
Steel	610,116.50	2.6	1,586,302.9	36.25	40.71
Ceramic tiles	246,560.00	0.68	167,660.8	3.83	4.63
Total			4,375,771.4		
Total floor area			11,335 m^2		
EC-GWP			**386 kgCO2 eq/m^2**		

* From building BOQ
** From Table 6.6
*** From Table 7.6

7.2.5.2 Case Study 2

Based on the data collected related to ECC of construction materials and the quantities of each material consumed in the building, the EC of case study 2 was calculated as shown in Table 7.13.

Table 7.13: Calculation to determine embodied carbon of case study 2 and its comparison with indirect embodied water (Source: Author)

Materials	Quantity (kg)* Q_M	EC-GWP (kgCO2 eq/kg)** ECC_M	EC-GWP (kgCO2 eq) $Q_M \; x \; ECC_M$	% EC-GWP	% IEW ***
Cement	1,140,979	0.91	1,038,290.89	47.07	8.97
Sand	2,789,726.49	0.0090	2,107.54	1.14	15.35
Stone	2,980,128	0.0090	26,821.15	1.22	16.4
Clay bricks	734,782.40	0.39	286,565.14	12.99	14.44
Steel	285,779.71	2.6	743,027.25	33.68	39.87
Ceramic tiles	126,600.00	0.68	86,088	3.90	4.98
Total			2,205,899.96		
Total floor area			5,900m^2		
EC-GWP			**373.88 kgCO2 eq/m^2**		

* From building BOQ
** From Table 6.6
*** From Table 7.8

7.2.5.3 Discussion of Embodied Carbon & Indirect Embodied Water Relationship for Case Study 1 & 2

Figure 7.5 shows the comparison between average EC and average IEW of case study 1 and 2. It can be noted that cement has the highest contribution towards EC, but the second lowest contribution towards EW. This is attributed to the fact that cement manufacturing is not water intensive but rather energy intensive due to the large amount of energy consumed in the blast furnace and basic oxygen furnace for heating the clinker and raw materials. Moreover, steel produces lower EC emissions compared to cement, but consumes significantly large amounts of water in the process. This is attributed to the large amounts of water consumed for cooling in the steel manufacturing process. Lastly, aggregates contribute very highly to the IEW but very little to the EC emissions. This is because the aggregate manufacturing process consumes large volumes of water for cleaning and sizing purposes. Energy is not consumed in large quantities and only used for grinding activities.

It can thus be seen that a material might have a low EC but high EW and vice versa. Decisions regarding the selection of a material cannot be made on just one component, but both the EC and EW impacts must be considered. This was also noted by Dixit and Kumar (2022) which state that when selecting materials decisions regarding its impact on both the EE and EW must be considered to aid in the selection of materials with lowest environmental impacts.

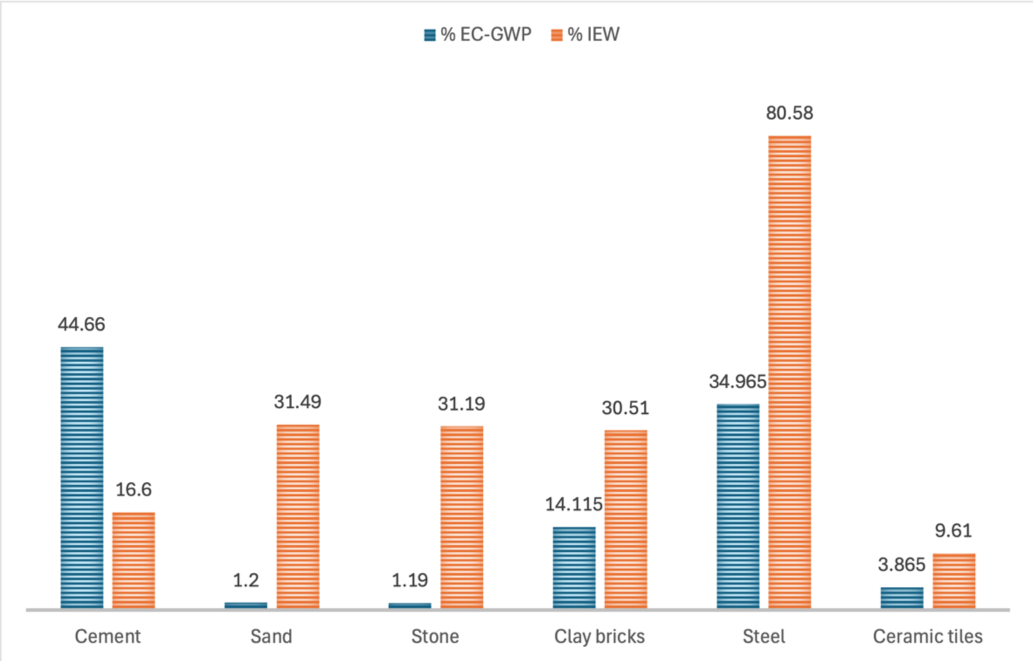

Figure 7.5: Embodied carbon and indirect embodied water comparison between case study 1 and 2 (Source: Author)

7.2.6 Questionnaire on Water Metering in the Indian Construction Industry

An online questionnaire collecting information on the adoption level of water metering on construction sites in India and the technique of water metering adopted was distributed among construction professionals as discussed in Section 6.2.4. The questionnaire consisted of three themes and six questions as shown in Table 5.9. This section discusses these findings, and each theme is presented in a separate sub-section. The open-ended responses received were analysed by creating a code book as discussed in Section 5.6.1.2.

7.2.6.1 Water Metering

Out of the 46 respondents, 25 respondents (54.4%) selected “no” for water metering, while 21 respondents (45.7%) selected “yes” for water metering on construction projects in India.

7.2.6.2 Don’t Meter Water Consumption

The most common reason why water is not metered on construction sites is due to the lack of awareness among people regarding water metering (17.4%) along with the lack of requirements for metering water consumption on construction sites (17.4%). In addition to these, as noted further in Section 7.3.1, construction sites in India use concrete that has been ready-mixed. This is one of the largest water-consuming activity that requires proper water monitoring. But since it is not conducted on a construction site, water metering is not adopted. The uncontrolled nature of the construction site (discussed in Section 7.3.1) also makes water metering challenging that limits its adoption among large number of respondents. Table 7.14 summarises the codebook created for the responses.

Table 7.14: Codebook for not metering water consumption (Source: Author)

Category	Code	Response	Frequency
Requirement	1	Water metering is not required	4
	2	Limited policies surrounding water use	1
	3	Concrete is made off-site	4
	4	No benchmarks to compare water consumption	1
Cost	5	Additional cost of water metering	1
	6	Billing of water is on pre-fixed amount	2
Awareness	7	Clients unwilling to adopt sustainable practices	1
	8	Lack of awareness regarding water metering	4
	9	Uncontrolled water consumption	3
	10	Water is easily available	2

7.2.6.4 Meter Water Consumption

Out of the 21 respondents that noted to meter water consumption on their construction site, majority of the respondents (38.1%) noted that they meter water on every project that they have been involved on. However, the second highest frequency of adoption (23.8%) was limited to metering water in only 1 out of every 20 projects the respondents were involved in. Table 7.15 summarises the frequency of each response received and its proportion in the total responses.

Table 7.15: Frequency of water metering (Source: Author)

Response	Frequency	% in Total
1 in every 20 projects	5	23.8%
1 in every 10 projects	2	9.5%
1 in every 5 projects	2	9.5%
1 in every 3 projects	1	4.8%
1 in every 2 projects	3	14.3%
1 in every 1 project	8	38.1%

71% of the respondents noted that using a water meter to meter the amount of water consumed is the most common method adopted on construction sites. Though seven respondents, simply stated that they use a water meter, two respondents clarified by stating that these water meters are installed at the tap of the municipality water connection. Furthermore, one respondent stated that these water meters are also installed at the point of groundwater extraction. Another method of calculating the water consumed on the construction site is based on calculating the number of tankers arriving at the construction site and the capacity of each tanker. Table 7.16 summarises the code book created for the responses.

Table 7.16: Codebook for methodology of water metering (Source: Author)

Category	Code	Response	Frequency
Water meter	11	Water meter	7
	12	Water meter at groundwater extraction pump	1
	13	Water meter at municipality water connection tap	2
Other meters	14	Rapid Moisture Meter	1
	15	Mass Flow Totalizer	1
Water tankers	16	Water tankers arriving on site	2

Most of the respondents noted that they keep a record of their daily water consumption. Following this, recording water consumption on monthly and weekly basis were the second and third most adopted durations of measurement. Besides these, 28% of the respondents further noted that the water consumption value that they record is an average value for a duration. Table 7.17 summarises the code book created for the responses.

Table 7.17: Codebook for water metering data collected (Source: Author)

Category	Code	Response	Frequency
Duration	17	Daily	6
	18	Weekly	2
	19	Monthly	3
	20	Six Months	1
	21	Annually	1
Type	22	Average	5

The respondents noted that the most common reason for water metering on construction sites is to monitor the water consumption. Three respondents noted that metering of water is a mandatory requirement however, only one of these respondents clarified that that this requirement is a part of the contract. This is also attributed to the fact that water is purchased, and its cost is transferred to the client. Thus, recording of water consumption for billing purposes is the second most common reason for water metering on construction sites. Besides this, the respondents also noted that water is metered so that the consumption can be recorded along with identification of opportunities for improving water use efficiency and minimising water wastage. Table 7.18 summarises the code book created for the responses.

Table 7.18: Codebook for metering water consumption (Source: Author)

Category	Code	Response	Frequency
Requirement	23	Mandatory requirement	2
	24	Requirement as part of the contract	1
Cost	25	Billing purposes	6
Sustainability	26	Monitor consumption	7
	27	Improve efficiency	4
	28	Control wastage	5
Availability	29	Limited availability	1

The questionnaire analysis revealed that majority of the construction sites in India do not meter their water consumption (54.4%) due to the lack of awareness among people and the lack of regulations mandating the same. On the other hand, the major reason for metering the water consumption is the willingness of the site staff to monitor their water consumption to improve efficiency. Another reason for this metering is to measure the amount of water consumed as the client has to pay for this consumed water. Moreover, installing a water meter at the point of water withdrawal is the most common technique adopted to meter the water consumption.

7.3 Stage 6 Qualitative Data Analysis

In this stage of the sequential explanatory multiphase mixed method study, the qualitative data collected in stage 5 through semi-structured interviews with construction professionals and material manufacturers was analysed as shown in Figure 7.6. This analysis helped accomplish Objective 6.

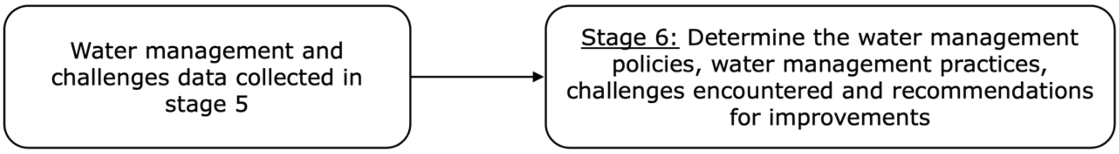

Figure 7.6: Stage 6 of the sequential explanatory multiphase mixed method (Source: Author)

The interviews were analysed using the thematic analysis process as outlined by Saunders, Lewis and Thornhill (2023) wherein the findings from each interviewee were divided into codes and its frequency determined. This section is divided into two parts, with the first focusing on interviews conducted with construction professionals and the latter focusing on those conducted with construction material manufacturers. The findings from these interviews in the form of water management policies, water management practices adopted, the challenges encountered and recommendations to improve water sustainability play a crucial role in the development of the proposed framework.

7.3.1 Building Construction

Semi-structured interviews were conducted with seven people working in the construction industry in India. The demographics of the interviewees were discussed in Section 6.3.1. Each interviewee was asked questions surrounding the themes of geographical location of working, water consuming activities on construction sites, government and company policies related to water management and how these impact the water management practices followed on their sites, the challenges faced for their adoption, and their recommendations to improve water sustainability on the construction sites. This section discusses these findings, and each question is presented in a separate sub-section.

7.3.1.1 Geographical Location and impact on water consumption

Interviewees 1, 2, 5 and 7 have worked in different parts of India (north, south, west, east, and central), interviewees 3 and 4 have worked mainly in the northern part and interviewee 6 has worked mainly in the western part.

Interviewee 1 and 7 noted that the amount of water consumed on construction sites majorly depends on the method of construction adopted (on-site or off-site construction) and the materials used (clay bricks, AAC bricks, concrete with fly ash, etc.) rather than the location of the site. Interviewee 1 further added that the soil type of a location impacts the amount of water required for activities like dust suppression and compaction. Coarse sand tends to remain settled as compared to fine sand that stays airborne. Thus, areas with coarse sand require less water for dust suppression and compaction. This difference was also noted by interviewee 5. Interviewee 2 who has worked in different parts of India noted that the cultural differences within the country impact the amount of water consumption. This interviewee noted that people in south India value water more than people in north India because the southern part of the country has always suffered from water scarcity episodes while the northern part has a lot of rivers flowing through as part of the Indo-Gangetic plain and has not witnessed many water scarcity episodes in the past. This was also noted by interviewee 6 who noted how the water availability of a region impacts the attitude of the people and ultimately water consumption. Interviewee 3 and 4 who have worked majorly in the northern part of India, noted how water is not valued and no one pays attention to the amount of water consumed on construction sites. To add to this interviewee 4 said that they only started paying attention to water consumed on construction sites after water scarcity episodes within the country were heavily discussed in the news.

These findings are categorised into codes and their frequencies are shown in Table 7.19.

Table 7.19: Thematic analysis for geographical location (Source: Author)

Theme	Code	Interviewee
Geographical location	Different locations in India	1,2,5,7
	North India	3,4
	West India	6
Reason for differences	Construction method adopted	1,7
	Materials used	1,7
	Soil	1,5
	Cultural differences	2,3,4,6

7.3.1.2 Water Consumption

All the interviewee's stated that concreting (preparation and curing), dust suppression and cleaning activities consume large volumes of water. Interviewee 1, 2, 5 and 7 further added that construction workers and site staff also consume large volumes of water which makes up a significant portion of the total water consumed on site. Interviewees 4 and 5 further added that in addition to the large amounts of water required for making concrete, large volume of water is also wasted in the process. Table 7.20 categorises these findings into codes and identifies their frequency.

Table 7.20: Thematic analysis for water consumption (Source: Author)

Theme	Code	Interviewee
Water consuming activities	Concreting	1,2,3,4,5,6,7
	Dust suppression	1,2,3,4,5,6,7
	Cleaning	1,2,3,4,5,6,7
	Human consumption	1,2,5,7

7.3.1.3 Sources of Water

All interviewee's said that the most common source of water on construction sites are treated wastewater from sewage treatment plants (STPs) as this is mandated by the Indian government. Interviewee 7 further added that sometimes identification of a STP in the vicinity of the construction site in a remote area poses as a challenge which forces construction sites to either source the water from a STP located further away or identify another source of water. All interviewees added that groundwater is used in regions where its extraction is permitted (like the city of Jaipur where case study 2 is located). Interviewee 2 and 6 added that for some areas groundwater is the only available and reliable source and hence is used even though using this source might be banned by the government. Interviewee 6 further added that the deeper the groundwater is extracted from, the purer it is. Interviewee 3 added that rainwater is used as a major source only in regions where rainfall is common throughout the year and sufficient water can be harvested. However, due to the high cost and space requirements of such a system, rainwater harvesting (RWH) is only practiced on large sites. Interviewee 3 further added that the regions that have plenty rainfall also have high groundwater levels from which water can be easily withdrawn. Withdrawal of this groundwater is comparatively easier than harvesting rainwater. Interviewee 2 added that for majority of locations in India since rain is not constant throughout the year, harvested rainwater is best used as an additional source rather than a primary source. Interviewee 1 added that treated wastewater from on-site wastewater treatment plants on large projects can be used for different activities. Interviewee 4 said that "since water is used daily on a construction site, the source of water used must be reliable and produce enough water for consumption daily".

Interviewees 1 and 3 said that different activities require water of different quality standards, and importance must be given to the quality of the water rather than the source of water. For instance, for making concrete, plaster, and mortar, only water meeting the water quality standards listed in BIS (2007) can be used. Thus, any source of water that provides this quality water should be used. Interviewee 1 quotes that "quality of water is extremely important for concreting activities. If the right type of water is not used, it can impact the quality of the concrete" and eventually its strength. Interviewee 3 further added that to ensure that the right quality of water is used, the incoming water should always be tested for its quality. Besides concreting, water used for human consumption must also meet certain water quality standards. Interviewee 1 and 3 also noted that for activities like cleaning and dust suppression, the quality of water is not important, and any source of water can be used.

Table 7.21 categorises these findings into codes and identifies their frequency.

Table 7.21: Thematic analysis for sources of water (Source: Author)

Theme	Code	Interviewee
Source of water used	Treated wastewater from STP	1,2,3,4,5,6,7
	Groundwater	1,2,3,4,5,6,7
	Rainwater	3
	On-site treated wastewater	1
Reason of selection	Government regulation	1,2,3,4,5,6,7
	Ease of availability and reliability	2,3,4,6
	Quality of water from source	1,3
Challenges	Availability of the source	2,3,7
	Space constraints	3
	High cost	3

7.3.1.4 Water Metering

All interviewees except interviewee 2 said that the unorganised and uncontrolled environment of a construction site makes it difficult to measure the exact amount of water consumed for different activities and they do not record such values on their site. Interviewee 2 added that they install a water meter at the point of water withdrawal and keep a record of the daily water consumption and activities undertaken that day to monitor and control the water consumption on the construction site. Interviewee 4 and 7 expressed their interest to start recording these values but stated that cost implications associated with these measurements limit their adoption on their site. Interviewee 6 added that construction sites majorly keep a record of their water consumption since they pay for purchasing the water (as was also noted from the questionnaire analysis in Section 7.2.6). This interviewee further added that the water consumed for each activity is rarely recorded. interviewee 1 added that the guidelines of BIS (2007) are helpful for calculating the amount of water required to make concrete, mortar, and plaster. Interviewee 2,4 and 5 also noted that the large number of consumption points on a construction site further make measuring the amount of water consumed difficult and challenging. Interviewee 2 added that "what is not measured is not conserved" and states that unless water consumption on site is not measured, it cannot be efficiently managed. Table 7.22 categorises these findings into codes and identifies their frequency.

Table 7.22: Thematic analysis for water metering (Source: Author)

Theme	Code	Interviewee
Water measurement	Water meters	2,6
	Published guidelines	1
	Water bills	6
Challenges	High cost	4,7
	Uncontrolled nature of construction site	1,3,4,5,6,7
	Unorganised environment of construction site	1,3,4,5,6,7
	Numerous consumption points	2,4,5

7.3.1.5 Water Management Policies

All the interviewees echoed that there is overall very little attention given to water management in construction. The most common government regulations are:

1) The ban on the use of groundwater for construction activities (in some regions of India where the groundwater table level is very low).
2) The use of only treated wastewater coming from a STP for these construction activities.

Interviewee 2,3 and 7 added that though there are regulations on the ban of groundwater for construction purposes, in some instances groundwater is the only reliable and available source, and companies need to use this water source. Moreover, interviewee 4 added that incoming water from STP is expensive which poses as a major challenge for companies, and they continue to rely on groundwater despite a ban on its consumption. Interviewee 1 said that "You may not be getting 100% compliance, but even with the little compliance you are getting, you are still saving water". Interviewee 2 further added that "there are regulations, but its enforcement is not seen through".
Interviewee 2 highlights that the attitude of the site staff or policies of the company plays a stronger role as compared to government regulations.

Table 7.23 categorises these findings into codes and identifies their frequency.

Table 7.23: Thematic analysis for water management policies (Source: Author)

Theme	Code	Interviewee
Government regulations	Little attention	1,2,3,4,5,6,7
	Ban on groundwater use	1,2,3,4,5,6,7
	Use of treated wastewater from STP	1,2,3,4,5,6,7
Effectiveness	Availability constraints	2,3
	Cost constraints	4
	Attitude	2
Challenges	Reliability and availability of the source	2,3,7
	Cost of obtaining that source	4

7.3.1.6 Water Management Practices

The following actions are being taken on constructions sites to reduce water consumption based on the interview findings:

1) Pre-cast elements: All interviewees said that the most common trend on construction sites in India these days is the use RMC rather than using site-mixed concrete. Since making concrete consumes a very large portion of water, the use of RMC can help reduce the amount of water consumed on site for making the concrete. This, however, does not reduce the amount of water consumed on site for curing the concrete. Interviewee 1 further added that though this method reduces the amount of water consumed on construction sites (DEW) it does not reduce the EW of the building. Interviewee 1 and 3 further noted that on large projects, pre-cast elements can either be used for the whole construction process or partially. Since these elements are mixed and cured in a manufacturing plant, there are numerous provisions for monitoring and controlling the amount of water consumed thereby minimising water wastage. This reduces the DEW but has little to no impact on the EW of the building. However, if hollow pre-cast elements are used, the EW of the building is also reduced as the amount of materials consumed are reduced (thereby reducing the IEW).
2) Curing agents: All interviewees said that curing agents are largely used on construction sites as they help reduce the amount of water required for curing purposes. Interviewee 5 further explained that these curing compounds are applied on freshly poured concrete after removing the formwork, which creates an impermeable layer on the concrete preventing

the evaporation of water poured on concrete for curing it along with increasing the oxidation rate of concrete. This interviewee further added that these agents are expensive and increase the cost of the project.

3) AAC Bricks: Interviewee 1 and 3 also noted that on the large projects they have worked, AAC bricks are used as compared to clay bricks. In addition to reducing the DEW of the building, the use of AAC bricks also increases the construction speed and reduces the weight of the building as they are lighter. This also helps reduce the amount of materials required for making the building foundation, thereby also reducing the IEW and eventually the EW. However, these bricks are more expensive compared to traditional clay bricks and this limits their adoption on small and medium size projects.
4) Chemicals: Interviewee 4 said that in some large project's chemicals are used for fixing the tiles rather than cement mortar. This also eliminates the need to curing the tiles.
5) Fogging machines: Interviewee 2 and 4 noted the use of fogging machines as a dry method of dust suppression. However, interviewee 4 added that the operation of these fogging machines consumes energy thereby increasing the EC footprint of the building. This interviewee said that "reducing one element (EW) increases another element (EC) and being able to maintain a balance between the two is extremely essential".
6) Cleaning platform: Interviewee 2 said they construct a cleaning platform to help with reducing the amount of freshwater required for cleaning activities by enabling the recycling of wastewater. This interviewee added that this space requirements and cost of setting up this platform results in challenges towards motivating the client to adopt this practice.
7) Water storage tank: Interviewee 6 added that water from water storage tanks can be used for all ancillary activities like cleaning and dust suppression. This helps reduce the use of free flowing water for these activities.
8) Behavioural change: Interviewee 2, 4, 5 and 7 added that changing the behaviour of site staff can help to reduce the amount of water consumed on the site. Activities like closing taps when not in use can be encouraged among the staff. Interviewee 4 said that in order to ensure this behavioural change, it is extremely essential to create awareness about water scarcity and management among the site staff and they do this on their site by

having workshops every few months. Interviewee 2 further added that the passing of vehicles in a high speed results in a lot of dust becoming air-borne and the need of water for its management. This air-borne dust can be minimised by setting up very low speed limits for vehicles being driven on unpaved roads on the construction site.

Table 7.24 categorises these findings into codes and identifies their frequency.

Table 7.24: Thematic analysis for water management practices (Source: Author)

Theme	Code	Interviewee
Water management practices followed	Off-site produced concrete	1,2,3,4,5,6,7
	Pre-cast elements	1,3
	Curing agents	1,2,3,4,5,6,7
	AAC bricks	1,3
	Chemicals	4
	Fogging machines	2,4
	Cleaning platform	2
	Water storage tank	6
	Behavioural change	2,4,5,7
Impact	Impact on DEW	1
	Impact on EW	1,3
	Impact on IEW	1,3
	Impact on EC	4
	Size of project	1,3,4
	Increased construction speed	1,3
	Impact on resources	1,2,3
Challenges	Cost of implementing	1,2,3,5
	Space requirement	2

7.3.1.7 Wastewater Management

interviewee 1 said that majority of water used on construction sites for curing activities is lost to the atmosphere through evaporation due to the lack of containment opportunities for collecting this water. Thus, large volumes of wastewater cannot be collected and managed. Interviewees 3 and 5 said along the same lines as interviewee 1 that the uncontrolled and complex nature of construction sites makes it difficult to control and monitor different activities making the collection of wastewaters from these activities extremely difficult. Furthermore, interviewee 4 added that they realise the importance reusing and recycling water that can be achieved through efficient wastewater management, but the lack of and difficulty in constructing containment areas for collection of wastewater limits the reuse and recycling of water. This interviewee further added that "if a containment zone is created, and a preliminary wastewater treatment plant is constructed on a site, large volumes of water can be recycled for activities like washing, cleaning, toilet flushing and dust suppression".

In contrary, interviewee 2 stated that with proper planning wastewater can be collected from cleaning activities and can be recycled after preliminary treatment on site. The interviewee added that on their construction sites they always construct a cleaning platform where all cleaning activities are undertaken. The wastewater from these cleaning activities is further collected in a sedimentation tank. The water after sedimentation can be recycled again for cleaning or other appropriate activities. Furthermore, this interviewee added that the sediments collected from the bottom of the sedimentation tank comprise of aggregates that can be cleaned and used for making concrete. On one of their sites, they had collected around $1m^3$/day of aggregates from these sediments. They stated that the creation of these cleaning platforms not only saves water but also reduces cost required to purchase aggregates for concreting activities.

All interviewees noted that the wastewater produced on construction sites as a result of human consumption is easier to collect as compared to other construction activities. Interviewee 1 and 3 added that large projects have a small wastewater treatment plant on their site, where the wastewater generated from human consumption can be treated and recycled for different on-site activities.

Table 7.25 categorises these findings into codes and identifies their frequency.

Table 7.25: Thematic analysis for wastewater management (Source: Author)

Theme	Code	Interviewee
Wastewater management	Lost to environment	1
	Difficult due to nature of construction site	1,2,3,4,5
	Containment zones	2,4
	Proper planning	2
	Ease of management	1,2,3,4,5
	Recycling and reuse	1,2,3,4,5
Challenges	Difficult due to nature of construction site	1,2,3,4,5
	Cost of implementing	1,2,3,5
	Space requirement	2

7.3.1.8 Recommendations

Interviewee 1 adds that providing water from STP on a subsidised rate will help motivate companies to use this water source more and reduce their dependence on groundwater. Interviewee 2 highlights the importance of integrating water management decisions at the planning stages of a project. Interviewee 3 states that the construction of a small preliminary wastewater treatment plant must be made compulsory on all sites irrespective of their size so that all wastewater (excluding those produced from human consumption) can be treated and recycled for ancillary activities (like cleaning and dust suppression) that do not require very high quality water for their execution. Interviewee 4 states that they would like to create containment zones on their site to collect wastewater that can be recycled after preliminary sedimentation. Interviewee 5 adds that educating people and creating awareness around water scarcity is extremely essential for efficient water management not only on construction sites, but in all aspects of life. Interviewee 7 added that "only making noise can help save water". Interviewee 6 noted that green building rating systems must give more attention to construction water management as this would motivate construction professionals to use water judiciously.

Table 7.26 categorises these findings into codes and identifies their frequency.

Table 7.26: Thematic analysis for recommendations (Source: Author)

Theme	Code	Interviewee
Recommendation	Reduced cost	1
	Improved planning stage	2
	On-site WWTP	3
	Containment zones	4
	Creating awareness	5,7
	Green Building Rating Systems	6
Challenges	Cost	3,4
	Space	3,4

7.3.2 Construction Materials

Semi-structured interviews were conducted with material manufacturers of the construction materials identified in section 7.1.1. The demographics of each interviewee were discussed in section 6.3.1. The interviewees were asked questions along the themes as shown in Table 5.11. This section discusses these findings and each question is discussed in different sections.

7.3.2.1 Geographical Location and impact on water consumption

7.3.2.1.1 Cement

Cement interviewee 1 said that majority of their plants are located in the western part of the country. Further, both the interviewees state that the process of cement manufacturing is the same in all plants located throughout the country. The amount of water consumed during the process only differs based on whether the dry, semi-dry or wet process is followed. The amount of water consumed is very high if a wet process is used and very low if a dry process is used.

7.3.2.1.2 Glass

The interviewees said that majority of their plants are located in the southern part of the country. Glass interviewee 1 said that the float glass manufacturing process is the same throughout the country and even globally. Glass interviewee 2 added that same amount of water is used in the process irrespective of the location. This interviewee added that the location however impacts the amount of water lost to the atmosphere through evaporation in the cooling tower. In a region with hot climate, more water is lost through evaporation as compared to a location with cooler climate.

7.3.2.1.3 Construction and Industrial Sand

Sand interviewee 1 clarified that industrial sand refers to the sand that will be used as a raw material for manufacturing of different products (glass, tiles, bricks, etc.), while sand interviewee 2 states that construction sand refers to the sand that will be used for different construction activities (like backfilling) and concreting purposes (making concrete, mortar, and plaster).

Both interviewees said that the process of sand manufacturing is the same throughout the country. The amount of water consumed only differs on the final application of the sand. If industrial sand is being made, sand interviewee 1 said that the sand is washed two to three times more than construction sand (when making manufactured-sand from excavated rocks) or not washed at all (when using river sand). Interviewee 2 added that the type of soil of the mining location determines the amount of water needed for dust suppression. If the soil is fine, more water is needed to suppress it as compared to if the soil is coarse.

7.3.2.1.4 Tiles

Tile interviewee 1 said that majority of the plants of their company are located in the northern and western parts of the country. This interviewee added that the process of ceramic tiles manufacturing is the same throughout the country with only few differences in the process based on finishing of the final product. The interviewee further added that the amount of water consumed in the process differs based on whether the raw materials are handled in a wet or dry state, and their plant follows the wet process.

7.3.2.1.5 Bricks

Brick interviewee 1 said that their plants are located majorly in the northern and eastern part of the country. This interviewee further added that the brick manufacturing process is similar throughout the country with only difference being in the production capacity of the plant. Large and medium sized plants are more machine oriented while smaller plants are more labour dependant. The interviewee further added that the location of a plant impacts the amount of water that is required for dust suppression as coarse sand requires less water for suppression compared to fine sand.

Table 7.27 categorises these findings into codes and identifies their frequency.

Table 7.27: Thematic analysis for geographical location (Source: Author)

Theme	Code	Interviewee
Geographical location	No impact on manufacturing process	Cement 1 & 2, Glass 1, Sand 1 & 2, Tiles 1, Bricks 1
	No impact on water consumption	Cement 1 & 2, Glass 2
	Impact on amount of water lost	Glass 2
	Impact on water needed for ancillary activities	Sand 2, Bricks 1
Water consumption in the process	Raw material handling	Cement 1 & 2, Tiles 1
	Final application of the product	Sand 1 & 2
	Finishing of the product	Tiles 1

7.3.2.2 Water Consumption

7.3.2.2.1 Cement

Cement interviewee 1 said that the process of manufacturing cement is not water intensive, but the operational use of cement is water intensive. The interviewee said that "you cannot use cement without water because all material made using it (concrete, mortar and plaster) require water for its manufacturing". Both interviewees said that water is used for the activities that support the main cement manufacturing process (known as ancillary activities) such as cooling of the cement clinker and machinery. It is further used for activities like dust suppression, green belt development (maintaining the green spaces in the plant area) and human consumption (manufacturing plants have 24 hour staff on site thus this component includes water for cleaning, cooking and sanitation purposes). Cement interviewee 2 added that the amount of water used also depends on whether the dry, semi-wet or wet process of cement manufacturing is adopted.

7.3.2.2.2 Glass

Glass interviewee 1 said that the glass manufacturing process is "more energy intensive than water intensive". The interviewee further added that since the process generates a lot of heat, a lot of cooling is required. This cooling is achieved using water. The hot water is further cooled in a cooling tower that also consumes large volumes of water. Interviewee 2 said that "the cooling tower is the heart of the glass manufacturing process because all equipment's associated with the process need to be cooled". Both interviewees also added that besides the cooling (equipment's and in the cooling water), water is also used for other activities like green belt development and human consumption (manufacturing plants have 24 hour staff on site thus this component includes water for cleaning, cooking and sanitation purposes).

7.3.2.2.3 Construction and Industrial Sand

Both interviewees said that irrespective of the type of sand being produced, large volume of water is used for cleaning the mined raw sand to remove its impurities. The grade of cleaning depends on the type of sand being produced and its final application. Besides this water is used for dust suppression and human consumption (manufacturing plants don't have provisions for 24hour staff thus water is used only for cleaning and sanitation purposes). Interviewee 2 further added that water is also used for cleaning and cooling of the equipment's used for mining.

7.3.2.2.4 Tiles

Tiles interviewee 1 said that the tile manufacturing process (specially the wet milling process) is very water intensive as large volumes of water is required for forming the raw slurry. Besides this water is also used for ancillary activities like cooling the equipment's as large amount of heat is generated throughout the various firing and drying stages, dust suppressions during the handling and sizing of raw materials, greenbelt development, and human consumption (manufacturing plants have 24hour staff on site thus this component includes water for cleaning, cooking and sanitation purposes).

7.3.2.2.5 Bricks

Brick interviewee 1 said that the process of brick manufacturing consumes large volumes of water because water is a primary raw material used in the process. Besides this, the interviewee also added that water is used for ancillary activities like cooling of kiln, green belt development and human consumption (manufacturing plants have 24 hour staff on site thus this component includes water for cleaning, cooking and sanitation purposes). Besides these, large amount of water is required for dust suppression as the raw materials are handled in powdered form and on areas that do not have smooth surfaces. The interviewee also added that water is used for cleaning activities like cleaning the moulds and mixing equipment's. The interviewee also added that not only is the manufacturing process of bricks water intensive, but also its operational use as the bricks need to be moisten and fixed with mortar and finally cured.

Table 7.28 categorises these findings into codes and identifies their frequency.

Table 7.28: Thematic analysis for water consumption (Source: Author)

Theme	**Code**	**Interviewee**
Water consuming activity	Less water use during manufacturing	Cement 1
	Water intensive during operation	Cement 1, Bricks 1
	Energy intensive	Glass 1
	Cooling	Cement 1 & 2, Glass 1, Sand 2, Tiles 1, Bricks 1
	Dust suppression	Cement 1 & 2, Sand 1 & 2, Tiles 1, Bricks 1
	Green belt development	Cement 1 & 2, Glass 1 & 2, Tiles 1, Bricks 1
	Human consumption (cleaning, cooking, and sanitation)	Cement 1 & 2, Glass 1 & 2, Sand 1 & 2, Tiles 1, Bricks 1
	Mixing of raw materials	Cement 1 & 2, Tiles 1, Bricks 1
	Cleaning	Sand 1 & 2, Bricks 1

7.3.2.3 Sources of Water

7.3.2.3.1 Cement

Cement interviewee 1 and 2 said that surface water, groundwater, rainwater, and recycled water are the common water sources used. Surface water is the most common water source for manufacturing plants located near a water body. Interviewee 1 added that if a company wants to use groundwater, they need to get approval from the Central Groundwater Board by specifying the amount of water that would be withdrawn depending on the capacity of the plant. The interviewee further added that this water source is used because in some areas this is the only available source. The interviewee also added that large manufacturing plants that have been operating for many years have open mine pits as a result of limestone mining, and these open pits are used as RWH tanks.

7.3.2.3.2 Glass

Glass interviewee 1 and 2 said that rainwater is the most common source of water at their manufacturing plants. Interviewee 1 adds that for their factories located in regions that receive a lot of rainfall, rainwater is the most common source. Interviewee 2 adds that at their plant they have two RWH tanks which helps them supply water for meeting 81% of the plant’s water needs. The interviewees further added that surface water and treated wastewater from a local STP are other common sources of water for meeting their water needs.

7.3.2.3.3 Construction and Industrial Sand

Both interviewees said that rainwater and groundwater are the two sources of water used. Mining sites have large open pits as a result of years of mining where rainwater can be collected. Interviewee 1 further added that depending on the depth of extracting rocks, these rocks might be wet with either groundwater or rainwater, and this water is used for different activities on site.

7.3.2.3.4 Tiles

Tiles interviewee 1 said that groundwater, harvested rainwater and treated wastewater are the common sources of water used. Groundwater is used because in some plants that is the only available source. The interviewee further added that in regions where rainfall is abundant, rainwater is used for the various activities, but this source is not considered a primary source as it is unable to fulfil all the water requirements of the plant. The interviewee further stated that for majority of their plants that are located in water scarce regions, the lack of groundwater and rainwater, forces them to treat all the wastewater they are producing in the plant on-site and recycle it for different applications.

7.3.2.3.5 Bricks

Brick interviewee 1 said that for their large plant, the most common sources of water consumption are treated wastewater, groundwater and rainwater. The interviewee added that large plants have provisions for collecting wastewater from the process and treating it for recycling. Moreover, large plants whose mining zones have been operational for many years have open mine pits where rainwater can be harvested. However, for smaller plants that don’t have provisions for wastewater treatment or RWH, the only available sources are groundwater and wastewater from STP.

Table 7.29 categorises these findings into codes and identifies their frequency.

Table 7.29: Thematic analysis for sources of water (Source: Author)

Theme	Code	Interviewee
Source of water used	Surface water	Cement 1 & 2, Glass 1 & 2
	Groundwater	Cement 1 & 2, Sand 1 & 2, Tiles 1, Bricks 1
	Rainwater	Cement 1 & 2, Glass 1 & 2, Sand 1 & 2, Tiles 1, Bricks 1
	Treated wastewater	Cement 1 & 2, Glass 1 & 2, Sand 1 & 2, Tiles 1, Bricks 1
Reason of selection	Ease of availability	Cement 1 & 2, Glass 1, Tiles 1, Bricks 1
	Space availability	Cement 1, Glass 1, Sand 1 & 2, Bricks 1

7.3.2.4 Water Metering

7.3.2.4.1 Cement

Interviewee 1 said that water meters are installed at the source of water withdrawal to determine how much water is being withdrawn. The large number of consumption points makes it difficult to monitor the amount of water consumed at each consumption point. Moreover, the increased cost of installing numerous water meters also has an impact. For different activities like green belt development, amount of water consumed can be calculated based on the number of trucks being used for watering the area and its capacity. The interviewee thus adds that the amount of water consumed in calculated rather than measured. Interviewee 2 was not asked this question because he does not work in the manufacturing plant.

7.3.2.4.2 Glass

Interviewee 2 adds that water meters are installed at each source of consumption to determine and monitor how much water is being consumed. Interviewee 1 was not asked this question because he does not work in any manufacturing plant.

7.3.2.4.3 Construction and Industrial Sand

The interviewees said that water meters are installed at the source of withdrawal to determine the total amount of water withdrawn. To this interviewee 2 added that since the sand manufacturing process is very unorganised, measuring the amount of water consumed at each source is very difficult and expensive.

7.3.2.4.4 Tiles

The interviewee said that water meters are installed at the source of withdrawal to determine the total amount of water withdrawn. The cost of installing water meters limits the adoption of measuring in some plants.

7.3.2.4.5 Bricks

The interviewee added that on their plant, water meters are added on the source of withdrawal to determine the amount of water withdrawn.

Table 7.30 categorises these findings into codes and identifies their frequency.

Table 7.30: Thematic analysis for water metering (Source: Author)

Theme	Code	Interviewee
Water measurement	Water meters at source of water withdrawal	Cement 1, Sand 1 & 2, Tiles 1, Bricks 1
	Water meters at each source of consumption	Glass 2
	Calculations	Cement 1
Challenges	Large number of consumption points	Cement 1
	Difficult task	Sand 2
	Cost	Cement 1, Sand 2, Tiles 1

<u>7.3.2.5 Water Management Policies</u>

7.3.2.5.1 Cement

Both interviewees said that the government specifies the following regulations that all cement manufacturing plants must adhere to:

1) Ban on the consumption of groundwater for consumption.
2) RWH has been made compulsory for new plants.

3) All plants must be zero-liquid discharge which means that no wastewater can be discharged to local water bodies and must be recycled or reused.
4) To ensure zero discharge, all plants must have an on-site STP and effluent treatment plant (ETP).
5) All plants must incorporate a greenbelt area.

Cement interviewee 2 adds that the requirement of having a RWH system poses a major challenge in terms of the large space requirements associated with its installation and the lack of rainfall in some areas to make this a reliable water source. This interviewee further adds that sometimes groundwater is the only available water source in an area and the ban on the use of this water poses a major setback for the company operations.

With respect to company policies, interviewee 1 adds that their company does not have any specific regulations in terms of water management. Moreover, this interviewee adds that the regulations set up by the Global Cement and Concrete Association (GCCA) and Global Reporting Initiatives (GRI) have a huge impact on the water management practices followed in concrete manufacturing plants. These organisations demand that all cement companies must record their water consumption values and set benchmarks to reduce their water consumption. However, this interviewee adds that the requirement to monitor and measure the amount of water consumed at each source of consumption requires the installation of water meters at each source of consumption which is difficult because of the large number of consumption points and also the cost of installing these. Interviewee 2 adds that "the company policies play a crucial role when it comes to water management in plants because the government regulations are not well implemented due to the lack of stringent policies for their adoption".

7.3.2.5.2 Glass

When asked about government regulations, both interviewees listed the same government regulations that were mentioned by the cement interviewees.

With respect to company policies, both interviewees said that their company sets targets for reducing water consumption by setting benchmarks. Interviewee 1 further added that accomplishing these benchmarks requires regular updates to their technology and this is a costly process. However, this interviewee added that "the company is very focused on sustainability and water management, and hence does not mind spending extra money on incorporating water management practices". Interviewee 2 adds to this by saying that "reduce, reuse and recycle are the moto of this company".

7.3.2.5.3 Construction and Industrial Sand

Both interviewees said that the only regulation in effect for sand manufacturing is the ban on the mining of river sand. To this interviewee 2 adds that 80% of the construction in India uses manufactured-sand. Besides this, there are no government regulations in effect since this industry is very unorganised which is a major challenge. Interviewee 1 further added that large material manufacturers have their own sand beneficiation plant where the same company policies are followed. Interviewee 2 adds that there are no major industries involved in the manufacturing of construction sand, and there are small scattered individual companies throughout the country that manufacture these. As a result, there is a lack of company policies for their management.

7.3.2.5.4 Tiles

When asked about government regulations, the interviewee listed the same government regulations that were mentioned by the cement and glass interviewees.

Moreover, the interviewee said that their company is motivated to save water and has set benchmarks for water reduction, and these are implemented through the adaptation of new water efficient technologies. The interviewee adds that "water saving is a continuous journey with milestones in it" and setting benchmarks for water reduction can help conserve water.

With respect to the effectiveness of the government regulations, the interviewee adds that in some locations groundwater is the only reliable source and the ban on its consumption impacts the production capacity of the plant. As a result, this source is used in some plants.

7.3.2.5.5 Bricks

When asked about government regulations, the interviewee listed that large companies follow the same government regulations as were mentioned by the cement interviewees. However, majority of the industries are either small or medium scale and this poses as a major challenge as this unorganised nature makes the provisions of water regulations and management very difficult in these plants.

The interviewee further added that besides these there are no company policies focused on water management.

Table 7.31 categorises these findings into codes and identifies their frequency.

Table 7.31: Thematic analysis for water management policies (Source: Author)

Theme	**Code**	**Interviewee**
Government regulations	Ban on groundwater consumption	Cement 1 & 2, Glass 1 & 2, Tiles 1, Bricks 1
	Compulsory RWH	Cement 1 & 2, Glass 1 & 2, Tiles 1, Bricks 1
	Zero liquid discharge	Cement 1 & 2, Glass 1 & 2, Tiles 1 , Bricks 1
	In-situ STP and ETP	Cement 1 & 2, Glass 1 & 2, Tiles 1, Bricks 1
	Incorporation of greenbelt area	Cement 1 & 2, Glass 1 & 2, Tiles 1, Bricks 1
	Ban on mining river sand	Sand 1 & 2
External bodies	Record water consumption values	Cement 1
	Set benchmarks	Cement 1
Company attitude	No specific regulation	Cement 1, Bricks 1
	Highly motivated	Glass 1 & 2, Tiles 1
Company policies	Set benchmarks	Glass 1 & 2, Tiles 1
	Update technology	Glass 1 & 2, Tiles 1
Effectiveness	Company policies are more effective	Cement 2
	Government regulations not well implemented	Cement 2
	Unorganized nature makes it difficult to have regulations	Sand 1 & 2, Bricks 1

Challenges	Availability of the source	Cement 2, Tiles 1
	Cost constraints	Cement 1, Glass 1
	Space limitations	Cement 2
	Feasibility	Cement 1
	Unorganised nature	Sand 2, Bricks 1

7.3.2.6 Water Management Practices

7.3.2.6.1 Cement

Both interviewees said that the following measures are taken within the plant to reduce water consumption:

1) Replacing water cooling throughout the process with air cooling.
2) Shifting to a dry cement manufacturing process from a semi-wet or wet process.
3) Using a Reverse Osmosis system
4) Replacing hose pipes with automatic water sprinklers for green belt development.

Interviewee 1 adds that the cost of installing new technology is a major limiting factor that impacts the adoption of new water efficient technologies in plants.

7.3.2.6.2 Glass

Both interviewees said the following measures are taken within the plant to reduce the water consumption:

1) Installing an adiabatic cooling tower along with their conventional cooling tower. Interviewee 2 adds that the adiabatic cooling tower reduces the amount of water required for cooling by four times. The interviewee further adds that the conventional cooling tower consumes 200 kL/ft of water while the adiabatic cooling tower reduces the demand to 50 kL/ft.
2) Using de-mineralised (DM) water instead of normal water for cooling the incoming hot water in a cooling tower. The use of DM water reduces the

quantity of water consumed by four times as it improves the heat transfer efficiency and reduces the amount of blowdown water.

3) Installing flow meters at different consumption points to monitor the flow of water and reduce it if required.
4) Installing nozzles on taps.
5) Replacing conventional handwash systems with automatic systems.
6) Using sprinklers and moisture-based sensors for green belt development.
7) Using a tipper truck covered with poly sheeting to transport raw materials to site. This specialised truck has a lifting and tilting mechanism to ensure easy transfer of raw materials into the storage silos without the creation of dust. This reduces the amount of water required for dust suppression for material transfer and moistening the raw materials during transport.

Besides these, interviewee 1 adds that their company has a Pollution Control Board that periodically visits their plants and conducts water audits.

Interviewee 1 adds that the major challenge associated with the installation of new technologies is the cost associated with it, but they overcome it due to the strong company policies on SWM. Interviewee 2 further adds that their company motivates other rival companies to perform better on sustainability targets.

7.3.2.6.3 Construction and Industrial Sand

Interviewee 1 said that large material manufacturing companies that require sand as a raw material for their process have a small sand beneficiation plant wherein the same water management practices are followed as the material manufacturing plant. However, both interviewees 1 and 2 said that the following measures are taken on all mine sites irrespective of the final use of sand to reduce the amount of water consumed during sand manufacturing:

1) Covering the sand with poly sheeting during transportation to prevent is from becoming airborne. This eliminates the need to moisten the sand prior to transportation.
2) All faucets are fitted with nozzles to reduce the flow of water.

3) Replacing water cooling of equipment’s with air cooling.

7.3.2.6.4 Tiles

Tiles interviewee adds that their company realises the importance of water and educating people regarding its efficient management. The interviewee said that as a result their company regularly organises workshops and training programs where the staff are encouraged for practicing water conservation solutions. The interviewee also added that their plants are taking measures to replace the wet tile manufacturing with the dry manufacturing process. Besides this, the following measures are taken to reduce water consumption:

1) Installation of waterless urinals.
2) Replacing traditional handwash systems with automatic handwash systems.
3) Reducing the flow of water is taps.

Tiles interviewee add that cost is a major challenge that the company faces in order to apply the water management practices.

7.3.2.6.5 Bricks

Brick interviewee said that in their plant they take the following measures to reduce the amount of water consumed:

1) Using moisture-based sensors for green-belt development
2) Using water mists for dust suppression.

The interviewee however adds that the high cost associated with technology that uses less water is a major challenge they have to overcome.

Table 7.32 categorises these findings into codes and identifies their frequency.

Table 7.32: Thematic analysis for water management practices (Source: Author)

Theme	Code	Interviewee
Water management practices followed	Air cooling	Cement 1 & 2, Sand 1 & 2
	Dry process	Cement 1 & 2, Tiles 1
	Reverse-Osmosis system	Cement 1 & 2
	Automatic water sprinklers	Cement 1 & 2, Glass 1 & 2
	Moisture based sensors	Glass 1 & 2, Bricks 1
	Adiabatic cooling tower	Glass 1 & 2
	DM water	Glass 1 & 2
	Water meters at each source of consumption	Glass 1 & 2
	Nozzles on taps	Glass 1 & 2, Sand 1 & 2, Tiles 1
	Automatic handwash	Glass 1 & 2, Tiles 1
	Waterless urinals	Tiles 1
	Covering on raw materials	Glass 1 & 2, Sand 1 & 2
	Water management training	Tiles 1
	Water mists for dust suppression	Bricks 1
	Regular audits	Glass 1
Challenges	Cost	Cement 1, Glass 1, Tiles 1, Bricks 1

7.3.2.7 Wastewater Management

7.3.2.7.1 Cement

With respect to wastewater management, cement interviewee 1 said that all cement plants have a STP and ETP wherein all the produced wastewater is treated. Both interviewees added that this treated wastewater is recycled within the plant for the different activities like dust suppression and green belt development. Cement interviewee 2 said that "recycling wastewater reduces the amount of freshwater withdrawal". Cement interviewee 2 added that the wastewater produced from cement manufacturing does not contain any harmful chemicals, tertiary treatment is not required. Cement interviewee 1 adds that the wastewater contains mainly dust particles and is "easy to manage and treat".

7.3.2.7.2 Glass

With respect to wastewater management, both interviewees said that they have a STP and ETP, where all the wastewater is treated to be recycled within the plant specially for the cooling tower. Moreover, glass interviewee 1 adds that wastewater which contains low total dissolved solids (TDS) such as from activities like cooling tower can be reused without prior treatment. The production of DM water also results in the creation of wastewater which is reused for greenbelt development.

7.3.2.7.3 Construction and Industrial Sand

Interviewee 2 said that the sand manufacturing process generates wastewater containing a lot of dust and this water can be treated through simple sedimentation and recycled for activities like dust suppression, cleaning and cooling the equipment's. Interviewee 1 adds that this wastewater can also be reused for flushing.

7.3.2.7.4 Tiles

Tiles interviewee 1 said that all the wastewater produced is treated and recycled within the plant for various activities. The wastewater that contains low TDS undergoes primary sedimentation and the treated water is used for activities like flushing and green belt development.

7.3.2.7.5 Bricks

Bricks interviewee 1 said that large volumes of water is lost to the atmosphere through evaporation during the drying and firing of the bricks. The interviewee also added that the wastewater from brick manufacturing does not contain any harmful chemicals and can be treated easily and stored for recycling.

Table 7.33 categorises these findings into codes and identifies their frequency.

Table 7.33: Thematic analysis for wastewater management (Source: Author)

Theme	Code	Interviewee
Wastewater management practices followed	On-site STP	Cement 1, Glass 1 & 2, Tiles 1
	On-site ETP	Cement 1, Glass 1 & 2, Tiles 1
	Wastewater contains only dust	Cement 1 & 2, Glass 1, Sand 2, Tiles 1, Bricks 1
	Simple sedimentation	Cement 1 & 2, Glass 1, Sand 2, Tiles 1, Bricks 1
	Recycling treated wastewater	Cement 1 & 2, Glass 1 & 2, Tiles 1, Bricks 1
	Recycled for ancillary activities	Cement 1 & 2, Glass 1 & 2, Sand 1 & 2, Tiles 1
	Large volumes lost to environment	Bricks 1

7.3.2.8 Recommendations

Under this theme the interviewees were asked for recommendations about how to increase water sustainability at their plant and what could be done further.

7.3.2.8.1 Cement

Interviewee 1 suggested that since RWH is being mandated by the government and the space constraints in a plant challenge it's application, the construction of an underground RWH system will help reduce the space constraints associated with installing this system. This interviewee further adds that by efficiently planning the cement manufacturing process and calculating the amount of water required for each activity, the current amount of water consumption can be reduced. Interviewee 2 adds that the provisions of tax rebates, lower abstraction charges for treated wastewater from STP, and the use of incentives for implementation of sustainable practices can help encourage companies to follow SWM practices. This interviewee further adds that the integration of an advanced filtration system for treating the process and cooling water can help increase the recycling rate of this wastewater.

7.3.2.8.2 Glass

Interviewee 2 suggests the integration of a fourth R (recovery) in their current 3R (reduce, reuse and recycle) policy by installing a secondary treatment for effluents to increase the amount of wastewater that can be treated and recycled within the plant. Interviewee 1 suggests that lowering of abstraction rates for using treated wastewater will allow companies to afford to buy this water since its cost is higher than extraction of surface water and groundwater. Interviewee 1 further adds that the flow meters installed at different consumption points in their plant can be connected to a cloud service to increase its monitoring. This interviewee adds that their current flow meters are manually monitored, and they plan to shift to cloud service soon.

7.3.2.8.3 Construction and Industrial Sand

Interviewee 1 adds that though sand manufacturing does not consume large volumes of water, the small amount of water consumed can also be effectively managed through the integration of policies. To this the interviewee adds that sometimes sand beneficiation plants of a material manufacturing company do not follow water management practices due to the lack of policies directly aimed at this industry, these must be avoided as much as possible by ensuring that stringent regulations are in place to ensure the adoption of company policies. This interviewee further adds that even if there is one big company that starts manufacturing construction sand, the water management for construction sand manufacturing could be significantly improved. The interviewee adds that since there are small scattered individual companies that supply sand, currently having policies is very challenging.

7.3.2.8.4 Tiles

Tiles interviewee 1 suggests the provision of economical alternative sources by the government. The interviewee adds that ensuring 100% recycling of wastewater will help reduce the amount of freshwater required. The interviewee further adds that efficient planning of the manufacturing process can help quantify the exact amount of water required for the process eliminating the use of excess water and wastage. The interviewee adds that if companies decide to focus on sustainability, and policies are implemented for water management, the lack of enforcement of government regulations will not have an impact. "But motivating people for the same is a challenge" the interviewee further added.

7.3.2.8.5 Bricks

Bricks interviewee 1 said that the major challenge the brick sector faces is that it is composed of many medium and small-scale companies and is highly unorganised. The interviewee adds that replacing water for dust suppression with filtering systems can help reduce water consumption. Another solution is the use of AAC bricks as they require less water during their operational stage. Another solution is using hollow bricks which drastically reduce the amount of raw materials required.

Table 7.34 categorises these findings into codes and identifies their frequency.

Table 7.34: Thematic analysis for recommendations (Source: Author)

Theme	Code	Interviewee
Recommendation	Underground rainwater harvesting system	Cement 1
	Efficiently plan the manufacturing process	Cement 1, Tiles 1
	Tax rebates	Cement 2
	Lower cost of withdrawing treated wastewater from STP	Cement 2, Glass 1
	Incentives	Cement 2, Tiles 1
	Increase recycling rate	Cement 2, Glass 2
	Stringent policies	Sand 1
	Organising the sector	Sand 1
	Filtering system for dust suppression	Bricks 1
	AAC bricks	Bricks 1
Challenge	Space constraint	Cement 1
	High cost	Cement 2
	Unorganised nature	Sand 1, Bricks 1

7.3.3 Discussion of Semi-Structured Interview Findings

This section discusses the findings of the interviewees with both the groups (construction professionals Section 7.3.1 and material manufacturers Section 7.3.2) and each question is discussed in a separate sub-heading.

7.3.3.1 Geographical Location and Impact on Water Consumption

Semi-structured interviews with both the groups revealed that the water availability, climatic conditions and soil type of a location impact the water consumption. People in areas with water scarcity value water more as compared to people in other regions. Moreover, the climatic conditions impact the amount of water required for activities like curing while also impacting the amount of water lost to the environment through evaporation. The soil type of a location also impacts the water required for ancillary activities like dust suppression. On construction site, the methodology of construction adoption (on-site vs off-site) and type of materials used (clay bricks, AAC bricks) also impacts the water consumption. And lastly, the water consumed during material manufacturing depends on the handling of the raw materials, the final application of the product and finishing of the product.

7.3.3.2 Water Consumption

For construction sites, majority of the water is consumed for concreting activities (making and curing the concrete). For material manufacturing plants, majority of the water is used for cooling purposes (of the machinery, and intermediate and final products). This is because the manufacturing of all materials requires energy for heating which increases the temperature of the machinery being used and the material being produced. These are eventually cooled using water. Besides this, the continuous operation of machinery also generates heat which needs to be cooled using water. In addition to these, on material manufacturing plants, water may also be used as a raw material such as during cement, tiles and bricks manufacturing. On both construction sites and manufacturing plants, water is also consumed by the site staff for ancillary activities like dust suppression and cleaning.

7.3.3.3 Source of Water

For construction sites, extracted groundwater and treated wastewater from a STP are the most common sources of water. Harvested rainwater and on-site treated wastewater are only used on large construction sites owing to the space and cost constraints of obtaining these water sources. On the contrary, in material manufacturing plants, harvested rainwater and on-site treated wastewater are the most common sources of water. Majority of the plants collect their wastewater, treat it on-site and recycle it for different activities on their plants. Moreover, majority of the plants also have space provisions for harvesting rainwater. In some areas groundwater is the only available and reliable source and is used even despite the ban on its consumption by the government. The availability and reliability of water from a source also impacts the selection of that source. For instance, rainwater might be available in a region, but if it is not reliable to produce enough harvested rainwater, it cannot be considered as an ideal source for that plant. Moreover, the availability of provisions for using that source (such as harvesting area for using rainwater, and on-site wastewater treatment plant for recycling water in-situ), also impact its selection.

7.3.3.4 Water Metering

Continuous monitoring of water consumed at each source of consumption is an ideal way to record and monitor water consumption by enabling opportunities to identify areas where water consumption can be reduced. However, due to the large number of consumption points on both construction sites and manufacturing plants, this process is difficult and expensive often owing to its limited adoption. Moreover, it was also observed that water monitoring is more widely adopted on material manufacturing plants due to the stringent regulations surrounding water management. However, there adoption is limited (45.7% from questionnaire analysis in Section 7.2.6) on construction sites due to the lack of requirements for the same and the unorganised nature of these sites.

7.3.3.5 Water Management Policies

The semi-structured interviews with construction professionals revealed that there is very little attention placed on water management on construction sites and hence there is a lack of regulations by the government regarding its management. On the contrary, there are stringent government regulations for water management in material manufacturing industries. The ban on the consumption on groundwater, using treated wastewater from an STP and the ban on the mining of river sand are three regulations enforced on both construction sites and material manufacturing plants. Besides these various other regulation like having an on-site STP and ETP, and incorporation of a green belt area are also mandated on all material manufacturing plants. The mandatory requirements of green-belt area is also responsible for large water consumption for these activities.

The availability and reliability of a water source impacts its selection, and since in some areas groundwater is the only available and reliable source, it is used despite a ban on its consumption. The semi-structured interviews also revealed the lack of implementation of the government regulations identified in Section 2.2. Point 5 of the Draft National Water Framework Bill 2016 states that "providing incentives and reducing taxes can help promote efficient water management practices in industries". However, all the interviews stated the lack of incentives provided by the government and recommended that the provision of these would help minimise water consumption and ensure water management. Point 6 of the Draft National Water Framework Bill 2016 states that "water consuming industries must not be located in water-stressed and drought prone areas. For industries located in water-stressed areas, they are allowed to withdraw a portion of their makeup water, but they must return their treated effluent to the hydrologic system". Tiles interviewee 1 revealed that this does not happen in practice, and industries are located in areas most profitable to the company. Moreover, cement interviewee 1 also revealed that this only exists on paper and is not practised. This lack of implementation of the government regulations and its monitoring is a major factor limiting water management in the Indian construction and material manufacturing sector and requires attention. This lack of adoption of government regulations due to challenges for its implementation suggest the need for a framework that considers the challenges and takes measures for its management.

The semi-structured interviews with both the groups revealed that the attitude of a company plays a stronger role in implementing water management practices as opposed to government regulations. Though very few construction sites focus on water management, it is a widely focused area in material manufacturing industries.

7.3.3.6 Water Management Practices

Construction sites can adopt simple measures like creating a cleaning platform to recycle water and covering freshly poured concrete with moist gunny bags to reduce water consumption by almost 10%. Though these are simple measures for water management, they are not commonly adopted due to the lack of awareness among people regarding these practices. This lack of awareness is attributed to the low economic value placed on water and lack of initiatives taken by people to manage it. Besides these, construction sites in India use RMC to reduce the amount of water consumed on site to mix concrete. Larger sites also adopt practices like using pre-cast elements (that have been mixed and cured off-site) to reduce the water consumed on the construction site (DEW). These practices of using RMC and pre-cast elements only reduces the DEW but has no impact on the EW. The EW of a building will be reduced if less materials are used for the construction of the building (such as using hollow pre-cast elements) or using materials that have a low EWC.

On the other hand, since the material manufacturing process is machine oriented, the plants need to take expensive measures such as upgrading to water efficient technology like adiabatic cooling tower to reduce the water consumed on their plant. Moreover, technologies like moisture-based sensors and waterless urinals can help reduce water consumed for activities like green-belt development and human consumption.

7.3.3.7 Wastewater Management

Wastewater management on construction sites is challenging due to the large number of consumption points and the lack of opportunities for collecting the wastewater. On the other hand, due to streamlined processes in material manufacturing plants, wastewater management is considerably easier. Moreover, since the government mandates manufacturing plants to incorporate on-site STP and ETP, these plants can collect and recycle their wastewater.

7.3.3.8 Recommendations

Interviewees from both the groups highlighted that the most common challenges construction sites and material manufacturing plants face to manage water is due to the high cost of water efficient technologies and solutions. The provision of incentives and tax rebates can motivate companies to improve their processes. Besides these both the groups also noted that water management can also be improved if the containment and recycling/ reuse of wastewater can be improved. Both interviewee groups also highlighted the importance of proper planning for water management. Lastly, the creation of awareness among people regarding water management is the most important step to manage water.

7.4 Stage 7 Point of Integration

The results of the quantitative and qualitative analysis are combined in this stage of the study to develop the proposed framework of efficient water management practices that can be adopted on construction sites and material manufacturing plants to efficiently manage water as shown in Figure 7.7.

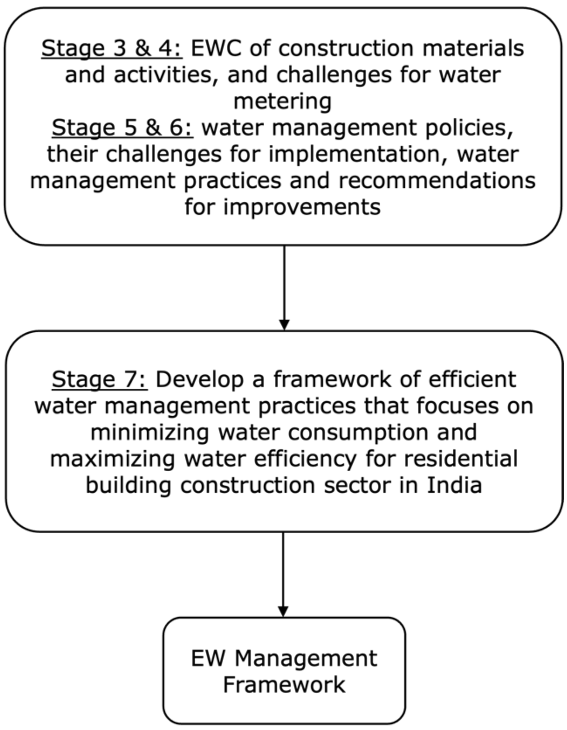

Figure 7.7: Stage 7 of the sequential explanatory multiphase mixed method (Source: Author)

The proposed framework builds up on the conceptual framework developed at the end of the literature review in Chapter 4. As discussed in Section 4.4, the conceptual framework has the following three stages:

1) Stage 1 (Review): Review existing Indian government regulations and frameworks for water management such as three pillars of sustainability (environmental, economic and social) for SWM, 6R (review, replace, reduce, reuse, recycle, remove) water hierarchy, Draft National Water Framework Bill 2016 and National Water Mission 2008.
2) Stage 2 (Benchmark): Review existing documents of water consumption requirements for construction material manufacturing (like EPD's and past studies).
3) Stage 3 (Implement): Identify steps for implementation of water management practices.

As discussed in Section 2.8, steel and concrete blocks (hollow and solid) are the only three materials with an updated and valid EWC record that can act as benchmarks of efficient water consumption for their management. Besides these other commonly used materials like cement, aggregates (sand and stone), clay bricks, ceramic tiles, and clear float glass don't have EWC data to act as benchmarks during their manufacturing. In addition to these, different construction activities also do not have benchmarks in terms of EWC of these activities. Thus, in stage 3 and 4 of this study, these data were collected and analysed. The EWC of materials and activities calculated in these stages serves as benchmarks for efficient water management and form an integral part of the proposed framework.

The quantitative analysis of the questionnaires and the qualitative analysis of the semi-structured interviews reveal the lack of policies and regulations which focus on efficient water management in the construction sector (which includes construction sites and material manufacturing industries) in India. In addition to these, it also revealed that the implementation of existing policies and regulations is associated with challenges that limit their adoption along with lack of their monitoring.

This signifies the need for a framework that analysis the existing regulations by identifying the challenges for their adoption, and determination of strategies to overcome these. It also discusses the need for the creation of water consuming benchmarks, and educating the people involved in the construction and manufacturing industries regarding measures that can be adopted for water management, along with its efficient monitoring. These steps are added to the conceptual framework to develop the proposed framework that can be applied at the planning stages of the construction and material manufacturing process, and the actual construction and material manufacturing stages to ensure efficient water management in India.

The proposed framework is shown in Figure 7.8. It is divided into five broad stages and each stage is discussed in a separate sub-section.

Stage	1 - Review Government Regulations	2 - Formulate Company Policy	3 - Create Awareness	4 - Implementation	5 - Monitoring & Review
Steps to Execute	Identify Existing Regulations Identify Requirements for Adoption Identify Challenges for Implementation	Formulate Policies & Practices Identify Solutions for Mitigation	Create Awareness	Set Benchmarks	Monitor
Stakeholders Involved	Decision makers at the company level	1) Decision makers at the company level 2) Policy makers at the government level	1) All staff of the company 2) Policy makers at the government level	Staff involved in the construction process and material manufacturing process	Decision makers at the company level
Lifecycle Stages	Planning stage (Prior to commencement of material manufacturing and construction)			Material manufacturing and construction stage	
Stage Importance	The challenges the company faces to implement government regulations often leads to the company not following the regulation and limits the chances of EW management.	The policies and practices set up by the company play a strong role in influencing the EW management practices adopted	The lack of awareness among people at all levels regarding EW management limits the measures taken for its management	The lack of current benchmarks for optimum water consumption during material manufacturing and construction results in water wastage and excess water consumption	Continuous monitoring is essential to ensure whether the policies and practices are being successful for EW management and if not it is essential to identify the reasons for it
Stage Outcome	Identification of the challenges the company will face to adopt the existing government regulations for EW management	Formulation of company policies and identification of practices the company can adopt during material manufacturing and building construction for EW management	Creation of awareness among all the staff members regarding the need for EW management and the practices for its implementation	The creation of benchmarks in terms of EWC of construction materials and construction activities for optimum water consumption	Continuous monitoring of water consumption during the material manufacturing and construction process to ensure the EW management company policies and practices are successful

Figure 7.8: Proposed framework for embodied water management in India (Source: Author)

7.4.1 Review Government Regulations

This is the first stage of the framework and is divided into three steps as shown in Figure 7.9

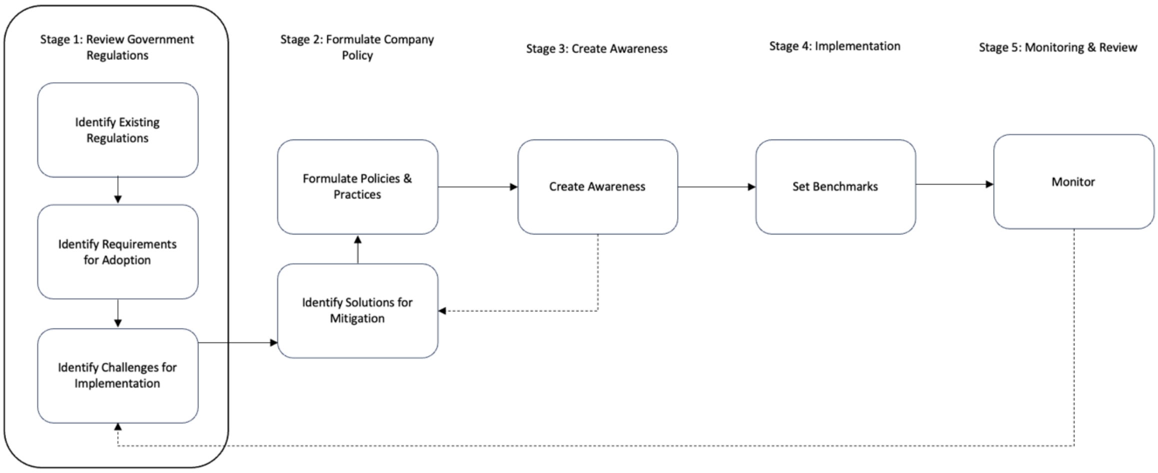

Figure 7.9: Stage 1 of the proposed framework (Source: Author)

This first step is similar to the first step of the conceptual framework and aims at identifying existing government regulations, and external body regulations (like the GCCA for cement). This is an important starting point as it defines the basis for what regulations need to be implemented. The questionnaires and semi-structured interviewee analysis along with literature review revealed that there is a lack of these regulations, and where they exist there are various challenges that the company encounters to implement those.

Once these regulations have been identified, the next step is to identify the requirements for the successful adoption of these regulations. This helps identify the challenges the company would face to adopt these regulations in the third step of the framework. Identification of these challenges is essential because strategies can then be made to overcome these (step 4).

The current practice of companies as determined through the semi-structured interview analysis is that when a challenge is encountered for implementing a regulation, the company disregards that regulation without developing strategies on how that challenge can be overcome while still following the regulation. One example is that the government has banned the use of groundwater for different activities and mandates the use of treated wastewater instead. Since the cost of obtaining this treated wastewater is higher than extracting groundwater, companies do not adopt the policy of using treated wastewater and instead rely of groundwater for some applications. This leads to a breach of both the regulations. However, if the government provides solutions to overcome these challenges, like the provision of treated wastewater at a lowered cost, this will enable companies to adopt these regulations.

Figure 7.10 summarises the findings of research objective 1, 4, 5 and 6, and their integration into stage 1 of the proposed framework.

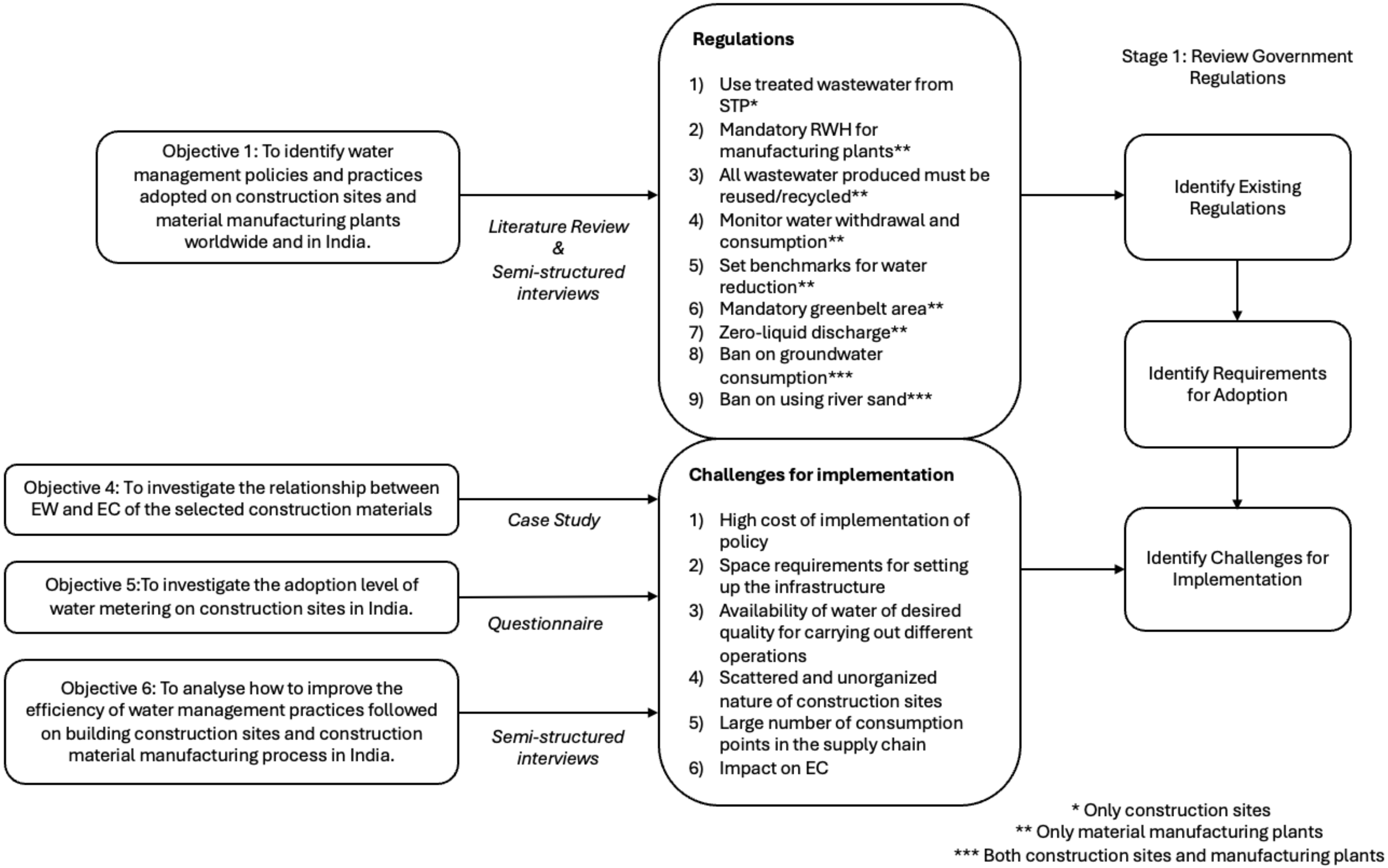

Figure 7.10: Findings of research objective 1, 4, 5 and 6, and their integration into stage 1 of the proposed framework (Source: Author)

Table 7.35 discusses the existing government regulations summarised in Figure 7.10, the requirements for their adoption and challenges their implementation.

From Table 7.35 it can also be noted that some regulations intended for construction material manufacturing industries could also be applied to construction sites to ensure more regulations in this sector. However, the adoption of these regulations on construction sites would also suffer from the same challenges as manufacturing plants. For instance, construction material manufacturing plants are mandated to monitor the amount of water they are consuming, but no regulation mandates the same monitoring on construction sites. This study reveals how both the DEW and IEW are equally important in the EW of a building (Section 7.2.4). Thus, regulations mandating the monitoring of water on construction sites will help reduce the amount of water wastage in these activities. Moreover, it can also be seen from Table 7.35 and as discussed in the semi-structured interview findings in section 7.3, the major challenges the company faces for the adoption of regulations are the cost, time, and space limitations.

Table 7.35: Application of Stage 1 (Review Government Regulations) (Source: Author)

No.	Step 1: Review government regulations	Step 2: Identify requirements for their adoption	Stage 3: Identify challenges for their implementation
1	Ban on the use of groundwater due to groundwater depletion on construction sites and manufacturing plants (this however is not regulated in all parts of India)	1) Presence of a reliable and cheap alternate source of water. 2) The alternate source must generate water of desired quality.	1) Higher cost of obtaining alternate water source. 2) The alternate source identified might not be reliable or produce water of desired quality.
2	Use of treated wastewater from STP on construction sites to reduce dependence on groundwater.	1) Presence of a local STP preferably close to the construction site.	1) Higher cost of obtaining water from STP. 2) The STP might not be close to the construction site, which adds extra cost and carbon emissions to source this water from that STP. It also increases the time of the project in case a suitable STP cannot be identified.
3	Ban on the use of river sand for construction projects and as a raw material to preserve the naturally occurring material and disruption of waterbody.	1) Identification of a company to procure manufactured sand.	1) Higher cost of obtaining manufactured sand as compared to procuring river sand.
4	Mandatory RWH for new material manufacturing plants to reduce the dependence on groundwater.	1) Space requirements for installing the RWH tanks.	1) Lack of space for placing the RWH tanks. 2) The rainwater harvested might not be of the desired water quality standards, thus requiring the need for preliminary treatment to produce water of desired quality standards. 3) Higher cost for setting up the RWH tank and subsequent treatment facility. 4) Time taken to create the RWH tanks.
5	Mandatory greenbelt area on manufacturing plants to improve air quality.	1) Space requirements on the plant for incorporating greenbelt area. 2) Selection of plants native to that location.	1) Cost of maintaining the greenbelt area. 2) Extra time and labour required for maintain the greenbelt area.

6	All manufacturing plants must be zero liquid discharge to prevent contamination of water bodies.	1) On-site wastewater treatment plant.	1) High cost of installing the wastewater treatment plant. 2) Space constraints for the location of the on-site wastewater treatment plant.
7	All wastewater generated in manufacturing plants must be recycled or reused within the plant to reduce dependence on fresh potable water.	1) On-site wastewater treatment plant. 2) Provisions for recycling and reusing the treated wastewater.	1) High cost of installing the wastewater treatment plant. 2) Space constraints for the location of the on-site wastewater treatment plant. 3) High cost for the provisions of recycling and reuse.
8	Manufacturing plants must monitor the amount of water being withdrawn and consumed to control their water consumption and minimise water wastage.	1) Installation of water meters.	1) Cost of installing these water meters. 2) Large number of consumption points makes it difficult to install water meters at all points. 3) Large number of consumption points increases the labour and time required for their identification.
9	Material manufacturing plants must set benchmarks for water reduction.	1) Knowledge of water consumed for each activity. 2) Knowledge of best practices implemented to reduce water required for that activity.	1) High cost of updating the current technology to technology that consumes less water. 2) Difficulties in monitoring water consumed at each consumption point.

7.4.2 Formulate Company Policy

This is the second stage of the framework and is divided into two steps as shown in Figure 7.11.

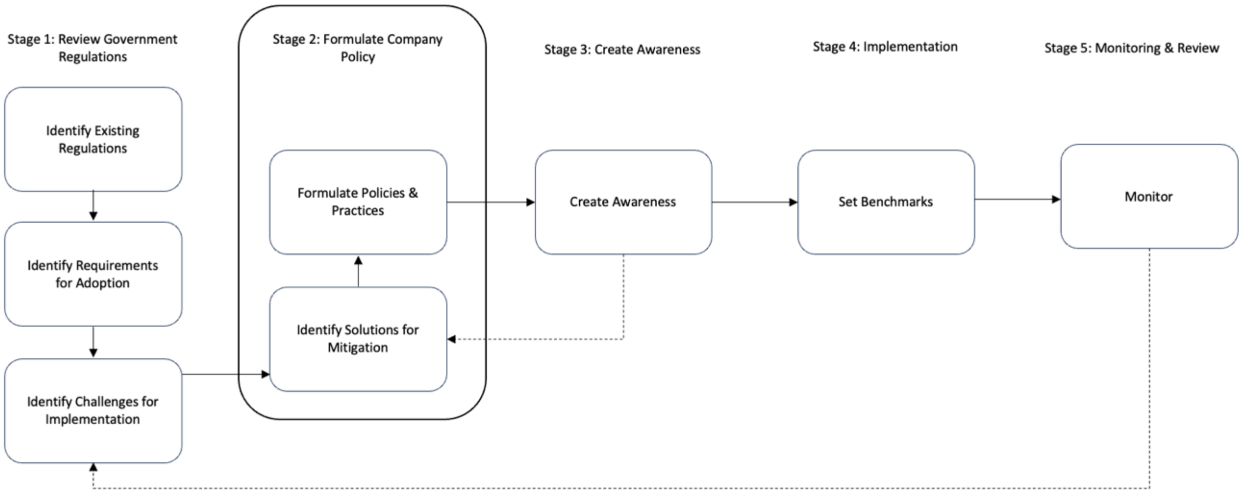

Figure 7.11: Stage 2 of the proposed framework (Source: Author)

Construction interviewee 2 and glass interviewee 1 and 2, as discussed in Section 7.3 states the huge role company policy has on the water management practices that are adopted. It can also be seen that the water management practices that are followed largely depend on the company policy as opposed to the government regulation. The qualitative data analysis in stage 6 indicates the lack of success in government regulation due to the lack of their penalty for non-compliance. A major factor impacting their implementation are challenges faced by companies to adapt these (as discussed in step 3 of this proposed framework) and the lack of solutions provided by the company and government in response to these. Thus, stage 2 of the framework aims at minimising this gap between government regulations and the policies implemented by the company.

Once the challenges for the adoption of a regulation have been identified in step 3, it is then essential to develop solutions for their mitigation which forms step 4 of the proposed framework. As noted above, solutions are required from both the government and companies. While some challenges can be overcome by strategies adopted by companies, other challenges can only be overcome by intervention by the government. For instance, tiles interviewee 1 stated that they cannot comply with the government regulation of not using groundwater in their factory as it is the only available water source and not using it would impact their production capacity. At such an instance, it is essential for the government to provide strategies to reduce the negative impact the adoption of their regulation would have on the company. Thus, at this stage, solutions need to be provided at both the company and government level.

At the company level, discussions and brainstorming sessions are conducted among the team members to identify probable solutions the company can take to minimise/overcome these challenges are identified. This technique also aims at identifying how changes can be made to the process or how different challenges and solutions might be linked to each other.

At the government level, the aims of identifying solutions to these challenges is to ensure ease of adoption of these regulations by the company by minimizing the challenges they would face in its adoption. As noted by the semi-structured interviews (Section 7.3), the provision of these solutions by the government will help increase the adoption rate of regulations. Thus, the identification of solutions by the government is extremely essential to improve the existing regulations while ensuring a higher adoption rate by the companies.

Following the identification of solutions for mitigating these challenges, appropriate company policies and practices can be created that forms step 5 of the framework. Figure 7.12 summarises the findings of research objective 6 and its integration into stage 2 of the proposed framework.

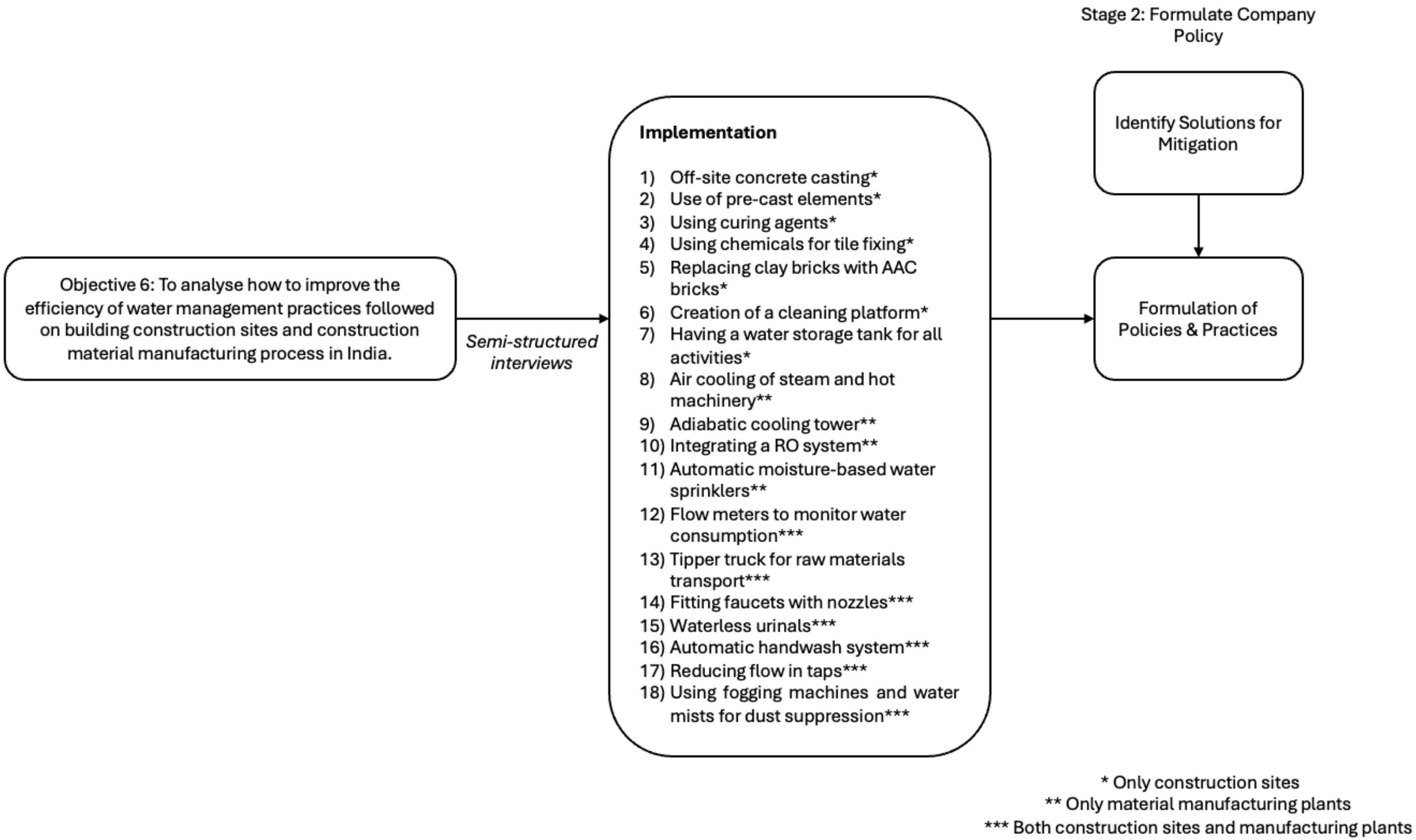

Figure 7.12: Findings of research objective 6 and its integration into stage 2 of the proposed framework (Source: Author)

Table 7.36 discusses the solutions to the challenges the company faces, and the subsequent company policies and practices that can be developed for EW management.

It can be seen from Table 7.36 that cost constraints can be managed through effective intervention by the government mainly through the provision of incentives like tax rebates and lower cost of adopting the regulation. Time constraints however have to be managed by the company and can be managed through efficient time management. It should also be noted that adhering to one regulation can facilitate the adoption of another government regulation. For instance, if the government lowers the cost of withdrawing wastewater from the STP, the company can use that saved money for setting up their own on-site wastewater treatment plant or RWH system. Moreover, upon successful compliance to these regulations, the company will also receive tax rebates. This helps to limit the financial constraints the company can face due to the adoption of government regulation

Table 7.36: Application of Stage 2 (Formulate Company Policy) (Source: Author)

<table>
<tr><th>No.</th><th>Step 3: Challenges for the implementation of government regulations from Stage 1</th><th>Step 4: Solutions that would aid in reducing these challenges</th><th>Step 5: Company policies and practices for EW management taking into account the challenges and solutions</th></tr>
<tr><td>1</td><td>Higher cost of obtaining alternate water source</td><td><u>Government</u>
1) Lower the cost of abstracting water from an alternate source.
2) Providing incentives to the company like tax rebates when they use an alternate source.</td><td rowspan="4">1) Identification of an alternate source to groundwater for construction activities and material manufacturing.
2) All water entering the site must be tested for its quality and potable water must only be used for activities that require the highest water quality standards.
3) Ancillary activities need to be accomplished using water of lower quality standard (high TDS but no harmful chemicals).</td></tr>
<tr><td>2</td><td>Reliability of alternate source</td><td><u>Company</u>
1) Identify an alternate source through which water can be collected throughout the year.
2) Identify more that 1 alternate source.</td></tr>
<tr><td>3</td><td>Availability of water of desired quality from alternate source</td><td><u>Company</u>
1) Check the incoming water for its quality.
<u>Government</u>
1) Providing incentives to the company like tax rebates when they use an alternate source.</td></tr>
<tr><td>4</td><td>Increased time frame due to challenges in identifying suitable alternate water source</td><td><u>Company</u>
1) Efficient time planning.
2) Identifying alternative sources during the project planning stages.</td></tr>
<tr><td>5</td><td>Increased time frame for the creation of RWH facilities</td><td><u>Company</u>
1) Efficient time planning.
2) Identifying requirements for setting up RWH system during the project planning stages.</td><td>1) Mandatory inclusion of a RWH on all manufacturing plants.
2) RWH tanks must be created at the time of construction for new plants.
3) RWH system could be built on ground or underground.</td></tr>
</table>

<table>
<tr><td>6</td><td>Space constraints for installing RWH tanks</td><td><u>Company</u>
1) Installing underground RWH tanks.</td><td rowspan="2">4) The harvested rainwater must be used for ancillary purposes without any prior treatment.
5) The harvested rainwater that needs to be used for activities that require high water quality standards, secondary treatment will be required.
6) Underground RWH tanks must be made compulsory on all construction sites as well since these tanks can be used even during the building operational stage.</td></tr>
<tr><td>7</td><td>Increased cost of setting up the RWH system</td><td><u>Government</u>
1) Providing the facilities required to set up RWH at a lower cost.
2) Providing incentives to the company like tax rebates when they incorporate RWH in their system.</td></tr>
<tr><td>8</td><td>Increased cost for maintaining greenbelt area</td><td><u>Government</u>
1) Providing incentives to the company like tax rebates when they maintain greenbelt area on their plant.</td><td>1) Use of water efficient technologies like water sprinklers for watering greenbelt area.
2) Water of lower quality (high TDS but no harmful chemicals) should be used for watering the greenbelt area.</td></tr>
<tr><td>9</td><td>Increased time frame for the creation of on-site wastewater treatment plant</td><td><u>Company</u>
1) Efficient time planning.
2) Identifying requirements for setting up on-site wastewater treatment plant during the project planning stages.</td><td rowspan="3">1) Mandatory inclusion of a wastewater treatment plant on all manufacturing plants.
2) Wastewater treatment plant must be created at the time of construction for new plants.
3) Wastewater treatment system could be built on ground or underground.
4) Wastewater treatment plant must treat all the wastewater produced on site from different plant activities and human consumption.
5) The wastewater treatment plant must have different level of treatments, so that water that contains only high TDS can undergo simple sedimentation to produce treated wastewater that can be used for ancillary activities.</td></tr>
<tr><td>10</td><td>Space constraints for installing on-site wastewater treatment plant</td><td><u>Company</u>
1) Installing underground wastewater treatment tanks.</td></tr>
<tr><td>11</td><td>Increased cost of setting up on-site wastewater treatment plant</td><td><u>Government</u>
1) Providing the facilities required to set up on-site wastewater treatment plant at a lower cost.
2) Providing incentives to the company like tax rebates when they incorporate wastewater recycling in their system.</td></tr>
</table>

			6) Treated wastewater that needs to be used for activities that require high quality water, secondary and tertiary treatment must be conducted depending on the degree of contaminants in the incoming wastewater. 7) A cleaning platform must be created on construction sites where all cleaning activities take place and the wastewater generated needs to be treated using simple sedimentation before being recycled for different ancillary purposes.
12	Increased cost of installing water meters at each source of consumption	<u>Government</u> 1) Providing water meters at a lower cost. 2) Providing access to monitoring system of these water meters at a lower cost. 3) Providing incentives to the company like tax rebates if they monitor their water consumption.	1) Water meters must be installed at point of withdrawal and all sources of consumption. This should be required for all manufacturing plants and construction sites. 2) The amount of water consumed as obtained from the water meters, and water required as obtained from calculations must be compared to identify areas of extra water consumption and possibilities of reduction.
13	Large number of consumption points making the process of water monitoring difficult	<u>Company</u> 1) Calculate the amount of water required for each activity by reviewing standards and regulations to determine the amount of water required for each activity thereby ensuring efficient water consumption and minimum water wastage.	
14	Higher cost of new water efficient technology	<u>Government</u> 1) Lowering the cost of new water efficient technology. 2) Providing incentives to the company like tax rebates if they upgrade to new water efficient technology.	1) Benchmarks must be set up for water consumption reduction goals.

7.4.3 Create Awareness

This is the third stage of the framework and consists of only one step as shown in Figure 7.13.

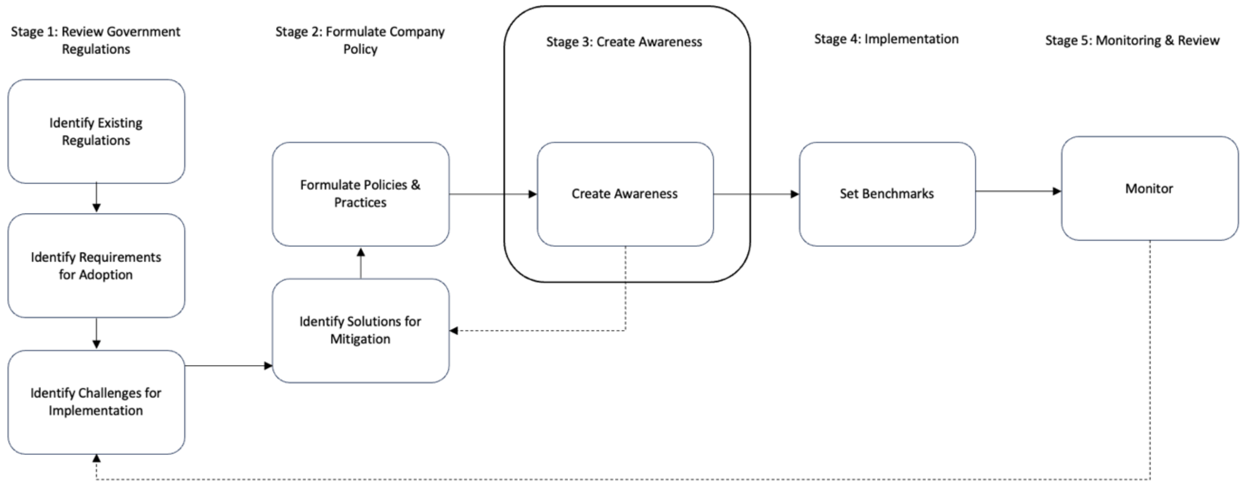

Figure 7.13: Stage 3 of the proposed framework (Source: Author)

The questionnaire and semi-structured interview analysis revealed the lack of priority given to water conservation on construction sites and material manufacturing plants. This is due to the lack of awareness about water management among the people involved in these processes. Moreover, the lack of awareness surrounding the huge significance of EW and the need for its management at the government level is also responsible for the lack of regulations and policies related to its efficient management. Thus, this stage of the framework is focused on creating awareness regarding water management. This awareness needs to be created at the company level (construction company and material manufacturing company) and government level (policymakers).

At the company level, awareness needs to be made among the company employees as these individuals are involved in the water management process. Moreover, for a policy to be implemented successfully, it is essential that people are not only aware of that policy, but also know what they need to do under that policy. For example, a policy of using low TDS water for watering the greenbelt area will only be successful if the on-site staff is made aware of only using that water source. If a greenbelt area is set up and staff is hired to maintain it, they could use any source of potable water instead of using low TDS water from RWH tanks. Thus, the third stage of the framework is to create awareness among staff with respect to the implementation of policies and their required actions.

The most efficient way of creating awareness among people is by organising workshops and trainings. The aim of these workshops and trainings is to educate people about the need for water management and the company policies in effect for their management. These workshops and trainings are also essential to explain to the staff what they are expected to do and how they should achieve it. This step is extremely essential because as aforementioned, a policy will not be successful unless people know what their actions must be to make them successful. Besides these sessions being aimed at educating the staff for water management, these are also good teambuilding sessions that ensure staff remains collaborative with each other.

It is essential for these sessions to also provide the staff with the opportunity to explain what they understand. This is an essential step to avoid any discrepancies in the understanding of the policies, and for the company to identify the clarity of its understanding among the staff.

At the government level, awareness is required since these are the people that formulate government regulations and policies surrounding water management. Moreover, as discussed in stage 1 and 2 of the framework, these policy makers also need to be made aware of the challenges the company faces for implementing the existing regulations. Thus, this stage of the framework also feeds to the second stage of the framework so that once the policy makers are aware of the challenges, they can implement measures for their mitigation. For both the groups, it is essential for the management team of the company to create awareness among its employees and policymakers. Figure 7.14 summarises the findings of research objective 5 and 6, and their integration into stage 3 of the proposed framework.

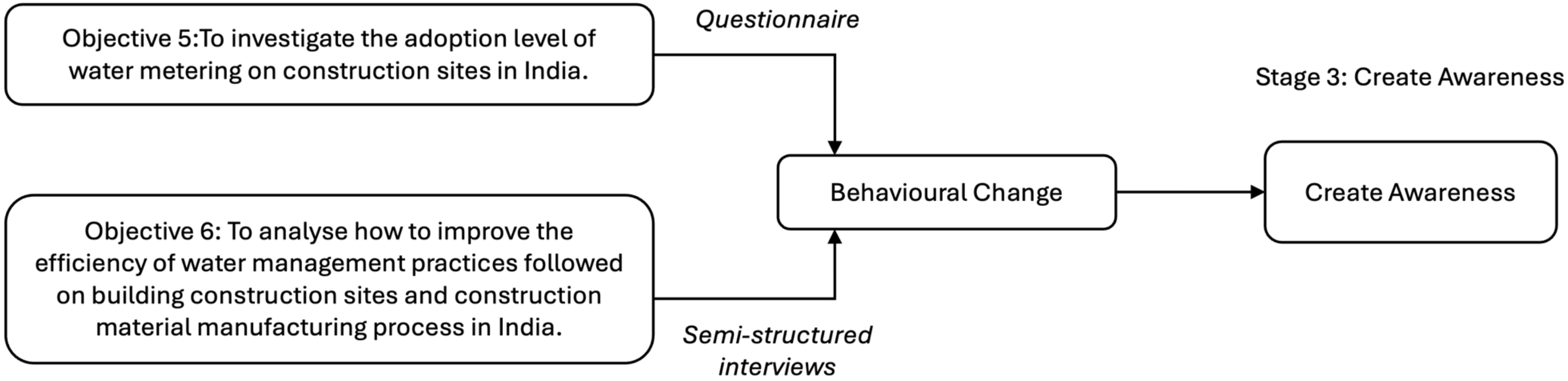

Figure 7.14: Findings of research objective 5 and 6, and their integration into stage 3 of the proposed framework (Source: Author)

7.4.4 Implementation

This is the fourth stage of the framework and is divided into one step as shown in Figure 7.15.

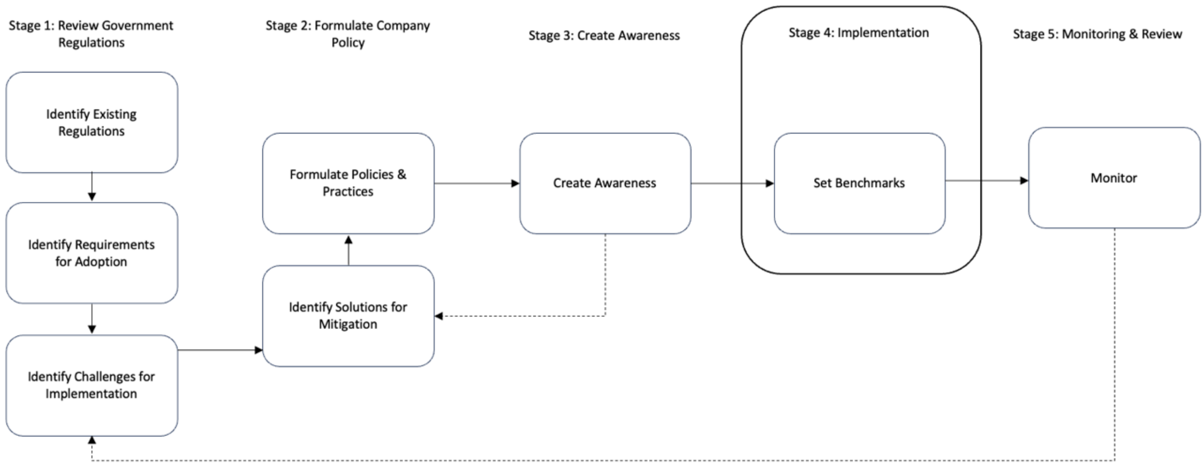

Figure 7.15: Stage 4 of the proposed framework (Source: Author)

Once the policies have been developed and awareness created regarding its adoption, the next stage of the framework is to implement these policies in practice. These policies can be implemented by creating two types of benchmarks. These are optimum water consumption and percentage reduction in water consumption.

For the former, the EWC values of construction materials and activities obtained from the case study analysis, and a review of existing databases, revealed the optimum amount of water required for manufacturing common construction materials in India and undertaking common construction activities. These EWC data can act as a benchmark for material manufacturing companies and construction companies regarding the optimum quantity of water required.

However, benchmarks also need to be set up regarding the percentage reduction in water consumption companies plan to accomplish. This benchmarking is required in regulations where 100% compliance cannot be achieved immediately and various improvements to the plant and manufacturing process are required before this policy can be completely adopted. It is essential that in order to achieve a goal, small achievable targets need to be set up. This is based on what tiles interviewee 1 mentioned “water saving is a process with benchmarks in it”.

Figure 7.16 summarises the findings of research objective 2, 3 and 6, and their integration into stage 4 of the proposed framework. Points 1 to 6 of Table 7.37 lists the types of benchmarks the companies can set for water management. Point 7 of Table 7.37 lists the collected EWC data, and these act as optimum water consumption values on construction sites and material manufacturing plants.

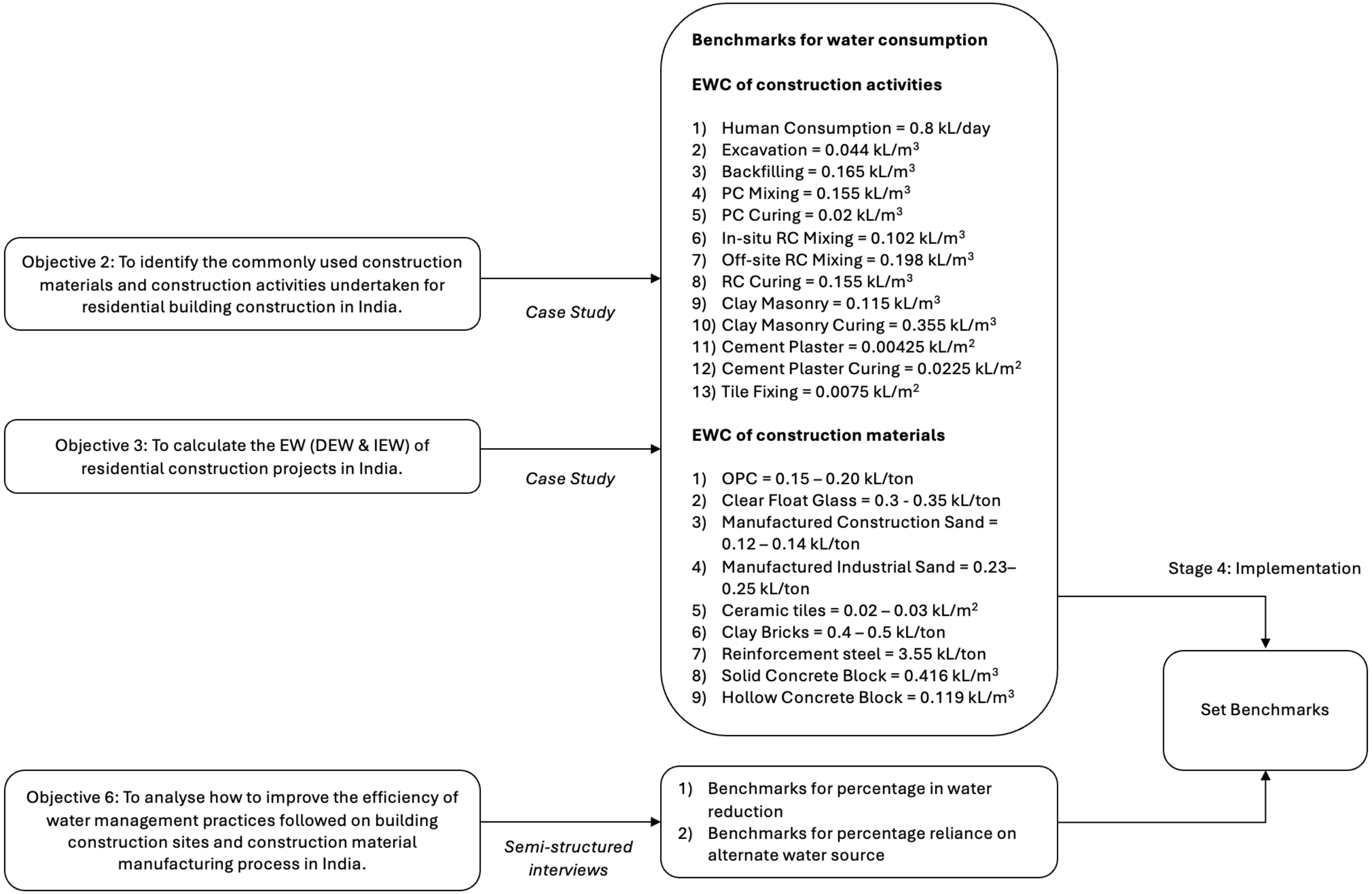

Figure 7.16: Findings of research objective 2, 3 and 6, and their integration into stage 4 of the proposed framework (Source: Author)

Table 7.37: Application of stage 4 (Implementation) (Source: Author)

No.	Step 5: Developed company policy from stage 2	Step 7: Set benchmarks for water consumption
1	Use harvested rainwater and treated wastewater for different activities to reduce dependence on groundwater.	1) Reduce dependence on groundwater by a certain amount (like up to 50%) by the end of a specified year (like year 2). 2) Complete dependence on alternative water source by the end of a specified year (like year 5). 3) These water sources must meet a certain percentage of the plant and site requirements (like 20%) by the end of a specified year (like year 1), with its requirements increasing with time.
2	Use of water efficient technologies	1) The use of water efficient technology can help reduce a certain percentage of water (like 20%) by the end of a specified year (like year 2), with its application increasing with time.
3	Installation of water meters	1) Water meters must be installed at source of water withdrawal by a certain year (like year 1). 2) By another year (like year 3), water meters must be installed at all sources of consumption.
4	Set benchmarks for water consumption by measuring the optimum amount of water required (EWC of construction activities and materials)	For Construction Sites 1) Human consumption = 0.8 kL/day 2) Excavation = 0.044 kL/m^3 3) Backfilling = 0.165 kL/m^3 4) PC Casting = 0.155 kL/m^3 5) PC Curing = 0.02 kL/m^3 6) In-situ RC Casting = 0.102 kL/m^3 7) Off-site RC Casting = 0.198 kL/m^3 8) RC Curing = 0.155 kL/m^3 9) Clay Masonry = 0.115 kL/m^3 10) Clay Masonry Curing = 0.355 kL/m^3 11) Cement Plaster = 0.00425 kL/m^2 12) Cement Plaster Curing = 0.0225 kL/m^2 13) Tile Fixing = 0.0075 kL/m^2 For Construction Materials 1) OPC = 0.15 – 0.2 kL/ton 2) Clear Float Glass = 0.3 – 0.35 kL/ton 3) Manufactured Construction Sand = 0.12 – 0.14 kL/ton 4) Manufactured Industrial Sand = 0.23 – 0.25 kL/ton 5) Ceramic Tiles = 0.02 – 0.03 kL/m^2 6) Clay Bricks = 0.4 – 0.5 kL/ton 7) Reinforcement Steel = 3.55 kL/ton 8) Solid Concrete Block = 0.416 kL/m^3 9) Hollow Concrete Block = 0.119 kL/m^3

7.4.5 Monitoring & Review

This is the fifth and last stage of the framework and consists of only one step as shown in Figure 7.17.

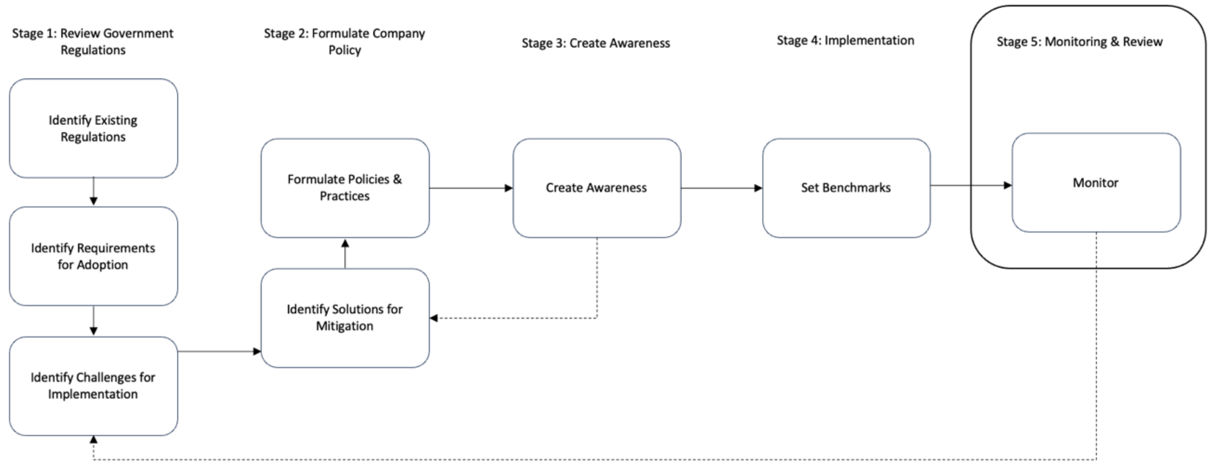

Figure 7.17: Stage 5 of the proposed framework (Source: Author)

The questionnaire and semi-structured interview analysis revealed that the lack of monitoring of a regulation is a crucial factor impacting its successful adoption. Thus, a final stage of monitoring is extremely essential in the developed framework. This stage requires the company to regularly monitor the policies they have implemented by checking whether the developed benchmarks have been accomplished. An external government body or internal company body can be appointed for this monitoring. It is similar to what glass interviewee 1 mentioned about a Central Pollution Control Board annually visiting their plant for audits. Completing water audit report must be made compulsory for companies. This report must clearly identify the sources of water used and amount of water used at the facility (construction site or manufacturing plant) in the fiscal year. It must also include the companies plan for reducing their water consumption aligning with their benchmark.

Another benefit of this stage is that the monitoring of a policy will help determine the success or failure of that policy. Moreover, it will also help identify any challenges that were encountered in its adoption that were not initially foreseen. This review of policies will help identify whether the policy needs to be modified or improved.

Figure 7.18 summarises the findings of research objective 5 and 6, and their integration into stage 4 of the proposed framework.

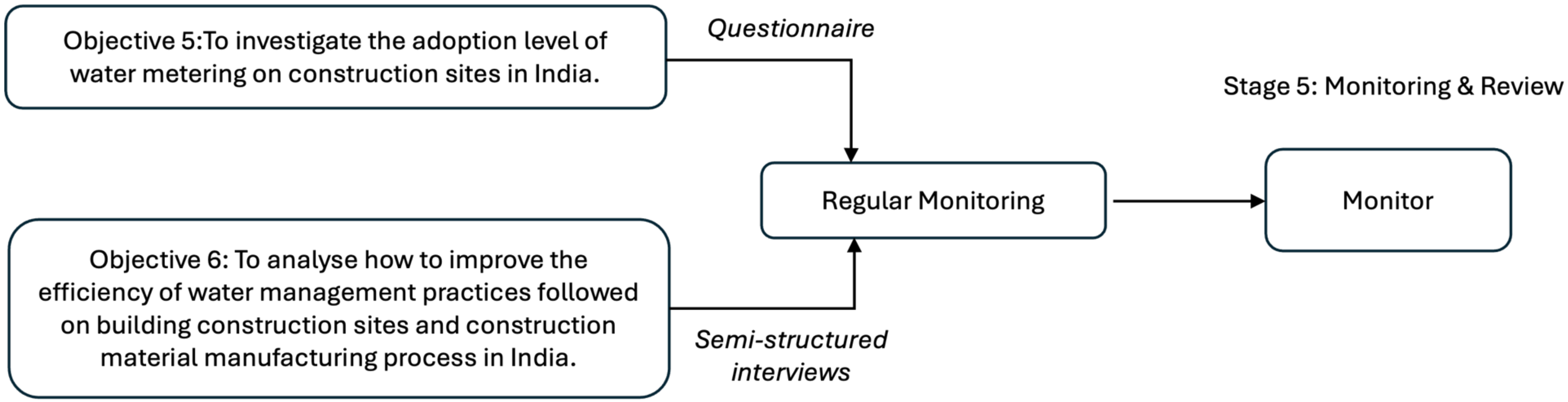

Figure 7.18: Findings of research objective 5 and 6, and their integration into stage 5 of the proposed framework (Source: Author)

7.5 Proposed Framework Validation

The proposed framework developed in stage 7 of this study (Section 7.4) was validated by following the participant validation process as outlined by Bryman (2012) and Saunders, Lewis and Thornhill (2023). In this validation process, a sample of respondents that participated in the first semi-structured interview, participated in a second semi-structured interview for their comments on the applicability of the proposed framework. Interviewing the same participants has an added advantage since it also helps in validating the original data that was collected. Four participants out of the thirteen semi-structured interviewees were interviewed for the framework validation and their demographical information is shown in Table 7.38. All the thirteen semi-structured interviewees listed in Table 6.8 and Table 6.9 play a crucial role in the application of the proposed framework in their respective companies due to their involvement in either the decision making of water management practices or application of decided water management practices. The selection of the four participants for the validation process was based on their availability and willingness to participate in a second semi-structured interview.

Table 7.38: Demographics of validators (Source: Author)

Validator	Group	Job Title
Validator 1	Construction Professional	Project Manager
Validator 2	Construction Professional	Architect
Validator 3	Material Manufacturer	General Manager
Validator 4	Material Manufacturer	Head of Technical Services

The semi-structured interviews for the framework validation were conducted on MS Teams and lasted approximately thirty minutes. For this section, all the four interviewees will be referred to as validators to avoid confusion with the earlier referred interviewees. At the start of the interview, the proposed framework was shown to each validator. At this instance, all the five stages of the framework were explained to them along with the rationale for their inclusion. Following this, the validators were asked questions covering the general themes of applicability of the framework, areas for improvements, and recommendations. Table 7.39 summarises the questions asked under each theme.

Table 7.39: Framework validation themes and questions (Source: Author)

Theme	Interview Questions
Applicability	1) What do you think are the strengths of the proposed framework? 2) What are the weaknesses of the proposed framework? 3) Do you see yourself implementing this framework in your organisation?
Stages of the framework	1) Do you agree with the arrangement of the five stages? 2) Are there any changes in the stages order that you would like to suggest and why?
Challenges	1) What challenges you might face when you try to apply this framework? 2) How would you overcome these challenges?

All the interviews were recorded and transcribed using the built-in feature on MS Teams. Following this, the generated automatic transcripts were analysed along with interview recordings to generate accurate transcripts and summaries of the key findings. These findings were further analysed using the thematic analysis process as outlined by Saunders, Lewis and Thornhill (2023) wherein the findings from each interviewee were divided into codes, its frequency determined and organised into themes. Section 7.5.1 to Section 7.5.5 discuss the findings of this validation and each question is discussed in a separate sub-heading.

7.5.1 Strengths of the Proposed Framework

All the validators noted that the proposed framework has potential for saving water and implementing water management practices on both construction sites and in construction material manufacturing companies. Validator 1 said that the planning stage of any project is very important since this is the stage where decisions regarding source of water and its appropriate sourcing are made. Validator 3 further added that decisions regarding the water management practices that can be implemented are made at this planning stage. These two validators noted the strength of the proposed framework in terms of its application at the planning stage. Validator 2 said that "people follow policies and not practices" and noted the importance of the government regulations (Stage 1 of the proposed framework) and company policies (Stage 2 of the proposed framework) for water management. Validator 4 further noted that government regulations play a pivotal role in setting the basis for what companies need to implement and their identification in the first stage of the framework is a strength of the framework. Validator 3 pointed out that with the growing water scarcity in India, saving water is the top priority of companies. Companies are motivated to make policies for water management even if it is not mandated by the government. He said "in today's time we all need to take measures to save water and not just depend on the government". This validator emphasised that the inclusion of company policies in the framework is a strength as it ensures implementation of water management practices even if not mandated by the government. Table 7.40 categorises these findings into codes and identifies their frequency.

Table 7.40: Thematic analysis for strengths of the proposed framework (Source: Author)

Theme	Code	Validator Number
Strength	Water saving	1,2,3,4
	Planning stage	1,3
	Government regulations	2,4
	Company policies	2,3
	Water scarcity	3

7.5.2 Weaknesses of the Proposed Framework

Though Validator 2 highlighted the importance of government regulations, many of these regulations are difficult to implement. They stated how it would be ideal if the government mandates regulations that are easier to implement and are accompanied by limited challenges in their adoption. They further stated that if regulations are reviewed at the government level prior to being mandated, the challenges for its adoption can be identified and mitigated.

With regards to the proposed solution of government providing funds to companies for implementing water management practices (Stage 2 of the proposed framework), Validator 4 pointed out a key issue related to the availability of funds for the government. The validator said "as per the latest budget of the country, we are in a 6% deficit. It is difficult for the government to provide investments to companies". The validator added that the government needs to provide other types of incentives like tax concessions, etc. to motivate the companies to implement water management practices.

Validator 1 and 4 noted the lack of awareness among people is a major weakness in general that limits the adoption of water management practices. Validator 3 pointed out that the companies that give low priority to water management, will consider this framework as an extra burden. This is because the framework implementation would require a lot of planning and time due to its different stages. Moreover, the stage of creating awareness among people includes trainings and workshops which poses as an additional cost and time constraint to companies.

Table 7.41 categorises these findings into codes and identifies their frequency.

Table 7.41: Thematic analysis for weaknesses of the proposed framework (Source: Author)

Theme	Code	Validator Number
Weakness	Government regulations	2
	Lack of funds	4
	Awareness	1,3,4

7.5.3 Framework Implementation

Validator 1 and 3 noted this framework has huge potential for water management when implemented at the planning stage. Validator 2 said that they would like to apply the framework on one of the projects they are working on. Validator 4 added that they are willing to implement the framework since they give utmost priority to water management. Table 7.42 categorises these findings into codes and identifies their frequency.

Table 7.42: Thematic analysis for implementation of the proposed framework (Source: Author)

Theme	Code	Validator Number
Implementation	Yes	1,2,3,4
	awareness	4

7.5.4 Stages of the Proposed Framework

Validator 2 stated the importance of having government regulations as the first stage since these define the measures companies need to take. However, they also revealed that since these regulations are accompanied with challenges for their implementation, the steps of the framework that focus on identifying the challenges and developing solutions for their mitigation are an important inclusion in the framework. They said that if the mandated government regulations have limited challenges for implementation in the first instance, the steps of identifying challenges and developing solutions to overcome those can be avoided. Validator 3 noted the importance of creating company policies and its inclusion in the proposed framework. Validator 1 said that the stages of the framework are well thought off and their order makes sense. Validator 4 said that awareness needs to be created among people at all levels within the company along with the government policy makers. Table 7.43 categorises these findings into codes and identifies their frequency.

Table 7.43: Thematic analysis for proposed framework stages (Source: Author)

Theme	Code	Validator Number
Stages	Government regulations	2
	Challenges	2
	Solutions	2
	Company policies	3
	Logical	1
	Awareness	4

7.5.5 Challenges for Framework Implementation

All the validators noted that the major challenge they would face in implementing the framework is in creating awareness among all staff members. Validator 3 said that since the proposed framework targets all the employees of an organisation creating awareness among all staff members will be expensive and time consuming. Validator 1 said that "implementing sustainable water management practices that the framework suggests requires an initial investment for companies which will be demotivating". Validator 4 added that the regular monitoring and review required during the framework implementation is also a challenge that might demotivate companies from implementing this framework. Table 7.44 categorises these findings into codes and identifies their frequency.

Table 7.44: Thematic analysis for challenges of the proposed framework implementation (Source: Author)

Theme	Code	Validator Number
Challenge	Awareness	1,2,3,4
	All staff	1,2,3,4
	Expensive	1,3
	Time consuming	3
	Regular monitoring	4

7.6 Chapter Summary

This chapter analysed the data collected in stage 1, 3 and 5 of this sequential explanatory multiphase mixed method study. In stage 2 (quantitative data analysis), the two case study building BOQ's collected in stage 1 were analysed to determine the commonly used construction materials and construction activities undertaken for residential building construction in India. In stage 4 (quantitative data analysis), the EWC of construction activities was determined using the water consumption records documents collected in stage 3. Furthermore, the EW of the two case study buildings was also calculated in stage 4. These calculated EWC values acts as benchmarks for optimum water consumption and are integrated into the proposed framework. Moreover, in stage 4, a comparison was conducted between the EC and IEW of the case study buildings, along with a code-book analysis of the questionnaire to determine the adoption level of water metering in the construction sector in India. In stage 6 (qualitative data analysis) of the study, the semi-structured interviews conducted in stage 5 were analysed using the thematic analysis process to identify the water management practices adopted, challenges faced for their implementation and strategies for EW management. All these quantitative and qualitative findings were used to develop the proposed framework in stage 7 (point of integration of quantitative and qualitative findings) of this study. The proposed framework consists of five stages and adds on to the three stage conceptual framework developed in Chapter 4. This chapter concludes with analysing the validation process of the proposed framework.

Chapter 8 : Conclusions and Recommendations

This chapter starts by reviewing the study objectives that were created to achieve the research aim. Each objective is explained in terms of the research strategy and methodology adopted to answer its research questions. It also highlights the contribution of this study to practice and theory. This chapter finally concludes by listing the limitations of this study and recommendations for future studies.

8.1 Review of the Study Findings

This study aimed at developing a framework of efficient water management practices that focuses on maximising water efficiency and minimising water consumption in the residential building construction sector to promote sustainable building construction in India. This framework is aimed at construction professionals working on residential building construction projects and material manufacturers working in construction material manufacturing companies. The study's aim was achieved through seven objectives. This section discusses each objective by defining the research strategy that was adopted and its main findings. It also discusses the findings for all the research questions.

8.1.1 Objective 1: To identify water management policies and practices adopted on construction sites and material manufacturing plants worldwide and in India

This objective aimed at identifying water management practices for EW management. It also aimed at identifying existing government regulations in India with respect to EW management. This objective was accomplished by conducting an extensive literature review, and semi-structured interviews with construction professionals and material manufacturers.

The literature review identified two practices that can be applied for EW management. These are the three pillars of sustainability for SWM (Section 2.11) and 6R water hierarchy principle developed by Waylen, Thornback and Garrett (2011) (Section 2.12). Moreover, the literature review helped identify two policy documents that outline policies for industrial water management in India that are mandated by the Indian government (Section 2.2). These are the Draft National Water Framework Bill 2016 and the National Water Mission 2008. TERI (2018) noted that due to weak governance and planning, these regulations and policies are failing to conserve water resources in India. This was also highlighted through the semi-structured interview findings (Section 7.3).

Semi-structured interviews with construction professionals revealed that the existing regulations imposed on construction sites are the ban on the use of groundwater and using treated wastewater from a STP (Section 7.3). The interviews also revealed that these regulations are not applicable to all parts of India. Moreover, the interviews also revealed that the cost of obtaining water from STP and the availability of a STP in the vicinity of the construction poses as a challenge in its adoption. Moreover, they revealed that the reliability and availability of groundwater often results in its consumption despite regulations banning its use.

Semi-structured interviews with construction material manufacturers revealed regulations like the requirement of a mandatory RWH system on new plants and that all manufacturing companies must be zero-liquid discharge (Section 7.3). The National Water Mission 2008 requires companies to monitor their water consumption at all areas of consumption through the installation of water meters. However, the semi-structured interviews revealed that these water meters are only installed at the water withdrawal site. This as aforementioned shows the lack of monitoring by the government regarding the proper implementation of water management policies. Moreover, the challenges to implement certain regulations limits its adoption.

Three research questions were answered under this objective. Figure 8.1 summarises the research strategy adopted to answer each research question and its findings.

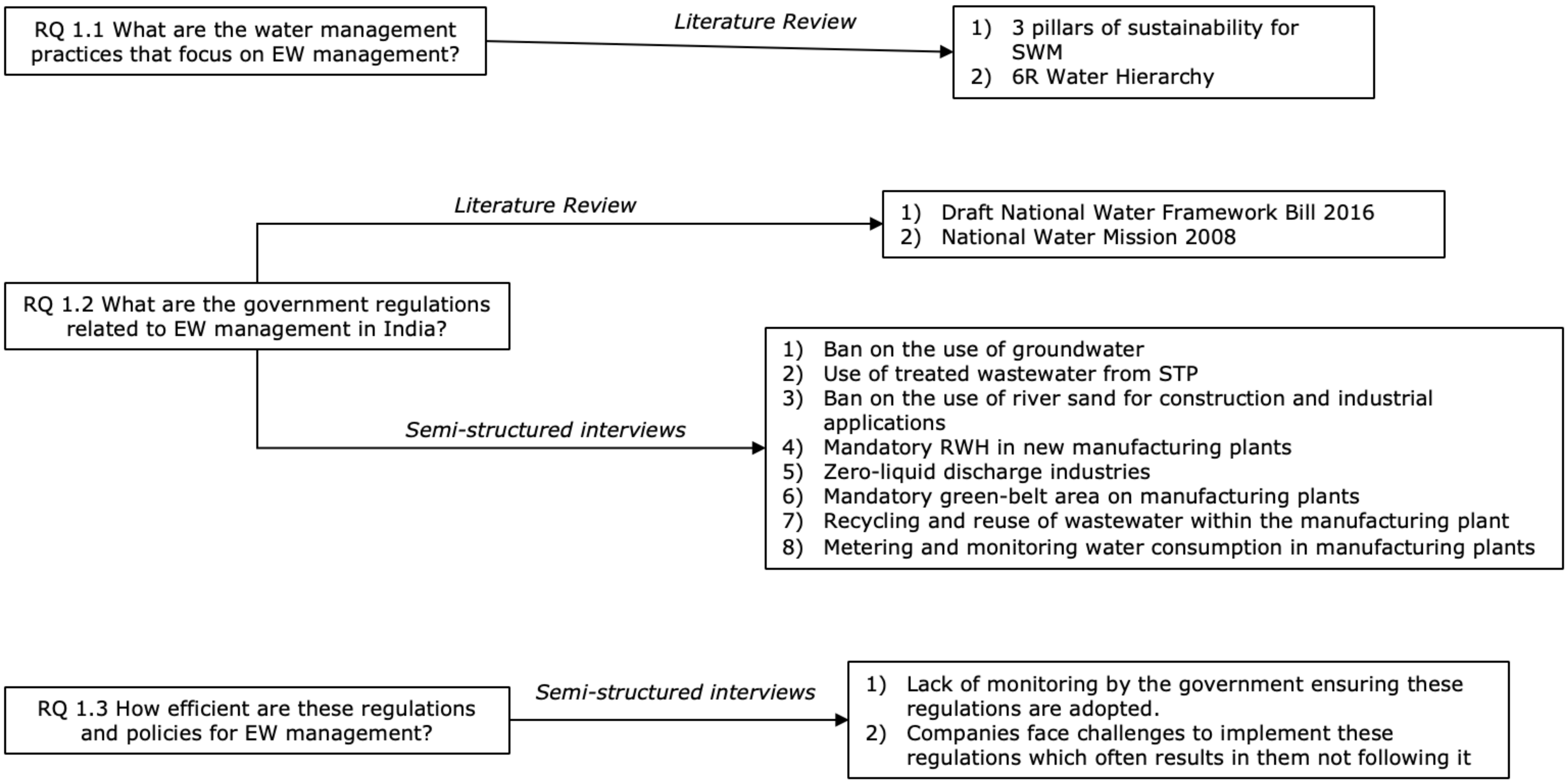

Figure 8.1: Objective 1 research questions and their findings (Source: Author)

This objective is essential as it helps identify the current policies for EW management that play an integral role in the proposed framework. Moreover, the limitations identified for the implementation of these policies help make informed decisions for their management and are included in the proposed framework.

8.1.2 Objective 2: To identify the commonly used construction materials and construction activities undertaken for residential building construction in India

This objective aimed at identifying the commonly used materials and activities undertaken for residential building construction in India. Two RC frame buildings with clay masonry walls were selected as case study buildings for analysis. This building typology is selected as it makes up 45% of the residential building stock in India (Census 2011). Documents in the form of construction BOQ's were collected from the project consultant working on the case study buildings and these were analysed to achieve this objective.

The guidelines listed in BIS (2000), BIS (2001), BIS (2005), BIS (2007a), BIS (2007b), BIS (2010), BIS (2011), BIS (2013) and BIS (2019) were used as guidelines to breakdown each component of the BOQ into smaller components to identify all the construction materials consumed for its execution along with their quantities (Section 7.1.1). Similarly, each component of the BOQ was also analysed to determine all the water consuming activities that were undertaken to accomplish it (Section 7.1.2).

Three research questions were answered under this objective. Figure 8.2 summarises the research strategy adopted to answer each research question and its findings.

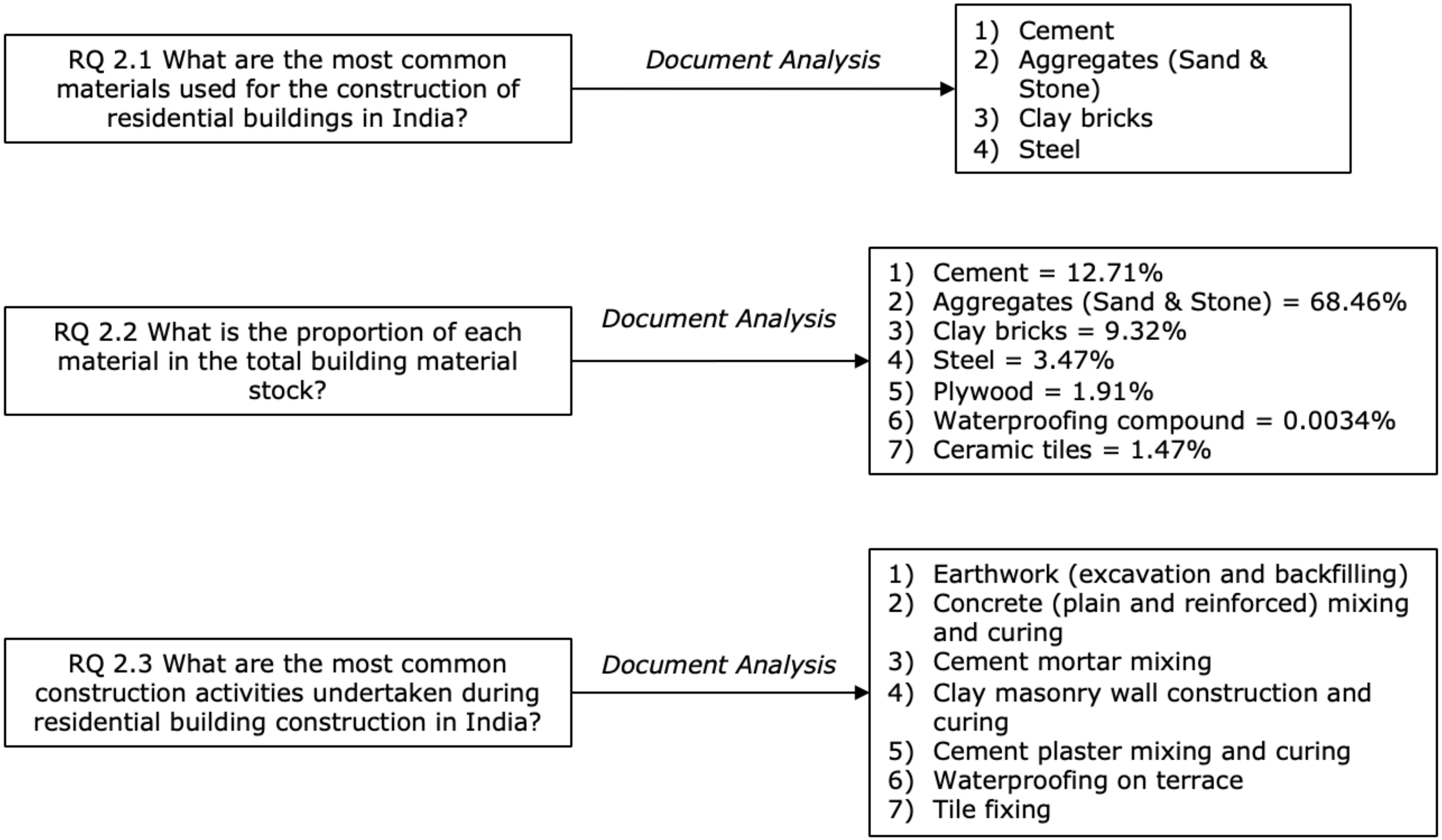

Figure 8.2: Objective 2 research questions and their findings (Source: Author)

This objective was essential because it helped identify the most used materials and activities undertaken for the construction of residential building construction in India. These materials and activities were further analysed in Objective 3 to determine their EWC and ultimately the EW of residential buildings in India.

8.1.3 Objective 3: To calculate the EW (DEW & IEW) of residential construction projects in India

This objective aimed at calculating the EW of the case study residential buildings by collecting data related to the EWC of the construction materials and construction activities identified in Objective 2. This objective was accomplished by conducting an extensive literature review and an analysis of documents (in the form of water consumption records) collected from the research participants.

An initial literature review revealed that there is no data related to the EWC of construction activities in Indian context. Hence, water consumption records were collected from the project consultants working on the case study residential buildings and these were analysed to determine the EWC of different construction activities (Section 7.2.1). The calculated EWC data was analysed along with the quantity of conducting that activity as obtained from the building BOQ to calculate the DEW of the building. The analysis revealed that the average DEW of the two case study buildings is 0.335kL/m^2 with curing activities constituting about 45% of the total water consumed on construction sites. The analysis also revealed that by incorporating water management practices like covering freshly poured concrete with moist gunny bags (to reduce the amount of curing water) and incorporating a cleaning platform on the construction site (to reduce potable water for cleaning activities), the DEW can be reduced by almost 10%. Almost 26% of the total water consumed on the construction site is used by the site staff for various activities like cleaning and sanitation.

For the construction materials, an initial literature review revealed that only three materials (steel, concrete blocks and coated flat glass) have a valid EWC in Indian context. For other materials (cement, aggregates, tiles and bricks) this data is either outdated or not existent (Chapter 2). As a result, for these five materials (cement, sand, uncoated flat glass, ceramic tiles and clay bricks) the EWC data was collected through documents obtained from material manufacturers (Section 6.2.1). These collected EWC data was analysed along with the quantities of material obtained from analysing the case study building BOQ in Objective 2 to calculate the IEW of the building. The analysis revealed that the average IEW of the two case study buildings is 0.52 kL/m^2. Though steel is used in very small quantity as opposed to other materials like cement, aggregates and bricks, it has a very high EWC and contributes the highest to the IEW at around 40%. Similarly, aggregates are used in the largest quantity and have a very low EWC but contribute the second largest towards the EWC at almost 30%.

The DEW and IEW values obtained were used to calculate the EW of case study residential buildings in India. It was observed that the average EW of the two case study buildings was 0.855 kL/m^2 with DEW constituting around 40%. This signifies that both DEW and IEW require equal attention for EW management as opposed to findings of Bardhan (2011) and Heravi and Abdolvand (2019) that state the IEW must be given more priority since it constitutes around 80% of the EW.

Five research questions were answered under this objective. Figure 8.3 and Figure 8.4 summarises the research strategy adopted to answer each research question and its findings.

RQ 3.1 How much water is consumed (kL) per unit (m^3, m^2) to carry out different construction activities?

Document Analysis

1) Human Consumption = 0.8 kL/day
2) Excavation = 0.044 kL/m^3
3) Backfilling = 0.165 kL/m^3
4) PC Mixing = 0.155 kL/m^3
5) PC Curing = 0.02 kL/m^3
6) On-site RC Mixing = 0.102 kL/m^3
7) Off-site RC Mixing = 0.198 kL/m^3
8) RC Curing = 0.155 kL/m^3
9) Clay Masonry = 0.115 kL/m^3
10) Clay Masonry Curing = 0.355 kL/m^3
11) Cement Plaster = 0.00425 kL/m^2
12) Cement Plaster Curing = 0.0225 kL/m^2
13) Tile Fixing = 0.0075 kL/m^2

RQ 3.2 What is the percentage contribution of each activity in the DEW of the building?

Document Analysis

1) Human Consumption = 28.1%
2) Excavation = 12.21%
3) Backfilling = 7.38%
4) PC Mixing = 1.47%
5) PC Curing = 0.17%
6) On-site RC Mixing = 4.54%
7) RC Curing = 18.29%
8) Clay Masonry = 5.3%
9) Clay Masonry Curing = 16.64%
10) Cement Plaster = 1.36%
11) Cement Plaster Curing = 7.06%
12) Tile Fixing = 1.65%

Figure 8.3: Objective 3 research questions and their findings (Source: Author)

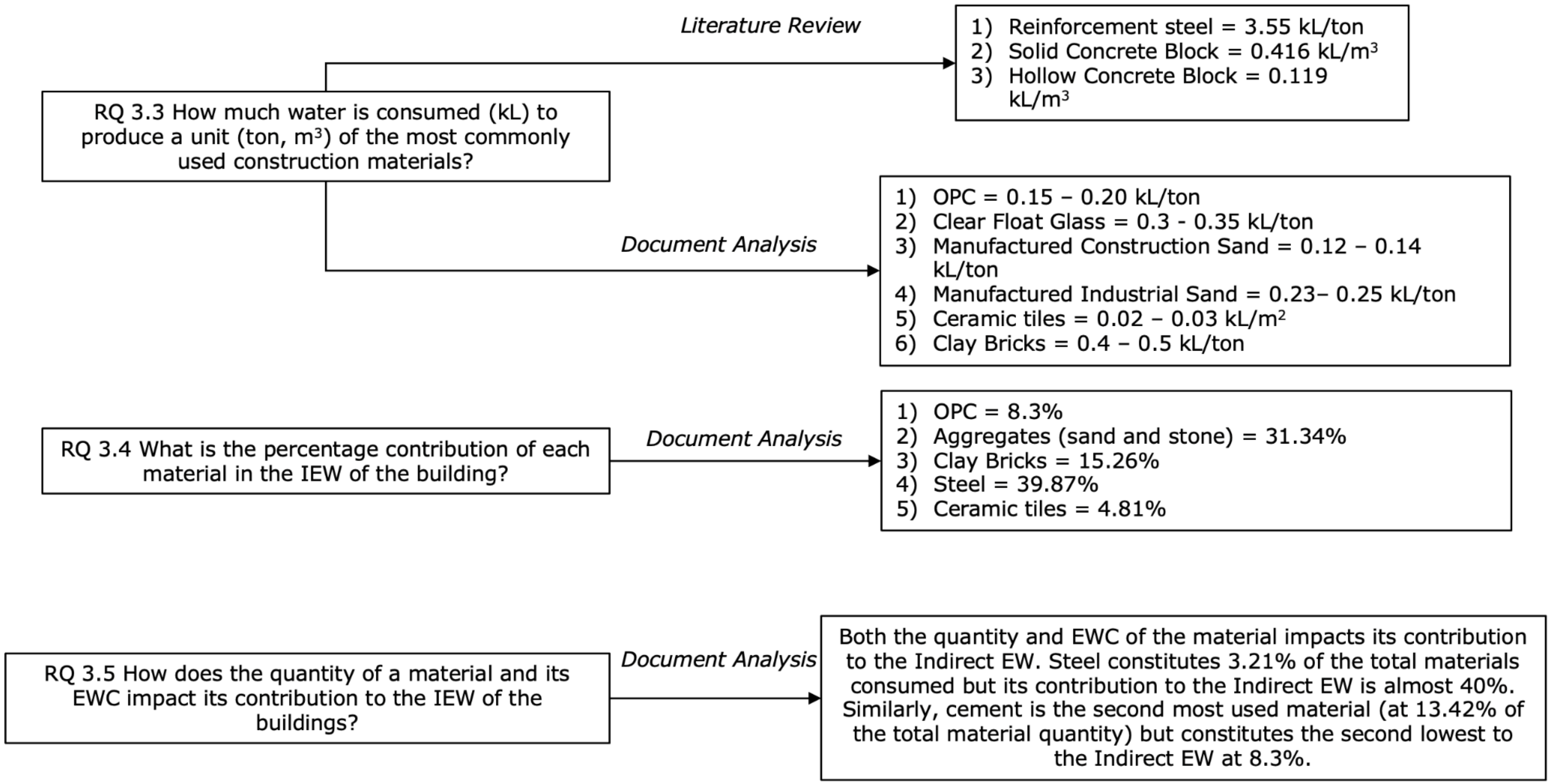

Figure 8.4: Objective 3 research questions and their findings (Source: Author)

This objective is essential as it results in the collection of data related to EWC of construction materials and activities in Indian context. This EWC data acts as a benchmark for water consumption for these activities and material manufacturing to ensure optimum water is consumed for their execution and manufacturing. This also plays a crucial role in the proposed framework.

8.1.4 Objective 4: To investigate the relationship between EW and EC of the selected construction materials

This objective aimed at calculating the EC of the case study buildings and comparing the calculated EC of each material with its EW calculated in Objective 3. The aim of this comparison was to identify any relationship between EW and EC. It also aimed at identifying what materials have a low EWC but high ECC and vice versa. An archival search was conducted to identify a database developed by International Finance Corporation of the World Bank Group (2017) that note the EC-GWP coefficients of construction materials in Indian context. Theses EC-GWP coefficients were analysed along with the quantities of the materials obtained from Objective 2 to calculate the EC of the building and each material.

The analysis revealed that cement which contributes the second lowest (around 8%) in the IEW, constitutes the highest (around 45%) to the EC of the building. Similarly, aggregates constitute the second highest (around 30%) proportion in the IEW, but have the lowest (around 3%) contribution to the EC. This is mainly attributed to the fact that large amounts of energy is consumed to manufacture cement while water is only used for the cooling activities in the process. For aggregate manufacturing on the other hand, water is consumed in at all stages of the production for cleaning and sizing activities, while energy is only used for crushing activities. It can thus be seen that a material might have a low EC but a high EW, and vice versa. Decisions regarding the selection of a material cannot be made on just one component, but both the EC and EW impacts must be considered. This was also noted by Dixit and Kumar (2022).

Due to the lack of a database regarding the ECC for different construction activities, the relationship between DEW and EC on the construction site could not be determined. However, semi-structured interviews with construction professionals revealed that various techniques can be applied on construction site that consume less or no water (such as using a fogging machine instead of water for dust suppression). However, their operation results in EC emissions. It can thus be seen that, similar to construction materials, an activity or material that consumes less water does not signify that it is a sustainable solution. As a result, the impact on both the EW and EC of the selected material and activity must be considered, and the option that results in the lowest value of the two combined must be selected. EC emissions can be reduced for a material by using a green and renewable energy source.

Three research questions were answered under this objective. Figure 8.5 summarises the research strategy adopted to answer each research question and its findings.

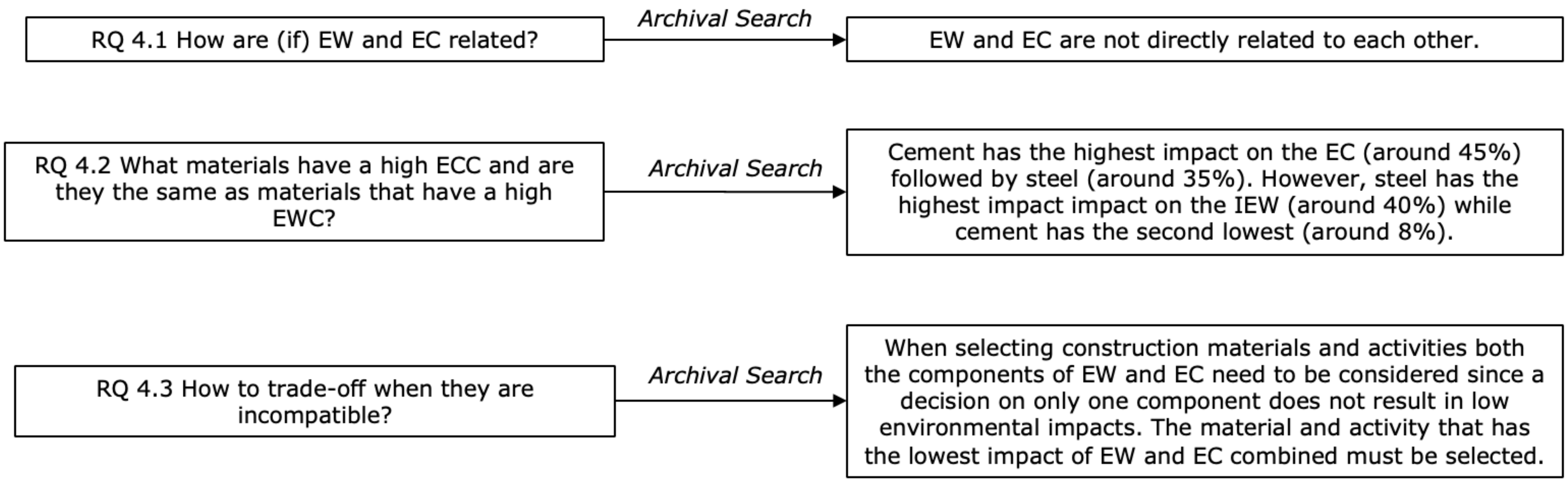

Figure 8.5: Objective 4 research questions and their findings (Source: Author)

This objective plays a crucial role for integration into the framework as it aids in making informed choices regarding the selection of appropriate materials and activities with respect to their impact on EW and EC.

8.1.5 Objective 5: To investigate the adoption level of water metering on construction sites in India

This objective aimed at identifying the adoption level of water metering on construction sites in India, the technique adopted for water metering, and the rationale behind metering (or not metering) the water consumption. It was accomplished by conducting a web-based questionnaire that was distributed among construction professionals working in India. The questionnaire respondents were selected using a systematic random sampling technique that resulted in 46 responses. The open-ended responses received were analysed by creating a codebook as defined by Saunders, Lewis and Thornhill (2023).

The questionnaire analysis revealed that 45.7% of respondents metered the water consumption on their construction sites. The most common technique of water metering is by installing a water meter at the point of water withdrawal on the construction site which is adopted by 50% of the respondents. The respondents that meter the water consumption revealed that they do so to monitor their water consumption to ensure minimum water wastage. Moreover, since water is purchased for consumption on construction sites, most of the respondents noted that they meter the water consumption for the billing purposes. On the other hand, the most common reason for not metering the water consumption was analysed to be the lack of requirements and awareness among people regarding the same.

Two research questions were answered under this objective. Figure 8.6 summarises the research strategy adopted to answer each research question and its findings.

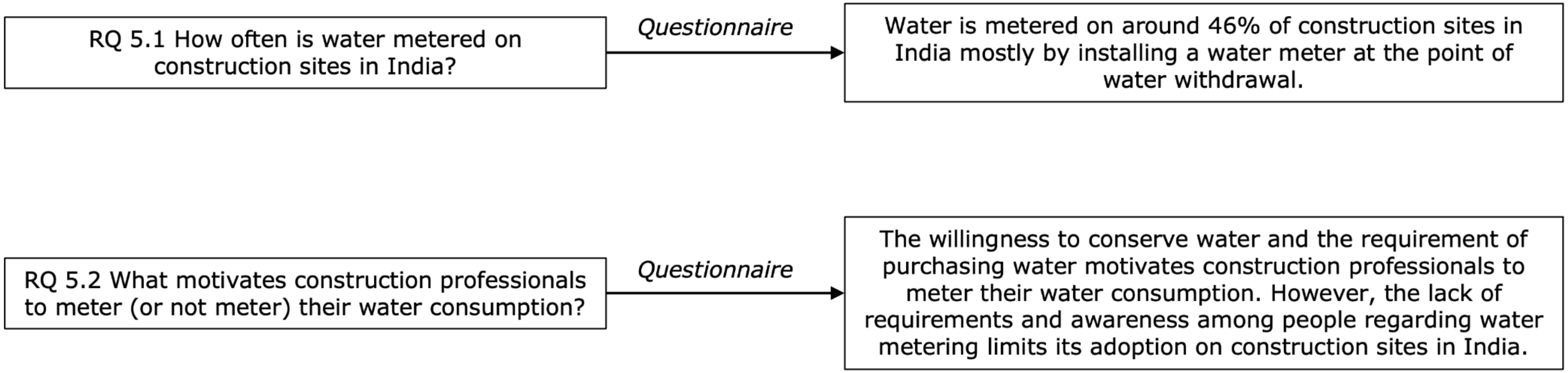

Figure 8.6: Objective 5 research questions and their findings (Source: Author)

This findings of this questionnaire in terms of the challenges and motivation surrounding water metering help make informed decisions regarding how water metering can be further encouraged on construction sites and plays an integral part in the proposed framework.

8.1.6 Objective 6: To analyse how to improve the efficiency of water management practices followed on building construction sites and construction material manufacturing process in India

This objective aimed at identifying the water management practices that are adopted on construction sites and material manufacturing plants. It also aimed at identifying the various factors (like cost, regulations, etc.) that impact the water management practices, and the challenges faced to implement these water management practices. This objective was accomplished by conducting semi-structured interviews with construction professionals and material manufacturers. The interview respondents were selected using a snowball sampling technique that resulted in the identification of seven construction professionals and eight material manufacturers. The semi-structured interviews were analysed using the thematic analysis process as outlined by Saunders, Lewis and Thornhill (2023).

The semi-structured interviews with construction professionals revealed that water conservation is not given adequate priority on construction sites which often leads to its wastage. Moreover, the unorganised nature of construction sites due to numerous activities being undertaken at different locations at the same time, makes water management and water metering very challenging. The challenges to collect the wastewater further limits the adoption of reusing and recycling on construction sites. However, the interviews revealed that simple measures can be adopted to conserve water like creating a cleaning platform where all cleaning activities can be undertaken and recycling the wastewater collected in the process. Moreover, covering freshly poured concrete with moist gunny bags can reduce the water evaporation during curing and ultimately reduce the requirements for curing water. These activities can help reduce water consumption by almost 10% when comparing the two case study buildings (Section 7.2.4). Other simple measures like creating a water storage tank for all the site water activities can limit the amount of water being consumed by reducing free flowing water. These learnings from the semi-structured interviews with construction professionals reveal the measures that can be taken to conserve water. However, the lack of awareness among site staff often results in these measures not being widely adopted.

The semi-structured interviews with material manufacturers revealed that water management is given more priority on material manufacturing plants due to the government regulations surrounding industrial water management and the presence of stringent external body regulations. Moreover, the organised nature of material manufacturing plants makes it easier for companies to monitor their water consumption and upgrade to water efficient technologies like adiabatic cooling tower and using de-mineralised water.

The semi-structured interviews further revealed the company policies play a very strong role in incorporating water management practices on construction sites and material manufacturing plant. They also highlight the importance and need for creating awareness among construction professionals and material manufacturers regarding the need for water management and the measures that can be adopted. And lastly, the interviews also revealed the importance of continuous monitoring of water consumption to ensure minimum water wastage.

Two research questions were answered under this objective. Figure 8.7 summarises the research strategy adopted to answer each research question and its findings.

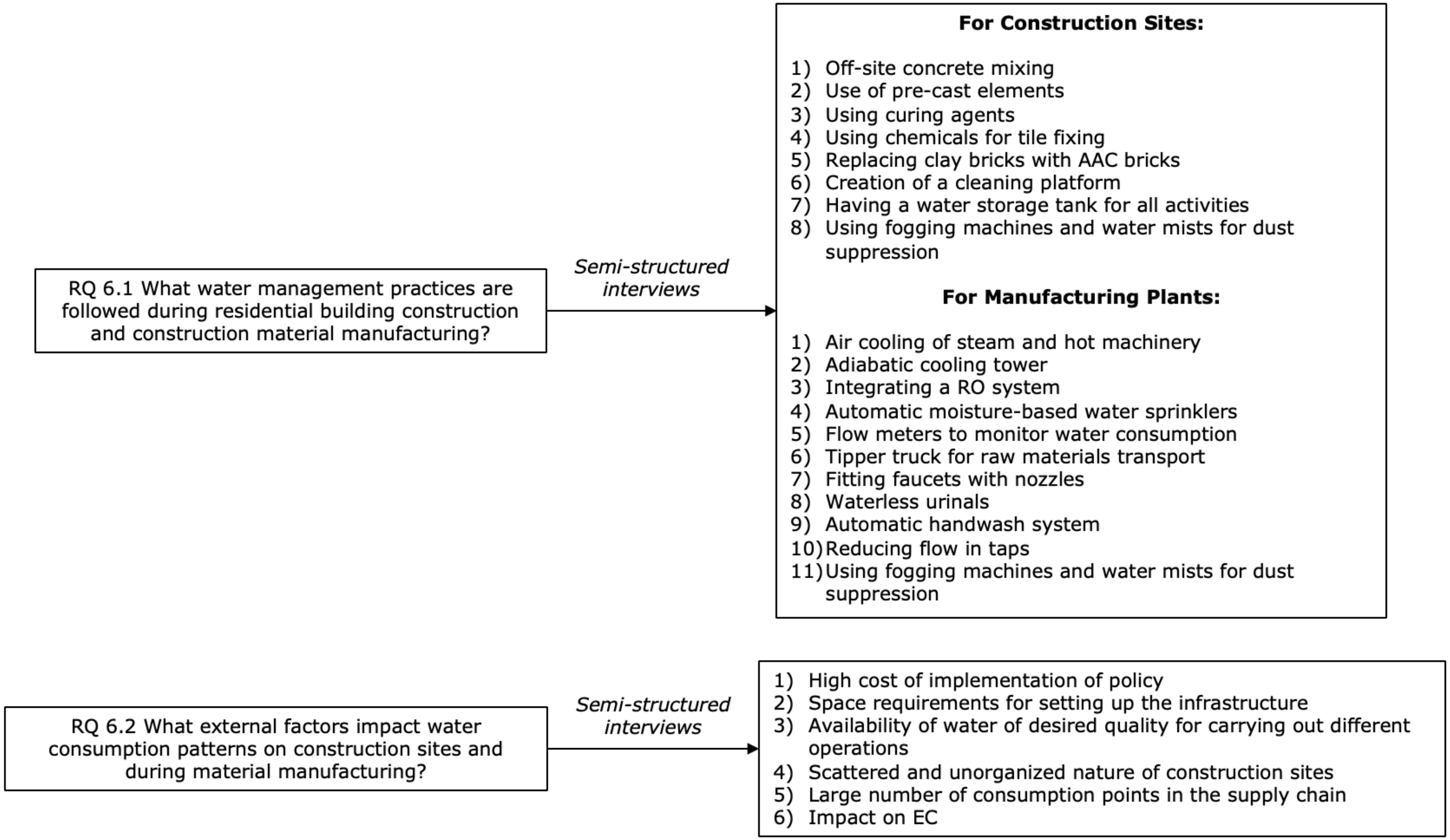

Figure 8.7: Objective 6 research questions and their findings (Source: Author)

This objective is essential because the water management practices adopted by the construction professionals and material manufacturers can be applied on a wider scale to improve water efficiency in India and hence are included in the proposed framework. Moreover, the challenges and limitations analysed from these interviews also help identify crucial measures that need to be taken for water management and are included in the proposed framework.

8.1.7 Objective 7: To develop and validate a framework for efficient water management practices that focuses on maximising water efficiency and minimizing water consumption in the residential building construction sector in India

This objective aimed at developing a SWM framework that can be applied on residential building construction sites and material manufacturing plants for EW management in India. A conceptual framework for EW management was developed in Chapter 4 after analysing the existing water management frameworks across all sectors globally (Chapter 3), along with existing policies and practices for water management and available EWC data in Indian context. The conceptual framework also helped identify the challenges of EW management that defined the need for further data collection through case studies, questionnaires and semi-structured interviews. The data thus collected was used to develop the proposed framework. The proposed framework consists of five broad stages and the integration of each set of data collected into these stages is discussed below.

The first stage of the framework focuses on identifying government regulations and the challenges for its implementation. This stage focuses on identifying challenges for the implementation of government regulations since these were revealed by the questionnaire and semi-structured interviews. In the second stage of the framework, the measures that can be taken (at both the company and government level) to overcome these challenges were identified. The aim of identification of these measures is to develop company policies for water management. The stage of development of company policies was included in the framework based on the findings of the semi-structured interviews that revealed the huge impact company policies have on water management, and that the companies that place strong emphasis on water management are usually the companies that adopt practices for their management (Section 7.3). Moreover, the measures to conserve water as obtained from the semi-structured interviews (Objective 6) are further added to the framework.

The questionnaire and semi-structured interviews also revealed the lack of awareness among construction professionals and material manufacturers regarding the need for water management and the measures that can be taken for its adoption. Hence, the third stage of the framework aimed at creating this awareness. The semi-structured interviews revealed the importance of benchmarks for water conservation (Section 7.3). Moreover, the literature review revealed the lack of existing data related to EWC of construction materials and construction activities (Section 2.8 and Section 2.9). The EWC values thus collected from the document analysis of the case studies and for material manufacturers (Objective 3) are intended to serve as benchmarks for EW management. Lastly, the semi-structured interviews revealed the lack of monitoring regarding the adoption of government regulations and water management practices, and hence this stage was also added to the framework since efficient monitoring can help identify the success of the policies and identify any challenges for their adoption.

The framework was further sent to two construction professionals and two material manufacturers for validation. All the four validators noted the importance of the framework for water management on their construction sites and manufacturing plants. They also noted the need for more government regulations that focus on EW management.

Two research questions were answered under this objective. Figure 8.8 summarises the research strategy adopted to answer each research question and its findings.

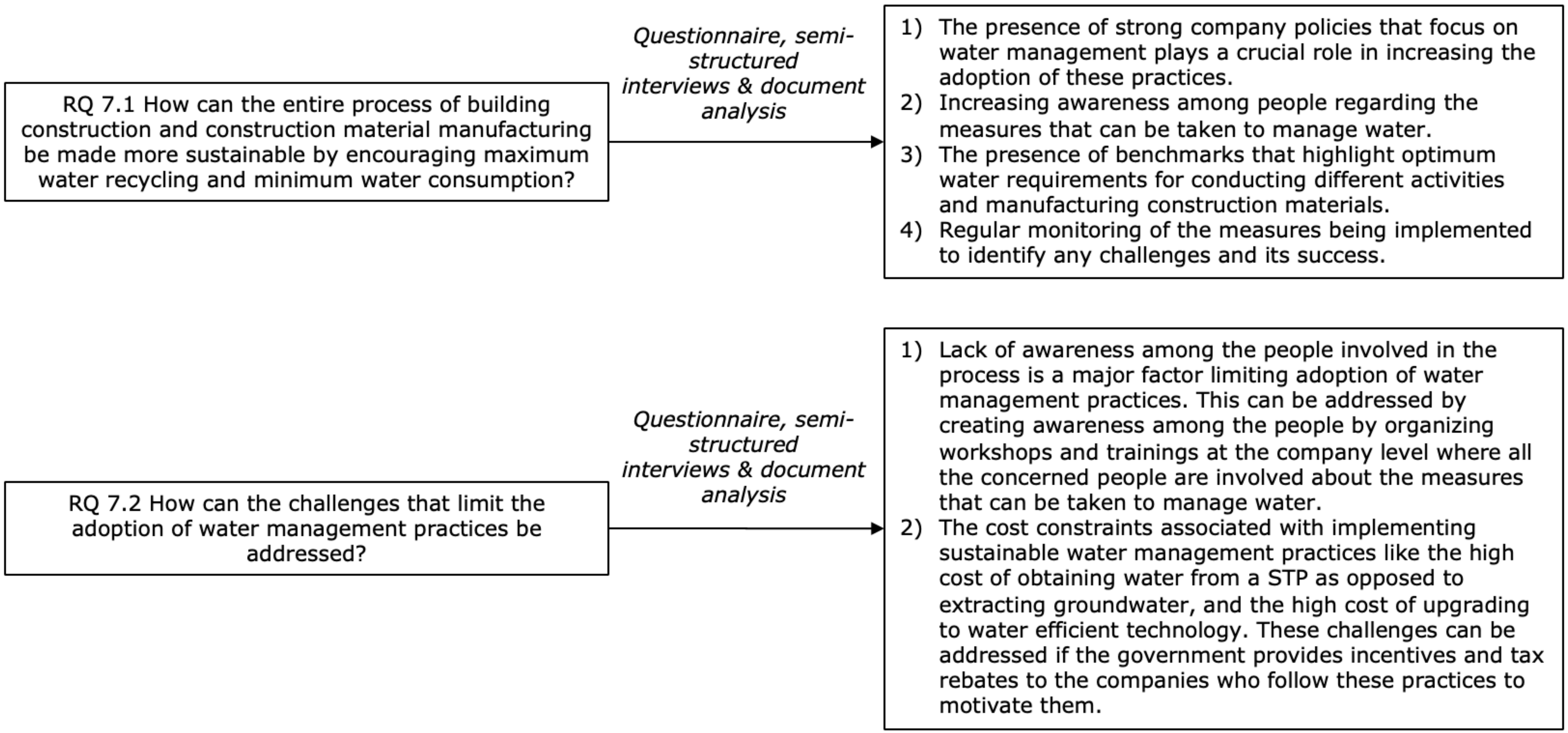

Figure 8.8: Objective 7 research questions and their findings (Source: Author)

8.2 Contribution to Knowledge

This section discusses the contribution of this study to practice and theory.

8.2.1 Contribution to Practice

Due to the lack of attention given to EW in India, there is no published framework for efficient water management in India. Through the adoption of the proposed framework water can be saved on construction sites and manufacturing plants and can be used for other activities (either in the residential building sector or another sector). This is extremely beneficial in India owing to the large episodes of water scarcity in the country. Moreover, though the proposed framework is intended for residential building construction sites and construction material manufacturing companies, this framework can be applied to all construction sites and manufacturing companies.

As discussed in Section 2.1, the poor management of water resources and less efficient water usage by industries are responsible for the increasing water scarcity episodes in the country. The proposed framework aims at increasing water efficiency by improving water management. Moreover, though the framework has been designed based on the data collection in India, the framework is also applicable to other countries that suffer from similar issues of implementing government regulations and lack of awareness among people. Additionally, even though the framework focuses on EW management in construction and material manufacturing plants, it is also applicable for other industries and activities.

The EWC values identified in this study can act as benchmarks for optimum water consumption during construction activities and material manufacturing to avoid water wastage. Moreover, the water management practices identified can be applied to all construction sites and manufacturing companies to efficiently manage water. Furthermore, the water management practices identified that are applicable to both construction sites and manufacturing plants are generic water management practices that can be applied in any sector (commercial building, industrial building, agriculture, etc.) and any country for reducing water consumption.

Construction sites and manufacturing companies usually focus on only one component (impact on water or energy) when making decisions regarding their practices. The relationship made between EC and EW, along with the discussions surrounding these, can help them make informed choices and aid in the selection of materials and activities with the lowest environmental impact.

Cement interviewee 1 at the start of the interview noted "it's good to talk to someone about EW because everyone usually talks about EC". This signifies the impact this study can have in terms of creating awareness among people regarding EW and its management.

8.2.2 Contribution to Theory

This study has developed an EWC database for the commonly used construction materials and construction activities in India context. This database will be beneficial for future studies on EW in India.

The methodology for EW calculation used in this study was previously not adopted in India. As compared to past studies like Bardhan (2011), Choudhuri and Bardhan (2015b) and Sharma and Chani (2022) this study adopts a more reliable methodology for DEW calculations based on installing a water meter on the construction site to meter the water consumption rather than calculating average values based on water withdrawn from a well and purchased from water tankers. Similarly, this study uses more reliable and up-to-date values for the EWC of construction materials collected through document analysis of water consumption records obtained from material manufacturers in India. These values and proposed methodology can be used for future EW studies being conducted in India.

8.3 Limitations of this Study

There is a lack of EC database for construction materials in Indian context, thus this study used the EC-GWP database when identifying the relationship between EC and EW of construction materials for Objective 4. Moreover, there is no EC database for construction activities. Hence, the relationship between EC and EW for different construction activities was not considered in this study.

This study only considered RC frame buildings with clay masonry walls. The comparison with different types of walls (concrete blocks, AAC bricks, etc.) was not conducted to compare the impact on the EW of the building for Objective 3.

Due to the difficulty in data collection, this study only calculated the EWC of construction materials based on the water that was consumed in the manufacturing plant (module A3) for Objective 3. The amount of water consumed during raw material extraction (module A1) and transportation (module A2 and A4) could not be collected due to difficulties in data collection and contacting the necessary people.

The case studies were based in India while the researcher was based in the UK. The cost implications of travelling to India restricted the researcher from travelling to the case study sites and using observations as a data collection strategy. To overcome this limitation, documents obtained from the case study participants and semi-structured interviews were used as the data collection strategies. This study would have benefitted from using observations as a strategy since this would enable the researcher to collect more accurate on-site data. By observing and talking to site staff involved in the construction process and material manufacturing industries, more in-depth data related to water management practices and challenges could be achieved. This extra data would have provided essential insights for the development of the proposed framework.

8.4 Recommendation for Future Studies

This study only determined the EWC of six construction materials (OPC, clay bricks, ceramic tiles, clear float glass, manufactured industrial sand and manufactured construction sand). An analysis of the EWC of more materials is recommended for future studies.

This study only considered the water consumed for the construction of two residential buildings. Studies can be conducted to determine the same for more residential buildings as well as commercial buildings. Commercial buildings EW analysis will follow the same principles as residential building. However, owing to their different final application, they might be constructed using different materials. This needs to be evaluated further.

This study determined the EWC of construction materials through document reviews. Future studies can determine the same using LCA software's with the geographical location based in India. Having a comparison of the differences (if any) in the EWC calculated from the two methodologies is worth exploring.

Though the proposed framework has been validated by industry professionals, further research can be conducted in testing its applicability in India or other countries. Moreover, the proposed framework focused on the technical aspects of water management (like water management practices adopted and developing benchmarks for optimum water consumption). The behavioural aspect of people was only considered briefly in the stage of creating awareness. This human aspect of water consumption can be further analysed in future research to understand its impact on EW management.

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Appendix A : Glossary

Adiabatic cooling tower	This structure uses pre-cooled air to cool the incoming process water, thereby enhancing the cooling efficiency and reducing the water consumption.
Ancillary activities	Activities that are undertaken to support the main activity.
Availability of water source	The presence of water source.
Bill of quantities	The BOQ of a building is a document that specifies all the activities undertaken to construct the building and its quantities.
Brick bat coba waterproofing	It is a common traditional type of waterproofing treatment applied on flat terraces in India in which broken or cut bricks are laid on the terrace and followed by a layer of waterproofing material.
Clear float glass	This refers to the type of glass produced from the float flotation process. The produced glass is clear of any coatings.
Concrete slump	It measures the consistency of freshly mixed concrete by measuring the distance between the slumped concrete and the top of the slump cone.
Concreting work	The process of making and curing concrete.
Construction sand	The sand used as an aggregate to make concrete, mortar and plaster, and other applications of construction site.
Conventional cooling tower	This is a structure that cools the incoming hot process water by exposing it to air. This aids in transferring the heat from the process water to the atmosphere by evaporating part of the water.
De-mineralised water	It is a type of water from which most of its dissolved minerals are removed. When used in a cooling tower, it improves heat transfer and reduces the amount of water required.
Direct embodied water	The water consumed on the construction site for the actual construction of the building.
Dry process	The process of material manufacturing that does not consume water.

Dry specific gravity	The specific gravity of a material that exists in dry state, i.e, its pore or surface is not in contact with water.
Earthwork activities	Activities like excavation and backfilling that are executed to prepare the construction ground for building construction.
Efficient water management	The process of ensuring water consumption for an activity or in a process is focused on optimizing the water consumption and minimising water wastage while focusing on the quality and quantity of consumed water.
Effluent treatment plant	This is a wastewater treatment plant designed to treat effluents.
Embodied carbon	The carbon emissions associated with the energy consumed during the construction of a building and manufacturing all its materials throughout their supply chain.
Embodied carbon coefficient	The amount of carbon released (in kg CO2) per unit of manufacturing of a product (in kg) throughout its supply chain.
Embodied carbon-global warming potential coefficient	The amount of greenhouse emissions (in kg CO2 eq) released per unit of manufacturing of a product (in kg) throughout its supply chain.
Embodied energy	The amount of energy consumed during the construction of a building and manufacturing all its materials throughout their supply chain.
Embodied energy coefficient	The amount of energy (in MJ) consumed to manufacture a unit of product (in kg) throughout its supply chain.
Embodied water	The embodied water of a product is the amount of water used to manufacture that product throughout its supply chain. Considering a building as a product, its embodied water is the water needed to manufacture all its materials (IEW) plus the water needed for the actual construction (DEW).
Embodied water coefficient	It is the amount of water (in kL) consumed to manufacture a unit of product (in ton, m2) throughout its supply chain, or execute a unit of an activity (in m2, m3).
Environmental product declarations	These are documents that provide the resources inputs, wastes outputs and environmental impacts of a product throughout its life cycle.

Green belt development	The development and maintenance of a green area to protect the natural environment.
Human consumption	Water that is consumed by humans for various activities like sanitation, cooking and cleaning.
Implied embodied water	The water that is consumed to manufacture the energy that will be used for the construction of the building and to manufacture all the building materials.
Indirect embodied water	The water consumed to manufacture all the materials used in the building throughout their supply chain that includes all the stage starting from the extraction of the raw materials, their transportation to manufacturing plant, the manufacturing of building materials, and finally the transportation of the building materials to the construction site.
Industrial sand	The sand that is used as a raw material for manufacturing of construction materials.
Life cycle analysis	It is a systematic process compiling and evaluating the inputs, outputs and environmental impacts associated with a product throughout its life cycle.
Manufactured sand	The sand that has been manufactured by crushing mined rocks. Depending on the quality of this sand, it can either be used as industrial or construction sand.
Masonry work	The process of laying the masonry walls including preparing the mortar, its application and curing.
Off-site construction	It is a type of construction in which the elements of the building are made off-site and are assembled on-site.
On-site construction	It is a type of construction in which the elements of the building are made on-site.
Ordinary Portland cement	It is general purpose cement composed of only limestone, clay and gypsum.
Plaster work	The process of plastering the masonry walls that includes preparation, application and curing of plaster.
Potable water	Water that is suitable for human consumption and is of drinking water quality standard.
Pre-cast elements	Elements that have been made and cured off-site and are assembled on the construction site.

Ready-Mix Concrete	Concrete that has been made off-site but cured on the construction site.
Recycling	The process of collecting wastewater produced from an activity, treating it to improve its water quality, and then using the treated wastewater for another activity.
Reliability of water source	The ability of the water source to provide sufficient quality and quantity of water.
Residential building	A built structure irrespective of its height and materials of construction, that provides sleeping and cooking services for its residents.
Reuse	The process of collecting wastewater produced from an activity and using it for another activity without any prior treatment.
Reverse Osmosis system	It is a water purification technology that uses semi-permeable membranes to remove impurities from the water.
Saturated surface dry specific gravity	The specific gravity of a material when its pores are saturated with water.
Sewage treatment plants	Treatment plants for treating the sewage that is primarily composed of human waste and household wastewater.
Specific gravity	This is a dimensionless value and presents the ratio between the true density (density of a substance independent of voids) of a substance to the density of a reference substance (usually water).
Sustainable construction	The process of creating buildings that are environmentally responsible and resource efficient throughout their life cycle.
Sustainable water management	Managing the present water needs taking into account the requirements of the future generations.
Terracing	The activities undertaken to prepare the terrace on the building.
Tile fixing	The process of fixing the tiles in the building.
Tipper truck	It is a specialised truck that has the feature to tilt while unloading materials.
Total building water footprint	The total building WF is the water consumed by the building throughout its lifecycle that includes all the stages starting of the extraction of the raw materials, their manufacturing

	into building materials, building construction, building operation and maintenance, building demolition, and any transportation of materials between sites.
Unorganised nature of construction sites	A construction site is a vast area with numerous activities being undertaken at different locations at different instances that makes the monitoring of these activities difficult.
Valid EWC	An EWC is considered valid in this study if it reports the value in Indian context and this value was calculated within the last five years.
Wastewater treatment plants	Treatment plants for treating all types of wastewater like industrial and construction wastewater.
Waterproofing	The process of making the constructed building impervious to water.
Water scarcity	The scenario when the water available in a region is not sufficient to meet the requirements of its population. A country is "water stressed" when its per capita water availability is less than 1,700m3 and "water scarce" when this water is less than 1,000m3.
Wet process	The process of material manufacturing that consumes large quantities of water.
Zero-liquid discharge	It is an advanced wastewater treatment process in which no wastewater is discharged outside the plant/wastewater treatment facility.

Appendix B : Detailed Calculations for Case Study Analysis

Case Study 1

The calculations to break down all the activities from the BOQ of case study 1 to determine the amount of materials (in kg) required to construct the building are shown below.

1) Plain concrete

From BOQ - Volume of concrete		81 m3
From BOQ - Proportion of all concrete ingredients	1 + 4 + 8	13
Volume of material (m3) = Proportion of material * (Volume of concrete ingredients / Proportion of all concrete ingredients)		
Volume of cement	1 * (81 / 13)	6.23 m3
Volume of sand	4 * (81 / 13)	24.92 m3
Volume of stone	8 * (81 / 13)	49.85 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	6.23 * 3.15 * 1000	**19,624.5 kg**
Mass of sand	24.92 *2.65 * 1000	**66,038 kg**
Mass of stone	49.85 * 2.74 * 1000	**136,589 kg**

2) RMC M-25 RC

From BOQ - Volume of concrete		4,111 m3
BIS (2019) states that for 50mm slump and 20mm nominal size aggregate, water content is 186 kg/m3 concrete.		
Thus, mass of water	186 * 4,111	764,646 kg
Volume of water	7,64,646 / (1 * 1000)	764.65 m3
From BIS (2007a), for M25 grade concrete the maximum water cement ratio must be 0.5.		
Mass of cement	7,64,646 / 0.5	1,529,292 kg
BIS (2019) states that for fly ash content in concrete over 20%, the amount of cementitious material must be increase by 10%.		
Thus, mass of cementitious material	1,529,2929 * 1.10	1,682,221.2 kg
Mass of 30% fly ash	0.3 * 1,682,221.2	**504,666.36 kg**
Volume of fly ash	5,04,666.36 / (2.2 * 1000)	229.29 m3
Mass of cement	1,682,221.2 – 5,04,666.36	**1,177,554.84 kg**
Volume of cement	1,177,554.84/ (3.15 * 1000)	373.83 m3
BIS (2007a) states that the minimum cement content for M25 RC should be 300 kg/m3. Thus, 373.83 kg/m3 is greater and hence the value can be considered.		
Volume of all aggregates in concrete	4,111 – (764.65 + 229.29 + 373.83)	2,743.23 m3
From BIS (2019), water: cement ratio of 0.5 and zone 2 fine aggregates, volume of coarse aggregates in total volume of aggregates is 0.62 m3/m3 concrete.		
Thus, volume of fine aggregates	1 – 0.62	0.38
Mass of stone	2,743.23 * 0.62 * 2.74 * 1000	**4,660,199.124 kg**
Mass of sand	2,743.23 * 0.38 * 2.65 * 1000	**2,762,432.61 kg**

3) RMC M-30 RC

From BOQ - Volume of concrete		365.94 m3
BIS (2019) states that for 50mm slump and 20mm nominal size aggregate, water content is 186 kg/m3 concrete.		
Thus, mass of water	186 * 365.94	68,064.84 kg
Volume of water	68,064.84 / (1 * 1000)	68.06 m3
From BIS (2007a), for M30 grade concrete the maximum water cement ratio must be 0.45.		
Mass of cement	68,064.84 / 0.45	151,255.2 kg
BIS (2019) states that for fly ash content in concrete over 20%, the amount of cementitious material must be increase by 10%.		
Thus, mass of cementitious material	1,51,255.2 * 1.10	166,380.72 kg
Mass of 30% fly ash	0.3 * 1,66,389.72	**49,914.2 kg**
Volume of fly ash	49,914.2 / (2.2 * 1000)	22.69 m3
Mass of cement	1,66,380.72 – 49,914.2	**116,466.52 kg**
Volume of cement	1,16,466.52/ (3.15 * 1000)	36.97 m3
BIS (2007a) states that the minimum cement content for M30 RC should be 320 kg/m3. Thus, 454.67 kg/m3 is greater and hence the value can be considered.		
Volume of all aggregates in concrete	365.94 – (68.06 + 22.69 + 36.97)	238.22 m3
From BIS (2019), water: cement ratio of 0.5 and zone 2 fine aggregates, volume of coarse aggregates in total volume of aggregates is 0.62 m3/m3 concrete. It also states that for every 0.05 decrease in water: cement ratio, the volume of coarse aggregates in total aggregates is increased by 0.01. Making adjustments for water: cement ratio 0.45.		
Volume of coarse aggregates	0.62 + 0.01	0.63
Volume of fine aggregates	1 – 0.63	0.37
Mass of stone	238.22 * 0.63 * 2.74 * 1000	**411,215.36 kg**
Mass of sand	238.22 * 0.37 * 2.65 * 1000	**233,574.71 kg**

4) RMC M-35 RC

From BOQ - Volume of concrete		365.94 m3
BIS (2019) states that for 50mm slump and 20mm nominal size aggregate, water content is 186 kg/m3 concrete.		
Thus, mass of water	186 * 365.94	68,064.84 kg
Volume of water	68,064.84 / (1 * 1000)	68.06 m3
From BIS (2007a), for M35 grade concrete the maximum water cement ratio must be 0.45.		
Mass of cement	68,064.84 / 0.45	151,255.2 kg
BIS (2019) states that for fly ash content in concrete over 20%, the amount of cementitious material must be increase by 10%.		
Thus, mass of cementitious material	1,51,255.2 * 1.10	166,380.72 kg
Mass of 30% fly ash	0.3 * 1,66,389.72	**49,914.2 kg**
Volume of fly ash	49,914.2 / (2.2 * 1000)	22.69 m3
Mass of cement	1,66,380.72 – 49,914.2	**116,466.52 kg**
Volume of cement	1,16,466.52/ (3.15 * 1000)	36.97 m3
BIS (2007a) states that the minimum cement content for M35 RC should be 340 kg/m3. Thus, 454.67 kg/m3 is greater and hence the value can be considered.		
Volume of all aggregates in concrete	365.94 – (68.06 + 22.69 + 36.97)	238.22 m3
From BIS (2019), water: cement ratio of 0.5 and zone 2 fine aggregates, volume of coarse aggregates in total volume of aggregates is 0.62 m3/m3 concrete. It also states that for every 0.05 decrease in water: cement ratio, the volume of coarse aggregates in total aggregates is increased by 0.01. Adjusting for water: cement ratio 0.45.		
Volume of coarse aggregates	0.62 + 0.01	0.63
Volume of fine aggregates	1 – 0.63	0.37
Mass of stone	238.22 * 0.63 * 2.74 * 1000	**411,215.36 kg**
Mass of sand	238.22 * 0.37 * 2.65 * 1000	**233,574.71 kg**

5) Steel reinforcement

From BOQ - Steel reinforcement		**610,116.50 kg**

6) Formwork

From BOQ - Area of formwork		30,245.44 m2
BIS (2011) revealed that the minimum thickness of plywood for shuttering should be 19mm		
Thus, thickness of formwork		0.019 m
Volume of formwork	30,245.44 * 0.019	574.66 m3
Mass of plywood formwork (kg) = Volume of formwork (m3) * Density of Plywood (kg/m3)		
From BIS (2011) density of plywood = 650 kg/m3		
Mass of formwork	574.66 * 650	**373,529 kg**

7) Clay brick masonry

From BOQ - Volume of brick masonry		1,991.8 m3
From BOQ - Thickness of brick masonry		0.230 m
Area of brick masonry	1,991.8 / 0.230	8,660 m2
From BIS (2007b) the size of the bricks in L x W x H is assumed as 230mm x 110mm x 70mm. BIS (2005) states the maximum thickness of cement mortar must be 12mm. For calculation, the maximum thickness of cement mortar is assumed as 10mm.		
Size of brick after adding 10mm mortar on the bed and cross joints (L x H)	(0.230 + 0.010) x (0.07 + 0.010)	0.240 m x 0.08 m
Area of 1 brick with mortar	0.240 * 0.08	0.0192 m2
Number of bricks in brick masonry = Total area of brick masonry / Area of 1 brick with mortar		
Number of bricks in brick masonry	8,660 / 0.0192	451,041.67
Area of 1 brick (L * H)	0.230 * 0.070	0.0161 m2
Area of only bricks	0.0161 * 451,041.67	7,261.77 m2
Volume of 1 brick (L * W * H)	0.230 * 0.110 * 0.07	0.001771 m3
Volume of only bricks	0.001771 * 451,041.67	798.79 m3
Mass of bricks (kg) = Volume of bricks (m3) * Dry Density of bricks (kg/m3)		
From BIS (2010), dry density of clay bricks is in the range of 1,600-1,920 kg/m3		
Mass of bricks	798.79 * 1760	**1,405,870.4 kg**
Area of mortar = Area of brick masonry – Area of only bricks		
Area of mortar	8,660 – 7,261.77	1,398.23 m2
Volume of mortar = Volume of brick masonry – Volume of only bricks		
Volume of mortar	1,991.8 – 798.79	**1,193.01 m3**

BIS (2000) states that for making mortar either mortar cement or OPC can be used. For ease of calculation and comparison, OPC will be considered.

Volume of mortar		1,193.01 m3
From BOQ - Proportion of all mortar ingredients	1 + 1 + 6	8
Volume of material (m3) = Proportion of material * (Volume of mortar ingredients / proportion of all mortar ingredients)		
Volume of cement	1 * (1,193.01 / 8)	149.13 m3
Volume of fly ash	1 * (1,193.01 / 8)	149.13 m3
Volume of sand	6 * (1,193.01 / 8)	894.76 m3

Mass of material (kg) = Volume of material (m3) * Specific Gravity of material * 1000 (kg/m3)		
Mass of cement	149.13 * 3.15 * 1000	**469,759.5 kg**
Mass of fly ash	149.13 * 2.2 * 1000	**328,086 kg**
Mass of sand	894.76 * 2.65 * 1000	**2,371,114 kg**

8) Half-clay brick masonry

From BOQ - Area of half-brick masonry		1,649 m2
From BOQ - Thickness of half-brick masonry		0.110 m
Volume of half-brick masonry	1,649 * 0.110	181.39 m3
For half-clay brick wall, the size of the brick in L x W x H is assumed as 230mm x 110mm x 70mm from BIS (2007b), similar to clay brick wall. The only difference between the two walls is in the thickness of the wall. For half-clay brick wall, the thickness of the wall is 110mm.		
Size of half-brick after adding 10mm mortar on the bed and cross joints (L x H)	(0.230 + 0.010) x (0.07 + 0.010)	0.240 m x 0.08 m
Area of 1 half-brick with mortar	0.240 * 0.08	0.0192 m2
Number of half-bricks in brick masonry = Area of brick masonry / Area of 1 half-brick with mortar		
Number of half-bricks	1,649 / 0.0192	85,885.42 bricks
Area of 1 half-brick	0.230 * 0.07	0.0161 m2
Area of only half-bricks	0.0161 * 85,885.42	1,382.76 m2
Volume of 1 half-brick	0.230 * 0.110 * 0.07	0.001771 m3
Volume of only half-bricks	0.001771 * 85,885.42	152.1 m3
Mass of bricks (kg) = Volume of bricks (m3) * Dry Density of bricks (kg/m3)		
From BIS (2010), dry density of clay bricks is in the range of 1,600-1,920 kg/m3		
Mass of bricks	152.1 * 1760	**267,696 kg**
Area of mortar = Area of half-bricks masonry – Area of only half-bricks		
Area of mortar	1,649 – 1,382.76	266.24 m2
Volume of mortar = Volume of half-bricks masonry – Volume of only half-bricks		
Volume of mortar	181.39 – 152.1	**29.29 m3**

Volume of mortar		29.29 m3
From BOQ - Proportion of mortar ingredients	1 + 1 + 6	8
Volume of material (m3) = Proportion of material * (Volume of mortar ingredients / proportion of all mortar ingredients)		
Volume of cement	1 * (29.29 / 8)	3.66 m3
Volume of fly ash	1 * (29.29 / 8)	3.66 m3
Volume of sand	6 * (29.29 / 8)	21.97 m3
Mass of material (kg) = Volume of material (m3) * Specific Gravity of material * 1000 (kg/m3)		
Mass of cement	3.66 * 3.15 * 1000	**11,529 kg**
Mass of fly ash	3.66 * 2.2 * 1000	**8,052 kg**
Mass of sand	21.97 * 2.65 * 1000	**58,220.5 kg**

9) External cement plaster

From BOQ - Area of plaster		7,475 m2
From BOQ - Thickness of plaster		0.006 m
Volume of plaster	7,475 * 0.006	44.85 m3
From BOQ - Proportion of plaster ingredients	1 + 4	5
Volume of material (m3) = Proportion of material * (Volume of plaster ingredients / proportion of all plaster ingredients)		
Volume of cement	1 * (44.85 / 5)	8.97 m3

Volume of sand	4 * (44.85 / 5)	35.88 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	8.97 * 3.15 * 1000	**28,255.5 kg**
Mass of sand	35.88 * 2.65 * 1000	**95,082 kg**

10) External cement plaster

From BOQ - Area of plaster		1,050 m2
From BOQ - Thickness of plaster		0.012 m
Volume of plaster	1,050 * 0.012	12.6 m3
From BOQ - Proportion of plaster ingredients	1 + 5	6
Volume of material (m3) = Proportion of material * (Volume of plaster ingredients / proportion of all plaster ingredients)		
Volume of cement	1 * (12.6 / 6)	2.1 m3
Volume of sand	5 * (12.6 / 6)	10.5 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	2.1 * 3.15 * 1000	**6,615 kg**
Mass of sand	10.5 * 2.65 * 1000	**27,825 kg**

11) External cement plaster

From BOQ - Area of plaster		1,050 m2
From BOQ - Thickness of plaster		0.006 m
Volume of plaster	1,050 * 0.006	6.3 m3
From BOQ - Proportion of plaster ingredients	1 + 12	13
Volume of material (m3) = Proportion of material * (Volume of plaster ingredients / proportion of all plaster ingredients)		
Volume of cement	1 * (6.3 / 13)	0.49 m3
Volume of sand	12 * (6.3 / 13)	5.82 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	0.49 * 3.15 * 1000	**1,543.5 kg**
Mass of sand	5.82 * 2.65 * 1000	**15,410.77 kg**

12) Waterproof external cement plaster

From BOQ - Area of plaster		750 m2
From BOQ - Thickness of plaster		0.015 m
Volume of plaster	750 * 0.015	11.25 m3
From BOQ - Proportion of plaster ingredients	1 + 4	5
Volume of material (m3) = Proportion of material * (Volume of plaster ingredients / proportion of all plaster ingredients)		
Volume of cement	1 * (11.25 / 5)	2.25 m3
Volume of sand	4 * (11.25 / 5)	9 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	2.25 * 3.15 * 1000	**7,087.5 kg**
BIS (2013) states that cement is sold in bags of 50kg. The BOQ specifies the inclusion of 1 kg waterproofing compound per 50kg cement.		
Thus, mass of waterproofing compound	7,087.5 / 50	**141.75 kg**
Mass of sand	9 * 2.65 * 1000	**23,850 kg**

13) Brick bat coba waterproofing

The steps taken for this type of terracing application are:

1) Applying an initial coat of cement slurry with cement content of 2.75 kg/m2 of cement.
2) Laying cement concrete made of broken bricks with 50% broken bricks and 50% cement mortar.
3) Applying a second coat of cement slurry mixed with appropriate waterproofing compound.
4) Finishing the surface with a layer of cement mortar.

Cement slurry:

From BOQ - Area of cement slurry		668 m2
Mass of cement	668 * 2.75	**1,837 kg**
Mass of waterproofing compound	1,837 / 50	**36.74 kg**

*Table shows calculation for 1 coat. 2 coats are applied on site.

Broken bricks cement concrete:

From BOQ - Area of broken bricks cement concrete		668 m2
From BOQ - Thickness of broken bricks cement concrete		0.0625 m
Volume of concrete	668 * 0.0625	41.75 m3
From BOQ - Volume of broken bricks in concrete	0.5 * 41.75	20.875 m3
Volume of mortar in concrete ingredients	0.5 * 41.75	20.875 m3
From BOQ - Proportion of all mortar ingredients	1 + 5	6
Volume of material (m3) = Proportion of material * (Volume of concrete ingredients / Proportion of all concrete ingredients)		
Volume of cement	1 * (20.875 / 6)	3.48 m3
Volume of sand	5 * (20.875 / 6)	17.39 m3
Mass of material (kg) = Volume of material (m3) * Specific Gravity of material * 1000 (kg/m3)		
Mass of cement	3.48 * 3.15 * 1000	**10,867.5 kg**
Mass of sand	17.39 * 2.65 * 1000	**46,098.96 kg**
Mass of broken bricks	20.875 * 1760	**36,740 kg**

Cement mortar:

From BOQ - Area of mortar		668 m2
From BOQ - Thickness of mortar		0.02 m
Volume of mortar	668 * 0.020	13.36 m3
From BOQ - Proportion of mortar ingredients	1 + 4	5
Volume of material (m3) = Proportion of material * (Volume of mortar ingredients / proportion of all mortar ingredients)		
Volume of cement	1 * (13.36 / 5)	2.672 m3
Volume of sand	4 * (13.36 / 5)	10.688 m3
Mass of material (kg) = Volume of material (m3) * Specific Gravity of material * 1000 (kg/m3)		
Mass of cement	2.672 * 3.15 * 1000	**8,416.8 kg**
Mass of sand	10.688 * 2.65 * 1000	**28,323.2 kg**

14) Ceramic tiles

The tiles are applied in two steps:

1) Underlayer of cement mortar with thickness of 10mm.
2) Fixing of tiles and grout with thickness of 15mm using tiles of size 600mm x 600mm.

Cement mortar underlayer:

From BOQ - Area of mortar		8,260 m2
BIS (2001) specifies thickness of mortar to be at least 10mm.		
Thickness of mortar		0.01 m
Volume of mortar	8,260 * 0.01	82.6 m3
From BOQ - Proportion of mortar ingredients	1 + 4	5
Volume of material (m3) = Proportion of material * (Volume of mortar ingredients / proportion of all mortar ingredients)		
Volume of cement	1 * (82.6 / 5)	16.52 m3
Volume of sand	4 * (82.6 / 5)	66.08 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	16.52 * 3.15 * 1000	**52,038 kg**
Mass of sand	66.08 * 2.65 * 1000	**175,112 kg**

Mass of tiles and grout:

From BOQ - Area of tiles		8,260 m2
BIS (2001) specifies thickness of grouting on each side of tile to be 1.5mm.		
Thus, Area of 1 tile after adding 0.0015 m grouting along its sides	(0.6 + 0.0015) x (0.6 + 0.0015)	0.6015 m x 0.6015 m
Area of 1 tile with grouting	0.6015 * 0.6015	0.3618 m2
Number of tiles	8,260 / 0.3618	22,830.293
From BOQ - Area of 1 tile	0.6 * 0.6	0.36 m2
Area of only tiles	0.36 * 22,830.293	8,218.91 m2
Thickness of tile		0.015 m
Volume of 1 tile	0.6 * 0.6 * 0.015	0.0054 m3
Volume of only tiles	0.0054 * 22,830.293	123.28 m3
Mass of tiles (kg) = Volume of tiles (m3) * Density of tiles (kg/m3)		
From an EPD of ceramic tiles, density = 2000 kg/m3		
Mass of tiles	123.28 * 2000	**246,560 kg**
From BOQ - thickness of floor		0.015 m
Volume of floor	8,260 * 0.015	123.9 m3
Volume of grout	123.9 – 123.28	0.62 m3

Grout:

Volume of grout		0.62 m3
Mass of cement	0.62 * 3.15 * 1000	**1,953 kg**

Case Study 2

The calculations to break down all the activities from the BOQ of case study 2 to determine the amount of materials (in kg) required to construct the building are shown below.

1) Plain concrete

From BOQ - Volume of concrete		307.41 m3
From BOQ - Proportion of all concrete ingredients	1 + 3 + 6	10
Volume of material (m3) = Proportion of material * (Volume of concrete ingredients / Proportion of all concrete ingredients)		
Volume of cement	1 * (307.41 / 10)	30.741 m3
Volume of sand	3 * (307.41 / 10)	92.223 m3
Volume of stone	6 * (307.41 / 10)	184.446 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	30.741 * 3.15 * 1000	**96,834.15 kg**
Mass of sand	92.223 *2.65 * 1000	**244,390.95 kg**
Mass of stone	184.446 * 2.74 * 1000	**505,382.04 kg**

2) RMC M-25 RC

From BOQ - Volume of concrete		1,678 m3
BIS (2019) states that for 50mm slump and 20mm nominal size aggregate, water content is 186 kg/m3 concrete.		
Thus, Mass of water	186 * 1678	312,108 kg
Volume of water	312,108 / (1 * 1000)	312.108 m3
From BIS (2007a), for M25 grade concrete the maximum water cement ratio must be 0.5.		
Mass of cement	312,108 / 0.5	**624,216 kg**
	624,216 / 1678	*372 kg/m3*
Volume of cement	624,216 / (3.15 * 1000)	198.16 m3
BIS (2007a) states that the minimum cement content for M25 RC should be 300 kg/m3. Thus, 372 kg/m3 is greater and hence the value can be considered.		
Volume of all aggregates in concrete	1,678 – (312.108 + 198.16)	1,167.732 m3
From BIS (2019), water: cement ratio of 0.5 and zone 2 fine aggregates, volume of coarse aggregates in total volume of aggregates is 0.62 m3/m3 concrete.		
Thus, volume of fine aggregates	1 – 0.62	0.38
Mass of stone	1,167.732 * 0.62 * 2.74 * 1000	**1,983,743.12 kg**
Mass of sand	1,167.732 * 0.38 * 2.65 * 1000	**1,175,906.12 kg**

3) In-situ M-25 RC

From BOQ - Volume of concrete		415.33 m3
BIS (2019) states that for 50mm slump and 20mm nominal size aggregate, water content is 186 kg/m3 concrete.		
Thus, Mass of water	186 * 415.33	77,251.38 kg
Volume of water	77,251.38 / (1 * 1000)	77.251 m3
From BIS (2007a), for M25 grade concrete the maximum water cement ratio must be 0.5.		
Mass of cement	77,251.38 / 0.5	**154,502.76 kg**
	154,502.76 / 415.33	*372 kg/m3*
Volume of cement	154,502.76 / (3.15 * 1000)	49.05 m3

BIS (2007a) states that the minimum cement content for M25 RC should be 300 kg/m3. Thus, 372 kg/m3 is greater and hence the value can be considered.		
Volume of all aggregates in concrete	415.33 – (77.251+ 49.05)	289.029 m3
From BIS (2019), water: cement ratio of 0.5 and zone 2 fine aggregates, volume of coarse aggregates in total volume of aggregates is 0.62 m3/m3 concrete.		
Thus, volume of fine aggregates	1 – 0.62	0.38
Mass of stone	289.029 * 0.62 * 2.74 * 1000	**491,002.465 kg**
Mass of sand	289.029 * 0.38 * 2.65 * 1000	**291,052.203 kg**

4) Steel reinforcement

From BOQ – Amount of steel		**285,779.71 kg**

5) Plywood formwork

From BOQ – Area of formwork		11,331.19 m2
BIS (2011) states the minimum thickness of plywood for shuttering should be 19mm		
Thus, thickness of formwork		0.019 m
Volume of formwork	0.019 * 11,331.19	215.29 m3
Mass of plywood (kg) = Volume of formwork (m3) * Density of plywood (kg/m3)		
From BIS (2011) density of plywood = 650 kg/m3		
Mass of plywood	215.29 * 650	**139,938.962 kg**

6) Clay brick masonry

From BOQ - Volume of brick masonry		391.25 m3
From BOQ - Thickness of brick masonry		0.2286 m
Area of brick masonry	391.25 / 0.2286	1,711.50 m2
From BIS (2007b) the size of the bricks in L x W x H is assumed as 230mm x 110mm x 70mm. BIS (2005) states the maximum thickness of cement mortar must be 12mm. For calculation, the maximum thickness of cement mortar is assumed as 10mm.		
Size of brick after adding 10mm mortar on the bed and cross joints (L x H)	(0.230 + 0.010) x (0.07 + 0.010)	0.240 m x 0.08 m
Area of 1 brick with mortar	0.240 * 0.08	0.0192 m2
Number of bricks in brick masonry = Total area of brick masonry / Area of 1 brick with mortar		
Number of bricks in brick masonry	1,711.50 / 0.0192	89,140.625
Area of 1 brick (L * H)	0.230 * 0.070	0.0161 m2
Area of only bricks	0.0161 * 89,140.625	1,435.16 m2
Volume of 1 brick (L * W * H)	0.230 * 0.110 * 0.07	0.001771 m3
Volume of only bricks	0.001771 * 89,140.625	157.87 m3
Mass of bricks (kg) = Volume of bricks (m3) * Dry Density of bricks (kg/m3)		
From BIS (2010), Dry Density of bricks is in the range of 1,600-1,920 kg/m3.		
Mass of bricks	157.87 * 1,760	**277,851.2 kg**
Area of mortar = Area of brick masonry – Area of only bricks		
Area of mortar	1,711.50 – 1,435.16	276.34 m2
Volume of mortar = Volume of brick masonry – Volume of only bricks		
Volume of mortar	391.25 – 157.87	**233.38 m3**

Mortar for masonry:

Volume of mortar		233.38 m3
From BOQ - Proportion of all mortar ingredients	1 + 6	7

Volume of material (m3) = Proportion of material * (Volume of mortar ingredients / proportion of all mortar ingredients)		
Volume of cement	1 * (233.38 / 7)	33.34 m3
Volume of sand	6 * (233.38 / 7)	200.04 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
BIS (2000) states that for making mortar either mortar cement or Ordinary Portland Cement can be used. For ease of calculation and comparison, OPC will be considered.		
Mass of cement	33.34 * 3.15 * 1000	**105,021 kg**
Mass of sand	200.04 * 2.65 * 1000	**530,106 kg**

7) Half-clay brick masonry

From BOQ - Area of half-brick masonry		2,593.53 m2
From BOQ - Thickness of half-brick masonry		0.110 m
Volume of half-brick masonry	2,593.53 * 0.110	285.29 m3
For half-clay brick wall, the size of the brick in L x W x H is assumed as 230mm x 110mm x 70mm from BIS (2007b), similar to clay brick wall. The only difference between the two walls is in the thickness of the wall. For half-clay brick wall, the thickness of the wall is 110mm.		
Size of half-brick after adding 10mm mortar on the bed and cross joints (L x H)	(0.230 + 0.010) x (0.07 + 0.010)	0.240 m x 0.08 m
Area of 1 half-brick with mortar	0.240 * 0.08	0.0192 m2
For 1 m2 of wall (L x H = 1 m x 1 m):		
Area of concrete band	0.05 x 1	0.05 m2
Area of half-bricks and mortar = Area of wall – Area of concrete band		
Area of half-bricks and mortar	1 – 0.05	0.95 m2
Volume of concrete band	0.05 * 0.110	0.0055 m3
For 2,593.53 m2 of wall:		
Area of concrete band	0.05 * 2,593.53	129.68 m2
Volume of concrete band	0.0055 * 2,593.53	**14.26 m3**
Area of half-bricks and mortar	0.95 * 2,593.53	2,463.85 m2
Volume of half-bricks and mortar = Volume of wall – Volume of concrete band		
Volume of half-bricks and mortar	285.29 – 14.26	271.03 m3
Number of half-bricks in brick masonry = Area of half-bricks and mortar / Area of 1 half-brick with mortar		
Number of half-bricks	2,463.85 / 0.0192	1,28,325.521 bricks
Area of only half-bricks = Area of 1 half-brick * Number of half-bricks		
Area of 1 half-brick	0.230 * 0.07	0.0161 m2
Area of only half-bricks	0.0161 * 1,28,325.521	2,066.04 m2
Volume of 1 half-brick	0.230 * 0.110 * 0.07	0.001771 m3
Volume of only half-bricks	0.001771 * 1,28,325.521	**227.26 m3**
Mass of bricks (kg) = Volume of bricks (m3) * Dry density of Bricks		
From BIS (2010), dry density of bricks is in the range of 1,600-1,920 kg/m3.		
Mass of bricks	227.26 * 1,760	**399,977.6 kg**
Area of mortar = Area of half-bricks and mortar – Area of only half-bricks		
Area of mortar	2,463.85 – 2,066.04	397.81 m2
Volume of mortar = Volume of half-bricks and mortar – Volume of only half-bricks		
Volume of mortar	271.03 – 227.26	**43.77 m3**

Mortar for masonry:

Volume of mortar		43.77 m3
From BOQ - Proportion of mortar ingredients	1 + 4	5
Volume of material (m3) = Proportion of material * (Volume of mortar ingredients / proportion of all mortar ingredients)		
Volume of cement	1 * (43.77 / 5)	8.754 m3
Volume of sand	4 * (43.77 / 5)	35.016 m3

Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	8.754 * 3.15 * 1000	**27,575.1 kg**
Mass of sand	35.016 * 2.65 * 1000	**92,792.4 kg**

Concrete band:

Volume of concrete band		14.26 m3
From BOQ - Proportion of all concrete ingredients	1 + 4	5
Volume of material (m3) = Proportion of material * (Volume of concrete ingredients / proportion of all concrete ingredients)		
Volume of cement	1 * (14.26 / 5)	2.852 m3
Volume of sand	4 * (14.26 / 5)	11.408 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	2.852 * 3.15 * 1000	**8,983.8 kg**
Mass of sand	11.408 * 2.65 * 1000	**30,231.2 kg**

8) External plaster

From BOQ - Area of plaster		7,685.22 m2
From BOQ - Thickness of plaster		0.015 m
Volume of plaster	7,685.22 * 0.015	115.28 m3
From BOQ - Proportion of plaster ingredients	1 + 6	7
Volume of material (m3) = Proportion of material * (Volume of plaster ingredients / proportion of all plaster ingredients)		
Volume of cement	1 * (115.28 / 7)	16.47 m3
Volume of sand	6 * (115.28 / 7)	98.81 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	16.47 * 3.15 * 1000	**51,880.5 kg**
Mass of sand	98.81 * 2.65 * 1000	**261,846.5 kg**

9) Brick bat coba waterproofing

The steps taken for this type of terracing application are:

1) Applying an initial coat of cement slurry with cement content of 2.75 kg/m2 of cement with appropriate waterproofing compound.
2) 20-25mm layer of cement mortar
3) Laying cement concrete made of broken bricks with 50% broken bricks and 50% cement mortar.
4) Applying a second coat of cement slurry mixed with appropriate waterproofing compound.
5) Finishing the surface with a layer of cement mortar.

Cement slurry:

From BOQ - Area of cement slurry		739.61 m2
Mass of cement	739.61 * 2.75	**2,033.93 kg**
From interviews it was concluded that for every 50kg cement, 1kg waterproofing compound will be used		
Mass of waterproofing compound	2,033.93 / 50	**40.68 kg**

*Table shows calculation for 1 coat. 2 coats are applied on site.

Cement mortar:

From BOQ - Area of mortar		739.61 m2
From BOQ - Thickness of mortar		0.0225 m

Volume of mortar	739.61 * 0.0225	16.64 m3
From BOQ - Proportion of mortar ingredients	1 + 4	5
Volume of material (m3) = Proportion of material * (Volume of mortar ingredients / proportion of all mortar ingredients)		
Volume of cement	1 * (16.64 / 5)	3.328 m3
Volume of sand	4 * (16.64 / 5)	13.312 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	3.328 * 3.15 * 1000	**10,483.2 kg**
Mass of sand	13.312 * 2.65 * 1000	**35,276.8 kg**
Mass of waterproofing compound	10,483.2 / 50	**209.66 kg**

Broken bricks cement concrete:

From BOQ - Area of broken bricks cement concrete		739.61 m2
From BOQ - Thickness of broken bricks cement concrete		0.0875 m
Volume of concrete	0.0875 *739.61	64.72 m3
From BOQ - Volume of broken bricks in concrete	0.5 * 64.72	32.36 m3
Volume of mortar in concrete ingredients	0.5 * 64.72	32.36 m3
From BOQ - Proportion of all mortar ingredients	1 + 4	5
Volume of material (m3) = Proportion of material * (Volume of concrete ingredients / Proportion of all concrete ingredients)		
Volume of cement	1 * (32.36 / 5)	6.472 m3
Volume of sand	4 * (32.36 / 5)	25.888 m3
Mass of broken bricks (kg) = Volume of bricks (m3) * Dry Density of bricks (kg/m3)		
From BIS (2010), Dry Density of bricks is in the range of 1,600-1,920 kg/m3.		
Mass of bricks	32.36 * 1760	**56,953.6 kg**
Mass of material (kg) = Volume of material (m3) * Specific Gravity of material * 1000 (kg/m3)		
Mass of cement	6.472 * 3.15 * 1000	**20,386.8 kg**
Mass of sand	25.888 * 2.65 * 1000	**6,860.32 kg**

Cement mortar:

From BOQ - Area of mortar		739.61 m2
From BOQ - Thickness of mortar		0.02 m
Volume of mortar	739.61 * 0.020	14.79 m3
From BOQ - Proportion of mortar ingredients	1 + 4	5
Volume of material (m3) = Proportion of material * (Volume of mortar ingredients / proportion of all mortar ingredients)		
Volume of cement	1 * (14.79 / 5)	2.958 m3
Volume of sand	4 * (14.79 / 5)	11.832 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	2.958 * 3.15 * 1000	**9,317.7 kg**
Mass of sand	11.832 * 2.65 * 1000	**31,354.8 kg**
Mass of waterproofing compound	9,317.7 / 50	**186.35 kg**

10) Tiles

The BOQ specifies the application of ceramic tiles for flooring purposes. The tiles are applied in two steps:

1) Underlayer of cement mortar with thickness of 10mm.
2) Fixing of tiles and grout with thickness of 15mm using tiles of size 600mm x 600mm.

Cement mortar underlayer:

From BOQ - Area of mortar		4,241 m2
BIS (2001) specifies thickness of mortar to be at least 10mm.		
Thickness of mortar		0.01 m
Volume of mortar	4,241 * 0.01	42.41 m3
From BOQ - Proportion of mortar ingredients	1 + 4	5
Volume of material (m3) = Proportion of material * (Volume of mortar ingredients / proportion of all mortar ingredients)		
Volume of cement	1 * (42.41 / 5)	8.482 m3
Volume of sand	4 * (42.41 / 5)	33.928 m3
Mass of material (kg) = Volume of material (m3) * Specific gravity of material * 1000 (kg/m3)		
Mass of cement	8.482 * 3.15 * 1000	**26,718.3 kg**
Mass of sand	33.928 * 2.65 * 1000	**89,909.2 kg**

Mass of tiles and grout:

From BOQ - Area of tiles		4,241 m2
BIS (2001) specifies thickness of grouting on each side of tile to be 1.5mm.		
Thus, Area of 1 tile after adding 0.0015 m grouting along its sides	(0.6 + 0.0015) x (0.6 + 0.0015)	0.6015 m x 0.6015 m
Area of 1 tile with grouting	0.6015 * 0.6015	0.3618 m2
Number of tiles	4,241 / 0.3618	11,721.95
From BOQ - Area of 1 tile	0.6 * 0.6	0.36 m2
Area of only tiles	0.36 * 11,721.95	4,219.902 m2
Thickness of tile		0.015 m
Volume of 1 tile	0.6 * 0.6 * 0.015	0.0054 m3
Volume of only tiles	0.0054 * 11,721.95	63.3 m3
Mass of tiles (kg) = Volume of tiles (m3) * Density of tiles (kg/m3)		
From an EPD of ceramic tiles, Density = 2000 kg/m3		
Mass of tiles	63.3 * 2000	**126,600 kg**
From BOQ - thickness of floor		0.015 m
Volume of floor	4,241 * 0.015	63.615 m3
Volume of grout	63.615 – 63.3	0.315 m3

Grout:

Volume of grout		0.315 m3
Mass of cement	0.315 * 3.15 * 1000	**992.25 kg**

Appendix C : Anonymity Letter for Questionnaires

Dear Sir/Madam,

I am Vishakha Chawla, a PhD research student at Aberdeen's Robert Gordon University, the School of Architecture and Built Environment. My PhD research is titled "Efficient Water Management in Building: An Approach to Achieving Building Sustainability in India".

The primary goal of my research is to develop a framework of sustainable water management practices for construction sites and construction materials in India. To do so, my research aims at determining the direct and indirect embodied water of construction in India by identifying the water metering methodology, water consumption patterns and suggesting possibilities for their sustainable management.

Given the above, I would appreciate if you can support this research by providing me with some information related to water metering/measuring in your construction projects in India. This questionnaire aims at determining whether you meter/measure the water consumption on your construction sites and if you do so what methodology you adopt. This questionnaire consists of 10 questions and will not take longer than 10 minutes to complete.

Following the Robert Gordon University data protection and management regulations, all data collected from you will be kept confidential and will solely be used for academic purposes. All information collected will be anonymised and no reference will be made to a specific individual within the PhD research.

If you have any queries, either prior to commencing the questionnaire or during its completion, please do not hesitate to contact myself (v.chawla1@rgu.ac.uk) or my Principal Supervisor Dr Naeimeh Jafarifar (n.jafarifar@rgu.ac.uk).

Please find below the link to the questionnaire.
https://forms.gle/a6ehGp8KK2bvHGmQ9

Thank you for taking the time to participate.
Yours sincerely
Vishakha Chawla Dr Naeimeh Jafarifar

Appendix D: Confidentiality Letter for Semi-Structured Interviews

To: **Date:**

Dear Sir/Madam,

Request to support with data collection for the PhD research titled 'Efficient Water Management in Building: An Approach to Achieving Building Sustainability in India'.

I am Vishakha Chawla, a PhD research student at the Scott Sutherland School of Architecture and Built Environment, the Robert Gordon University of Aberdeen. The primary goal of my research is to develop a framework of efficient water management practices that can be applied on construction sites and material manufacturing industries in India to achieve sustainability. To do so, my research aims at determining the direct and indirect embodied water of construction in India by identifying the water consumption patterns and suggesting possibilities for their sustainable management.

Given the above, **I appreciate if you can support this research by providing me with information related to water consumptions and water management practices followed on your construction sites/ in your material manufacturing plant.** The collected data as explained above will provide insight to all the water consuming activities during the construction of a building.

Following the Robert Gordon University data protection and management regulations, all collected data from you will be kept confidential. I will also commit myself to the following:

1) I will not disclose the names or other identifying information about the study sites and participants, within the PhD research thesis.
2) I will solely use the collected data for academic purposes within my PhD.
3) I will not share the collected information with any third party.

If you have any question or concern, please do not hesitate to contact me or my supervisor using the below contacts:

Dr Naeimeh Jafarifar – Supervisor (n.jafarifar@rgu.ac.uk)

Vishakha Chawla – PhD researcher (v.chawla1@rgu.ac.uk)

Yours sincerely

Vishakha Chawla

Appendix E: Summary of Semi-Structured Interview Transcripts

Construction Interviewee 1

1. Designation and years of experience

   I have my own construction consultancy firm and am the general manager. I have over 25 years of work experience.

2. Which all sites have you worked in India?

   I have worked in almost all parts of India from Delhi and NCR, Mumbai, Dehradun. In the South, I have worked in Bangalore and Chennai.

3. If in multiple locations around India, have you noticed any difference in water consumption pattern on construction sites for different activities? What could be the reason for these differences? (different climatic conditions, different soil type, government regulations, etc.)

   No, the location of a construction site does not impact the water consumption. Instead, the choice of materials used impacts the water consumption. For example, if we use AAC bricks, we use less water for the masonry activities since these brick do not need mortar to join them. However, if we use clay bricks, we use large amount of water. Another factor that impacts water consumption is the method of construction adopted. You could either have a fully off-site construction where the elements are simply positioned in site. Or you could have a partial off-site construction and the remaining is cast in-situ. Another factor that impacts water consumption is the type of sand that impacts water needed for dust suppression.

4. What are the major water consuming activities on the construction site?

   Most water is used to make and cure concrete. In traditional construction, all the concrete was made on-site. But now all the concrete is made off—site. It is simple poured and cured on construction sites for 5-7 days. Moreover, the water used for curing changes with season. During rainy months, due to the high moisture in the air, less water is consumed. Water is also used to control the dust generated on the site and cleaning.

5. What source of water do you use and why?

   The water used depends on its application. Usually treated wastewater from a STP is used. Most water is used for concreting activities and these activities require strict quality of water as listed in IS 456. All the water entering the site is tested for its quality. If the water does not meet the standard, new water is outsourced. The quality of the water used is very important. If the right quality water is not used, it can be very detrimental. So we need to continue searching for a water source till we don't get water of the desired quality. Besides this, groundwater is also used in areas where its extraction is permitted to get pure water. Moreover, large projects might have an on-site wastewater treatment plant. If the incoming water does not meet the desired quality, it can be further treated. Moreover, these plants can also treat the wastewater collected on site for using in different activities.

6. How do you measure the water consumed on your construction sites?

   IS 456 can be used to calculate the amount of water required for concreting activities. Besides this water is not measured on the construction sites since it is difficult to identify all the activities and manage them.

7. What are the government regulations for water management on construction sites?

   The government mandates the use of STP water for construction activities. Moreover, in some regions groundwater extraction is banned. Many times however, these regulations are not implemented due to different challenges. But even though you are not getting 100% compliance with these policies, even with the little compliance that is received, water is still conserved. So the end goal of saving water is still accomplished.

8. What are the company policies for water management on construction sites?

   There are no policies in my company for water management. I apply all the government regulations on my projects.

9. What measures do you take on reduce water consumption on your sites?

Making concrete consumes large amount of water and also requires water of stringent quality. As a result, construction sites these days make the concrete off-site. The freshly prepared concrete is poured on site and cured. Additionally, using pre-cast elements that have already been cured can be used either for the full construction or partially. These elements only need to be placed on the construction site. These methods only reduce the amount of water consumed on the construction site but have no impact on the total EW. The use of hollow pre-cast elements will help reduce the total EW. Besides this curing agents are used to reduce water required for curing. Large projects also use AAC bricks instead of clay bricks. The use of AAC bricks increases the construction speed as these walls do not need to be cured. Moreover, they are not plastered with cement. They are simply coated and finished with a layer of plaster of paris. Since AAC bricks are lighter than clay bricks, the overall structure is lighter and requires less materials to make the foundation.

10. How do you manage wastewater?

    Generally on building construction sites, large amount of water is used for curing purposes that evaporates and is lost to the environment. Containment of this evaporated water is difficult. Thus, reuse of water doesn't happen that much. On large sites, if there is a wastewater treatment plant, wastewater from human consumption can be collected, treated and recycled for different activities.

11. Do you have any recommendations to improve water management on construction sites?

    Since the government mandates the use of STP water, if this water can be provided at a subsidised rate, it will motivate companies to use this water more.

Construction Interviewee 2

1. Designation and years of experience

    I am a freelance consultant and I have been working with different companies and departments throughout my career. I have been working in this field for the last 30 years.

2. Which all sites have you worked in India?

   I have worked in different parts of India like Delhi and NCR region. I have worked on few projects in Rajasthan. I also have had projects in Chennai.

3. If in multiple locations around India, have you noticed any difference in water consumption pattern on construction sites for different activities? What could be the reason for these differences? (different climatic conditions, different soil type, government regulations, etc.)

   Yes, there is a difference. I would say the major difference is due to the mindset and culture of the people. In the north of India we have a lot of rivers flowing. There is a lot of water because of these rivers that its surrounding areas get flooded. In the south of India, there are not many rivers and people of these regions have always witnessed water scarcity and have been fighting for water. As a result, they value the water and do not waste it.

4. What are the major water consuming activities on the construction site?

   Water is used mainly for curing the concrete. The site staff also consume large amount of water for their different purposes like sanitation and in the staff rooms. Besides small activities like dust suppression and cleaning of vehicles and equipment's also consume water.

5. What source of water do you use and why?

   The Indian government has strict regulations regarding using only water from a STP for construction activities. Besides this groundwater is also another common water source. In some regions, groundwater maybe used even if its extraction is banned since it might be the only available source. During rainy seasons, rain water can be harvested for consumption since it is of very good quality. But rainwater is not the main source of water that is used since rainfall is not constant throughout the year.

6. How do you measure the water consumed on your construction sites?

   I install a water meter at the point of water withdrawal to record the water consumption. On few of my sites I have recorded the daily water consumption along with the activities we undertook that day to manage the water consumption. I believe that what is not measured is not conserved, and if we want to save water, we need to measure our consumption. It is challenging to measure the water consumed for each activity because they are all scattered on the construction site and are undertaken at different times. That is why I install a water meter at the point of water withdrawal.

7. What are the government regulations for water management on construction sites?

   There is very little attention placed by the government on water management. Two common regulations are the ban on the extraction of groundwater and using treated wastewater from a STP. In some regions, groundwater is extracted despite its ban. This shows that though there are regulations, its enforcement is not seen through.

8. What are the company policies for water management on construction sites?

   I have strict policies for water management and take many measures to save it. Whichever company I consultant, I make sure to educated them and motivate them to take extra measures to manage water. The companies that make these policies end up saving water and other resources.

9. What measures do you take on reduce water consumption on your sites?

   Concrete casting consumes a lot of water, and hence construction sites these days cast their concrete off-site. Besides this curing agents are also commonly being used. With the huge demand to manage dust, dust suppression consumes a lot of water. In some sites, fogging machines are used for dust suppression instead of water. On my construction sites I create a cleaning platform where all cleaning activities are undertaken. This helps to reduce free flowing water and increases the chances of recycling the water. However, setting up this platform requires cost and space, which often limits some companies I suggest this to from implementing it. Construction sites don’t have a paved surface. As a result, the passing of vehicles on the site generates dust which needs to be further suppressed using water. By limiting the speed of these passing vehicles, the dust generated can be reduced and water requirement eliminated.

10. How do you manage wastewater?

    It is not easy to collect wastewater on a construction site because of its nature. But with proper planning this is not difficult. For example, the cleaning platform that I create can be used to collect all the wastewater from these cleaning activities into a sedimentation tank. Since the wastewater does not contain any harmful chemicals, simple sedimentation is sufficient to produce water that can be recycled for ancillary activities. The water that is produced from sedimentation can be used again for cleaning. Moreover, I observed that the sediments collected at the bottom of the tank include aggregates. On one site, I even ended up collecting 1m3 of aggregates a day. These collected aggregates can be used to make concrete, mortar or plaster. This sedimentation tank not only saves water but also saves resources. Moreover, since projects usually go on for a long time, the cost of setting up this platform can be easily recovered from the water and resources that are saved.

11. Do you have any recommendations to improve water management on construction sites?

    Water management decisions must be made during the planning stages and its management must be given equal attention as any other factor.

Construction Interviewee 3

1. Designation and years of experience

   I am a Project Manager and work as a freelancer for construction projects. I have around 25 years of experience.

2. Which all sites have you worked in India?

   I have majorly worked in Northern region of India. I have worked on many projects in Punjab, Gujarat and Delhi.

3. If in multiple locations around India, have you noticed any difference in water consumption pattern on construction sites for different activities? What could be the reason for these differences? (different climatic conditions, different soil type, government regulations, etc.)

Nobody values water in North India. Water is not considered in making any decisions. This is one reason why we are suffering from water scarcity. When I first started my career as a civil engineer, we had to only dig the ground around 20 feet groundwater. Now we need to dig atleast 200-300 feet for this groundwater. That is how low the groundwater table has dropped.

4. What are the major water consuming activities on the construction site?

   Water is needed to make the concrete and cure it. It is also used to make plaster and mortar. The curing of plaster also consumes significant water. In recent years, a lot of focus is also placed on the air quality and construction sites are required to control dust generation. Hence, a lot of water is also used for dust suppression. Besides this cleaning of the site and the equipment's used to make concrete, mortar and plaster, also consume water.

5. What source of water do you use and why?

   The quality of water used is extremely important. IS 456 specifies the water quality requirements for concreting activities. Any water source that provides this quality water is used. Water is purchased from STP. It is also extracted from the ground in regions where this extraction is permitted. This extracted raw water might be suitable for human consumption and other ancillary activities. But its quality must be checked before using for concreting work. Rainwater is mostly used on large sites and in areas where rainfall is constant. However, if a region has plenty rainfall, it will not suffer from groundwater depletion and extracting this groundwater is easier and cheaper than harvesting the rainwater.

6. How do you measure the water consumed on your construction sites?

   I do not measure the water consumed on my construction sites for different activities. It is very difficult to do this in practice.

7. What are the government regulations for water management on construction sites?

   The government has banned the use of groundwater is Delhi and NCR. However, on some projects groundwater is still used since it is easily available in that area.

Besides this, the government also mandates the use of only STP water for construction activities.

8. What are the company policies for water management on construction sites?

   The companies I have worked with do not have any specific policies for water management.

9. What measures do you take on reduce water consumption on your sites?

   On large projects pre-cast elements are used. This also increases the speed of the construction. All construction sites these days used ready mix concrete that is cast off-site but only needs to be cured on the site. These off-site elements are cast in a controlled environment that makes the process more efficient while also reducing water wastage. Additionally, curing agents are used to reduce water for curing. Large projects also use AAC bricks instead of clay bricks. The advantage of these bricks is that they do not need to be plastered and cured. A simple layer of plaster of paris is applied to finish the walls. This is specifically useful for tall buildings since curing of walls is challenging at tall heights.

10. How do you manage wastewater?

    Different activities are undertaken at different times on a construction site which makes it very difficult to manage these activities and collect wastewater. As a result, majority of the wastewater produced cannot be collected. The only wastewater that can be collected, treated and recycled is the wastewater generated from human consumption. However, wastewater treatment plants are only available on some large projects which further limits the recycling.

11. Do you have any recommendations to improve water management on construction sites?

    The creation of a small preliminary wastewater treatment plant on all construction sites can help recycle water for ancillary activities. Furthermore, if the government support companies to this by providing tax incentives, it will motivate more construction sites to adopt this practice.

Construction Interviewee 4

1. Designation and years of experience

   I am a civil engineer by profession and work with a big construction firm in Mumbai. I have been in this company for the last 7 years but have been a civil engineer since 20 years.

2. Which all sites have you worked in India?

   Most of my sites are located in Mumbai and its surrounding areas.

3. If in multiple locations around India, have you noticed any difference in water consumption pattern on construction sites for different activities? What could be the reason for these differences? (different climatic conditions, different soil type, government regulations, etc.)

   I have not noticed any difference in water consumption on my sites. Earlier I would not consider water consumption for different activities, but ever since water scarcity and water management have been on the news lately, I have started to consider this and motivate my site staff as well.

4. What are the major water consuming activities on the construction site?

   Concreting work consumes a lot of water. These activities include making concrete, mortar and plaster, and curing them. Depending on the workmanship of the site, water is also wasted during these concreting activities. Water is also used to clean the different equipment's and vehicles on site. Dust suppression also consumes water.

5. What source of water do you use and why?

   Since construction sites use water on a daily basis, the source of water that is selected is based on its reliability and availability. Water from a STP is most reliable and is used on all sites. Along with that, groundwater is also used when it is available and its extraction is permitted.

6. How do you measure the water consumed on your construction sites?

   At the moment I do not measure the water consumption, but I would like to start doing this. But since there are large number of consumption points, I believe measuring the consumption at each point will be very challenging.

7. What are the government regulations for water management on construction sites?

   The government has banned the extraction of groundwater in some regions of India. It also mandates using STP water. I have observed that in some sites, the access and cost challenges for purchasing STP water limits its adoption. In such cases, the construction site staff relies on other sources of water like groundwater.

8. What are the company policies for water management on construction sites?

   There are no specific water management regulations in my company.

9. What measures do you take on reduce water consumption on your sites?

   Curing agents are used to reduce the water required for curing. Chemicals are also used in large projects to join the tiles rather than cement mortar. Additionally, fogging machines can be used for dust suppression. However, the use of fogging machines requires energy and adds to the EC emissions of the building. Reducing one element increases another element and being able to maintain a balance between the two is extremely essential. Since the site staff are responsible for water consumption and management, increasing awareness among them can help save water. This can be done by organising workshops regarding these.

10. How do you manage wastewater?

    The nature of the construction sites makes it difficult to collect wastewater. If containment zones can be created and preliminary wastewater treatment plants are constructed on a site, large volumes of water can be recycled for ancillary activities. I know this will be very helpful in managing water and reducing freshwater consumption, but its application is very challenging.

11. Do you have any recommendations to improve water management on construction sites?

    I would like to create containment zones to collect wastewater and increase the reuse and recycling of wastewater.

Construction Interviewee 5

1. Designation and years of experience

   My background is in civil engineering and I work as a civil engineer in a construction company in Delhi. I have 20 years of experience.

2. Which all sites have you worked in India?

   I have mostly worked in Delhi and NCR. But I have also been posted on different projects in different locations of India like Dehradun, Uttar Pradesh and Hyderabad.

3. If in multiple locations around India, have you noticed any difference in water consumption pattern on construction sites for different activities? What could be the reason for these differences? (different climatic conditions, different soil type, government regulations, etc.)

   I have noticed that the water needed for dust suppression changes among different sites. For example, Hyderabad has coarse sand as compared to Delhi, and more water is consumed in Delhi for dust suppression.

4. What are the major water consuming activities on the construction site?

   Large amount of water is used to make concrete. This also results in large water wastage. To avoid this, most of the concrete used on construction sites is Ready-Mix Concrete that has been cast off-site and is only cured on the construction site. Water is used for other activities like cleaning and dust suppression. Water is also consumed in the toilets on site and in the staff rooms.

5. What source of water do you use and why?

   The government requires you to use water from a STP specially in Delhi and NCR. Thus, this water is used. In some areas groundwater is also used.

6. How do you measure the water consumed on your construction sites?

   I do not measure the water consumed on my sites. There are large number of activities being undertaken at different places simultaneously, which makes it challenging to measure the consumption at each point.

7. What are the government regulations for water management on construction sites?

   The government mandates the use of STP water for construction activities.

8. What are the company policies for water management on construction sites?

   No specific policies in my company for water management.

9. What measures do you take on reduce water consumption on your sites?

   Concrete is made off-site which helps to reduce a large amount of water consumed on the construction site. Curing agents are applied on freshly poured concrete. This creates an impermeable layer on the concrete that prevents the evaporation of curing water. This helps reduce water required for curing. These agents are however expensive and increase the cost of the project which often limits their adoption. Changing the attitude of the site staff can also help save water.

10. How do you manage wastewater?

    Wastewater from activities like cleaning cannot be collected. These are simply discharged to the ground.

11. Do you have any recommendations to improve water management on construction sites?

    Water management can only be improved if people are educated about water scarcity and the need to save water. This is general knowledge that people need to be made aware of.

Construction Interviewee 6

1. Designation and years of experience

   I am an architect by profession and have my own architectural firm. Before starting my own firm, I have also worked in another big architectural firm. I have around 10 years of experience.

2. Which all sites have you worked in India?

   I have only worked in my hometown in Western India.

3. If in multiple locations around India, have you noticed any difference in water consumption pattern on construction sites for different activities? What could be the reason for these differences? (different climatic conditions, different soil type, government regulations, etc.)

   The amount of water available does impact the attitude of people towards water management. If less water is available for consumption, the people will be more conscious for its consumption to avoid wastage.

4. What are the major water consuming activities on the construction site?

   Water is used to make and cure concrete. Working with materials in powder form generates a lot of dust. Also construction sites do not have a concrete pavement. As a result there is a lot of dust generated on the site. Water is used for suppressing this dust to maintain the air quality. It is also used to clean the different materials and equipment's.

5. What source of water do you use and why?

   The most common source of water is water from STP and groundwater. In some areas the government has banned the extraction of groundwater and only mandates the use of STP water. However, groundwater is still used in banned areas since it might be the only reliable source in the region. Moreover, the deeper the groundwater is extracted from the purer it is and its application on the construction site increases.

6. How do you measure the water consumed on your construction sites?

   I keep a record of the water consumed on my construction sites since we pay for the water that we are purchasing. But I don't have a record of water consumed for each activity.

7. What are the government regulations for water management on construction sites?

   There is very little attention on water management in construction sites. One regulation I know of is the ban on the use of groundwater.

8. What are the company policies for water management on construction sites?

   I focus a lot of sustainability since my mentor from the company I have worked for before focused a lot on the same. We take measures to avoid water wastage but there are no specific policies for water management.

9. What measures do you take on reduce water consumption on your sites?

   Using ready-mix concrete helps to reduce water. On few of my projects, we created a water storage tank. Water was used from this tank for ancillary activities. This helped keep control on the water used.

10. Do you have any recommendations to improve water management on construction sites?

    I would suggest that Green Building Rating Systems should focus more on water management. At the moment, these rating systems do not focus on reducing water consumption. Having points for water management will surely motivate people to use water properly and identify measures for its management.

Construction Interviewee 7

1. Designation and years of experience

   I am an architect and work as a freelance consultant. I have been in this field for almost 10 years.

2. Which all sites have you worked in India?

   I have worked in different parts of India.

3. If in multiple locations around India, have you noticed any difference in water consumption pattern on construction sites for different activities? What could be the reason for these differences? (different climatic conditions, different soil type, government regulations, etc.)

   The materials used for the building construction impact the water consumption. On large sites I have noticed off-site construction is adopted which also impacts water consumption. This uses less water than traditional construction.

4. What are the major water consuming activities on the construction site?

   Water is needed for concreting work and dust suppression. The site staff also use water. It depends, if the site staff is staying on the site the whole time, there need to be provisions for their accommodation. So large amount of water is used for cooking, cleaning and sanitation.

5. What source of water do you use and why?

   Majorly water is purchased from a STP. However, sometimes it is difficult to find a STP in the vicinity of the construction site specially if the site is in a remote region. For a STP to operate, it requires atleast 80% of incoming sewage. In a remote region, finding this large quantity of sewage is sometimes a challenge, and an operational STP far from the construction site would need to be selected. Or in cases where it is expensive or not feasible to do so, another source of water like groundwater needs to be identified.

6. How do you measure the water consumed on your construction sites?

   I do not meter the water consumption on my site but I would like to start this. However, the cost of a water meter poses as a challenge to convince the client and company to install these.

7. What are the government regulations for water management on construction sites?

   The government has banned the use of groundwater in areas where they groundwater table is very low like Delhi and NCR. Another regulation is the use of STP water. Even though groundwater is banned, it is used in some regions since STP water is expensive and there might not be an STP close to the project site.

8. What are the company policies for water management on construction sites?

   I do not have any specific policies for water management nor do the companies I consult.

9. What measures do you take on reduce water consumption on your sites?

   Using curing agents and ready-mix concrete are the most common methods to save water. Additionally, changing the behaviour of the site staff and incorporating good housekeeping behaviour like closing taps when not in use can also help reduce water wastage.

10. Do you have any recommendations to improve water management on construction sites?

    People need to be made aware of water scarcity and how to manage water. Only making noise will help to save water.

Cement Interviewee 1

1. Where is your factory located?

   We are a big company and we have plants located in different parts of the country. Majority of our manufacturing plants are in outskirts of Rajasthan, Mumbai and Gujarat.

2. If in multiple locations around India, is the process the same? Is the same amount of water consumed?

   The process of cement manufacturing is the same in all factories. The amount of water used depends on the type of cement manufacturing process. Cement can be manufactured using the dry, semi-wet or wet process. 90% of the production in India is through the dry process. Very few plants are semi-wet of wet.

3. What are the major water consuming activities?

   Cement manufacturing as a process is not water intensive. Water is used to use the cement to make concrete, plaster and mortar. You cannot use cement without water as all the materials made using it require water for its manufacturing. Cement is not a water intensive industry, concrete is. Besides this water is used for ancillary activities cooling and greenbelt development.

4. What source of water do you use?

   Water bought from the municipality is usually surface water or treated wastewater from an STP. Companies close to the river also sometimes withdraw water from there. To withdraw water from the groundwater, you need to get a no objection certificate from the central groundwater board regarding how much water you want to withdraw and this depends on the capacity of the plant. This might be the only available source for a plant. Large manufacturing plants that have been in operation for many years have their own limestone mining sites and the open mine pits can be used for harvesting rainwater.

5. How do you measure the amount of water used?

   A water meter is installed at the point of water withdrawal from the municipality. This measures the total water withdrawn. This water is then distributed for different activities. The water consumed at each source is not measured since there are large number of consumption points and measuring consumption at each point is expensive. For other activities like green-belt development the water consumed can be calculated based on the number of water trucks watering the area and their capacity. To validate these calculated water readings, a water meter can be installed but this is again expensive.

6. What are the government regulations for water management in cement manufacturing plants?

   The government has banned the use of groundwater for industrial purposes and mandates using rainwater and recycled wastewater instead. All plants must ensure that they are zero-liquid discharge. Also all new plants must have a green-belt area.

7. Does your company have any policies for water management?

   My company doesn't have any policies for water management. There are policies set up by the Global Cement and Concrete Association (GCCA) and Global Reporting Initiatives (GRI) that must be followed in all cement plants. They require all plants to monitor their water consumption at each point by installing water meters.

8. What water management practices do you adopt?

   Majority of the plants in India follow the dry process of cement manufacturing which helps to reduce water consumption. We have replaced water cooling of equipment's with air cooling in some plants. Since the air cooling technology is expensive than water cooling, we are slowly applying this to all the plants. In our green-belt area, we have we use automatic water sprinklers.

9. How do you manage the wastewater that is produced?

   We have an in-site STP and ETP since the government mandates this. All the wastewater produced in the plants is treated and recycled depending on the quality of water produced. The wastewater mainly only contains dust and is easy to manage and treat.

10. Do you have any recommendations to improve water management in cement plants?

    Companies can be advised about creating an underground rainwater harvesting system to deal with the challenge of space constraints on the ground. Another recommendation would be to efficiently plan the manufacturing process regarding the amount of water required for each activity to avoid water wastage.

Cement Interviewee 2

1. Where is your factory located?

   I do not work in a manufacturing company.

2. If in multiple locations around India, is the process the same? Is the same amount of water consumed?

   The process of cement manufacturing is the same irrespective of the location.

3. What are the major water consuming activities?

   The semi-wet and wet process consume large amounts of water for making the slurry and the float-flotation process. In the dry process, water is only used for activities like cooling the clinker and machinery, green-belt development and dust suppression. Manufacturing plants usually have site staff that stay there for 24 hours and water is needed for their daily consumption.

4. What source of water do you use?

   Manufacturing plants usually have their own on-site STP and ETP where they treat all their water. This water is recycled within the plant. They also buy water from the municipality. This could be surface water, groundwater or treated wastewater. Since they are purchasing water from the municipality, municipality water is not the source of water withdrawal. Rainwater is also used in plants where they can harvest this water.

5. What are the government regulations for water management in cement manufacturing plants?

   All manufacturing plants must be zero-liquid discharge. They must have an STP or ETP plants to recycle all their wastewater. This is very important to reduce the freshwater withdrawal by manufacturing plants. Besides this all plants must harvest their rainwater which is sometimes challenging for plants due to space constraints and the availability of this source. The government has also banned the use of groundwater but for some companies, this is the only available source. Lastly, the government also requires all plants to have a green-belt area. In addition to these, GCCA also sets out policies for cement manufacturing plants.

6. Does your company have any policies for water management?

   Besides the government regulations, companies usually do not take any initiatives on their own for water management. It would be good for companies to formulate their own policies since government regulations are sometimes not implemented due to challenges for their adoption and lack of stringent policies to ensure their adoption.

7. What water management practices do you adopt?

   An RO system is used in some plants to reduce their water consumption. Besides this majority of the plants in India follow the dry process. For cooling purposes, some of the plants have adopted to replace water cooling with air cooling. Since these practices are not mandated by the government, not all plants have implemented these.

8. How do you manage the wastewater that is produced?

   Cement manufacturing does not produce any wastewater with chemicals and no tertiary treatment is required. Thus, wastewater is recycled for ancillary activities. Recycling the wastewater reduces the freshwater withdrawal by the plant.

9. Do you have any recommendations to improve water management in cement plants?

   I think the adoption of water management practices in plants can be increased if the government takes initiatives to reward the companies like through tax rebates. Other incentives to companies could be the lower cost of buying recycled water. Manufacturing plants can install an advanced filtration system to treat the cooling and process water, to increase its recovery rate and recycling.

Glass Interviewee 1

1. Where is your factory located?

   Our company is an international company with six float plants in India. We have plants in Chennai, Gujarat and Rajasthan.

2. If in multiple locations around India, is the process the same? Is the same amount of water consumed?

   The float glass manufacturing process is the same irrespective of the country.

3. What are the major water consuming activities?

   The float glass process is more energy intensive than water intensive as a lot of heating is involved in the furnace. The heat generated is cooled using water. The water which is used for cooling needs to be further cooled in a cooling tower using water. Besides the process, water is also used for ancillary activities.

4. What source of water do you use?

   We get our water from STP and municipality. The municipality water is usually surface water. Besides that we also use harvested rainwater in regions where we can harvest sufficient quantity.

5. What are the government regulations for water management in glass manufacturing plants?

   Groundwater withdrawal is banned. All industries must use alternate sources like rainwater and recycled water for their operation. Moreover, all plants must be zero-liquid discharge.

6. Does your company have any policies for water management?

   Since we are an international company, we have many company policies for sustainability even when these are not mandated by the government. We are very focused on water management and don't mind spending extra money on incorporating water management practices. We regularly set benchmarks for reducing water consumption which often means we need to upgrade our technology which is expensive. But we don't mind spending this money as saving water is our priority. We have a pollution control board that periodically audits our plants to check for water consumption and effluent treatment system.

7. What water management practices do you adopt?

   In few plants we have installed an adiabatic cooling tower along with the conventional cooling tower. Again, we don't mind spending extra money on updating our technology due to our strong company policies. To control water during ancillary activities, we have installed nozzles on taps to reduce flow, and have replaced conventional hand wash systems with automatic systems to prevent the chances of free flowing water wastage.

8. How do you manage the wastewater that is produced?

   All our plants have an on-site ETP and STP where all wastewater is treated and recycled within the plant. The wastewater produced in the cooling tower contains low TDS and is simply reused for cooling purposes.

9. Do you have any recommendations to improve water management in cement plants?

   The provision of treated wastewater at a lower rate by the government will motivate companies to use this source more. At the moment, in all our plants we have installed water meters that are manually read. We have conducted a pilot experiment in 1 plant where we have upgraded the manual systems to a cloud system and this has improved continuous monitoring. We plan to incorporate this change to all plants.

Glass Interviewee 2

1. Where is your factory located?

   I work in the plant in Chennai which is the largest float plant in India. We have three floors and 2 quarters in this plant. Most of our float plants are in the vicinity. We also have few plants in the Northern part of the country.

2. If in multiple locations around India, is the process the same? Is the same amount of water consumed?

   The glass manufacturing process and the water used is the same irrespective of the location. The weather of a location impacts the amount of water that is lost through evaporation. Due to hotter climate in India as compared to Europe, more water is lost to evaporation in the cooling tower. Similarly, different locations in India have different climate throughout the year. So this water lost changes on a daily basis but remains similar on an average basis.

3. What are the major water consuming activities?

   The whole process of glass manufacturing uses water for cooling purposes. The cooling tower is the heart of the glass manufacturing process because all equipment's associated with the process need to be cooled. Besides this water is also consumed by the staff in the quarters and for green-belt development.

4. What source of water do you use?

   81% of our plant needs are satisfied using rainwater. We have two rainwater harvesting tanks in this plant. We plan to install another harvesting tank soon to meet all our plant needs and become water neutral by 2025. At the moment, other needs are met by surface water and STP water.

5. How do you measure the amount of water used?

   We have installed water meters at each point of consumption to keep a record of how much water we are consuming.

6. What are the government regulations for water management in glass manufacturing plants?

   All industries have to follow the government regulations. They must be zero-liquid discharge and must have an ETP/STP accomplish the same. All plants must also incorporate a green-belt area. In addition to these, groundwater extraction is banned.

7. Does your company have any policies for water management?

   Reduce, reuse and recycle are the moto of our company. We have benchmarks for water management that all float plants must accomplish. Moreover, our company takes many actions to reduce water even if they are expensive as it is highly motivated for water conservation.

8. What water management practices do you adopt?

   Since the cooling tower consumes the largest amount of water, we have taken measures to improve the efficiency of these cooling towers. We have two types of cooling systems in our plants – conventional and adiabatic. The conventional cooling tower uses almost as high as 200 kL/ft of water. Adiabatic cooling tower reduces this water demand by almost 75%. Moreover, in the cooling tower we use DM water for blow down. We have our own DM manufacturing plant. The process of making DM water generates 20% wastewater that is used for gardening. We use tipper trucks and cover the raw materials with poly sheeting to control dust during transportation. In the staff quarters, we have replaced installed automatic handwash systems. For the garden areas, we use moisture-based sensors. We have taken many measures to manage water and also motivate other rival companies to adopt the same.

9. How do you manage the wastewater that is produced?

   We have an in-site STP where all wastewater from the quarters is treated and recycled back. Additionally, we have an ETP to preliminary treat the wastewater produced in the process.

10. Do you have any recommendations to improve water management in cement plants?

   We plan to include a fourth R (recovery) to the current 3R. This fourth R will focus on increasing the recovery of water from the STP by installing secondary treatment facility. This will help increase water recycling rate by 20% in the plant.

Construction and Industrial Sand Interviewee 1

1. If in multiple locations around India, is the process the same? Is the same amount of water consumed?

   The sand manufacturing process is the same wherein the sand is sieved, sized and cleaned. Industrial sand requires sand of higher quality as it is the input raw material, it is washed two to three times more than construction site.

2. What are the major water consuming activities?

   Water is consumed in the process to clean the sand. The degree of cleaning depends on the final application of the sand and its required quality. Water is also used for human consumption on the site.

3. What source of water do you use?

   The large open pits on our mining sites are used to harvest rainwater and this water is used for different activities. Moreover, sometimes the excavated rocks might be moist with groundwater or rainwater and this water can also be used.

4. How do you measure the amount of water used?

   A water meter is installed at the source of water withdrawal.

5. What are the government regulations for water management in sand manufacturing plants?

   The only regulation in effect is the ban on the use of river sand. So the sand we use if manufactured by crushing rocks. There are no major industries that manufacture sand. This is one reason why the process is scattered and there are no regulations in effect.

6. Does your company have any policies for water management?

   Most large companies have their own sand beneficiation plant where all the company policies are implemented. The policies we have for glass manufacturing in terms of sustainability are all applicable to our sand beneficiation plants.

7. What water management practices do you adopt?

   To reduce dust, we cover sand with poly sheeting during its transportation. All faucet’s are fitted with nozzles to control the flow of water. Similar to our float plants, we have replaced water cooling the equipment’s with air cooling.

8. How do you manage the wastewater that is produced?

   The wastewater collected does not contain any harmful chemicals and can be easily treated for recycling in activities like flushing and cleaning.

9. Do you have any recommendations to improve water management in sand manufacturing process?

   Though the sand manufacturing process is not very water intensive, there is always scope for water management. However, the unorganised nature of this sector due to the lack of big companies that manufacture sand, makes it difficult to manage water. If there is even one big company that manufactures sand, it will become easier to manage water consumption.

Construction and Industrial Sand Interviewee 2

1. If in multiple locations around India, is the process the same? Is the same amount of water consumed?

   The process of sand manufacturing is the same throughout the country. To make M-sand, rocks are dug from the ground that are crushed, sieved and cleaned to make M-sand suitable for construction use. The sand is cleaned only once or twice depending on its size. The water consumption differs from location to location depending on the type of sand in the mining area. If the area has fine sand, more water is required for dust suppression.

2. What are the major water consuming activities?

   Cleaning of the sand consumes the most water. Water is also consumed for ancillary activities like dust suppression, cleaning, cooling and human consumption.

3. What source of water do you use?

   We use rainwater that has been collected in our mining sites. Besides that we use groundwater.

4. How do you measure the amount of water used?

   The sand manufacturing process is very scattered and unorganised since all the operations are undertaken on the mining site. This makes it difficult to monitor the water consumed at each point. Thus, we only measure the water withdrawn through a water meter that is installed on site.

5. What are the government regulations for water management in sand manufacturing plants?

   The government has banned the use of river sand for construction activities. This is the only regulation in effect. So 80% of the construction occurring in India is through the use of M-sand.

6. Does your company have any policies for water management?

   For construction sand, there are no big industries that manufacture and supply these. Thus, there are no regulations.

7. What water management practices do you adopt?

   We cover the raw sand during transportation to avoid it from becoming air borne. All faucets on the site and plant are covered with nozzles to control water flow.

8. How do you manage the wastewater that is produced?

   The wastewater from sand manufacturing contains high quantities of dust that can be treated through simple sedimentation. Our sites have a sedimentation tank and all the treated wastewater collected from there is used for different ancillary activities.

Tiles Interviewee 1

1. Where is your factory located?

   We have factories located in different parts of India such as Alwar and Gujarat. The plant I work is in Alwar.

2. If in multiple locations around India, is the process the same? Is the same amount of water consumed?

   The main tile manufacturing process is the same throughout the country with few differences depending on the final product and finishing. For example, for a tile with glaze, more water is consumed than for one without glaze. The amount of water consumed also depends on the state of the raw materials and how they are handled. The raw materials maybe mixed with water to form a slurry and flow the wet tile manufacturing, or are manufactured using the dry process. Majority of tile plants in India, including our plant follows the wet process.

3. What are the major water consuming activities?

   The wet tile manufacturing process is very water intensive as large amount of water is needed to make the slurry. Irrespective of the wet or dry process, water is used for cooling the machinery. Water is also used for environmental activities like dust control and green-belt area. It is also used by the site staff.

4. What source of water do you use?

   Despite being a water intensive manufacturing industry, most of our manufacturing plants are located in water scarce regions since the land in these areas is cheap. This forces us to treat all our wastewater on site and recycle it within the plant. Besides this, in areas where groundwater is available that is used. Rainwater is also used in areas where enough can be harvested. But rainwater is more of an extra water source rather than a main source since its availability is not constant.

5. How do you measure the amount of water used?

   We have installed water meters in few of our plants at the point of municipal water connection. The cost limits its adoption in small plants.

6. What are the government regulations for water management in tile manufacturing plants?

   The government has banned the extraction of groundwater; however, this source is still used in some plants. We cannot stop all the functions of our plant just because we can’t extract groundwater and there is not available source. This will impact our plant performance. The government also requires all manufacturing plants to be zero-liquid discharge, and have on-site STP and ETP to recycle and treat their wastewater.

7. Does your company have any policies for water management?

   The main focus of our company is to save water. This is also very important for us since most of our plants are in water scarce areas. So we have no option but to be focused on saving water. Moreover, we believe that water saving is a continuous journey with milestones in it. Thus, in our company we keep setting benchmarks for water consumption reduction. For instance, we plan to increase our demand met by treated wastewater to reduce the dependence on groundwater.

8. What water management practices do you adopt?

The most reduction in water consumption will occur by updating our process from a wet to dry process. We are already implementing this in many of our plants and plan to increase this adoption by 2030. In our staff quarters, we have installed waterless urinals and have replaced the conventional handwash system with automatic handwash system. The flow rate in all our taps is reduced to reduce water wastage. Since our company is very motivated for water management, we realise the impact site staff has on water management, and we have workshops regarding the same at least twice a year that are part of our team building exercises.

9. How do you manage the wastewater that is produced?

We recycle all our wastewater within the plant. Most of the wastewater contains very low TDS and this is recycled for ancillary activities like green belt development and flushing after simple sedimentation.

10. Do you have any recommendations to improve water management in tile plants?

The government regulations for water management have clearly not been very successful for water management. I think if companies make strong policies for water management, and they are motivated to save water, it will really help deal with the issues of water scarcity. But motivating people for the same is a challenge. Especially when the companies are not getting any incentives for water management and applying these practices is expensive. However, if the government provides incentives to the companies it will motivate them to apply many practices which they would otherwise not apply. By planning the manufacturing process and identifying how much water is required at each stage, can help reduce water wastage. Moreover, the more wastewater companies are able to recycle, the lower they will rely on freshwater.

Bricks Interviewee 1

1. Where is your factory located?

   We have factories located Uttar Pradesh, Kanpur, Kolkata and Bangalore. I am based in the head office in Bangalore.
2. If in multiple locations around India, is the process the same? Is the same amount of water consumed?

   The brick manufacturing process is the same in terms of the mixing, casting, firing and cooling. The only difference is in the process being machine oriented or labour oriented. Large and medium factories have automated their process whereas small companies still rely on human labour. A lot of dust is generated in the process that requires water for dust suppression. In areas of fine sand more water is needed for suppression as compared to areas with coarse sand.

3. What are the major water consuming activities?

   Bricks consume water for their manufacturing and their operational use. Water is used in large quantities specially in clay bricks since it is one of the raw materials. It is also used in the process for cooling activities. Water is also used for cleaning of the moulds and dust suppression on the site, along with human consumption. During the use phase of the bricks, they consume water for moistening, mortar, plaster and curing.

4. What source of water do you use?

   Again the sources of water used depend on the size of the plant. Large plants usually have provisions for collecting rainwater and recycling treated wastewater. Small plants on the other hand have to rely on groundwater and treated wastewater from an STP.

5. How do you measure the amount of water used?

   We have installed water meters at the source of municipal water connection.

6. What are the government regulations for water management in bricks manufacturing plants?

   The brick manufacturing industry is very scattered and there are many medium and small scale companies involved in the process that makes having regulations difficult. Large companies on the other hand follow government regulations like being zero-liquid discharge, ban on groundwater consumption, and mandatory inclusion of green-belt area.

7. Does your company have any policies for water management?

   Our company is focused on water management but there are no specific policies we have set up.

8. What water management practices do you adopt?

   For dust suppression rather than free flowing water we use water mists. Moreover, we use moisture based sensors for green-belt development.

9. How do you manage the wastewater that is produced?

   Most of the water is lost to the atmosphere through evaporation during drying and firing of the bricks. Besides this on small plants, the activities are scattered which makes it difficult to collect the wastewater. On large plants, due to streamlined process, wastewater can be collected and treated for recycling. Since the wastewater does not contain any harmful chemicals, simple sedimentation and preliminary treatment is sufficient to produce water for ancillary activities like dust suppression, green-belt development and flushing.

10. Do you have any recommendations to improve water management in bricks plants?

    Clay bricks consume a lot of water for their use. Replacing these with clay bricks can be beneficial for the overall building as they require less water. Besides this, using filtering systems for dust suppression can help reduce water demand. Besides all of this, if the scattered nature of the industry can be tackled, we can make regulations for management.

Appendix F: Bill of Quantities of Case Study Buildings

Case Study 1

S.N.		Description	Unit	Qty
		Area considered	Sqm	**11335**
	1	**SITE WORK**		
1.1		Earthwork in excavation by mechanical means (hydraulic excavator)/manual means over areas (exeeding 30cm in depth, 1.5 mtr in width as well as 10 sqm on plan) including getting out and disposal of excavated earth lead alround inside the site and lift upto 1.5 mtr as directed by Engineer-in-charge.		
	a)	All kind of soil.	Cum	5400
1.2		Extra for every additional lift of 1.5 m or part there of in excavation/ banking excavated or staking materials.		
		All kinds of soil.		
	a)	1.5 m to 3.0 m	Cum	1543
	b)	3.0 m to 4.5 m	Cum	1543
	c)	4.5 m to 6.0 m	Cum	514
1.3		Filling available excavated earth (excluding rock) in trenches, plinth, sides of foundation etc in layers not exceeding 20 cm in depth, consolidating each deposited layer by ramming and watering, of all leads and all lift.	Cum	2160

1.4		Providing and injecting chemical emulsion for PRE-CONSTRUCTION anti-termite treatment & creating a continuous chemical barrier under & around the columns pits, walls, trenches, basement excavation, top surface of plinth filling, junction of wall, & floor, along the external perimeter of building, expansion joint, over the top surface of consolidated earth on which apron is to be laid, surrounding of pipes and conduits etc. complete as per specification (plinth area of the building at ground floor only shall measured for payment) - Chlorpyriphos / Lindane emulsifiable concentrate of 20% with 1% concentration.(Plinth area will be measured).	Sqm	788
1.0		**TOTAL FOR EARTHWORK**		
	2	**CONCRETE WORK**		
2.1		Providing and laying in position cement concrete of specified grade excluding the cost of centering and shuttering - All work upto plinth level.		
i)		1:4:8 (1 cement : 4 coarse sand : 8 graded stone aggregate 20mm nominal size).	Cum	81
		TOTAL		
	3	**RCC WORK**		
3.1		Providing and laying in position specified grade of reinforced cement concrete, excluding the cost centering, shuttering, finishing and reinforcement as per direction of Engineer-in-charge	Cum	
3.2		Providing and laying in position ready mixed M25 grade concrete for reinforced cement concrete work, using fly ash and cement content as per approved design mix, manufactured in fully automatic batching plant and tranported to site of work in transit mixers for all leads, having contineous agitated mixer, manufactured as per mix design of specified grade of reinforced cement concrete work, including pumping of RMC concrete from transit mixer to site of laying but excluding the cost of centering, shuttering, finishing and reinforcement including admixtures in recommended proportions as per IS:9103 to accelerate, retard setting of concrete, improve workablity without impairing strength and durablity as per direction of Engineer-in-charge		
		Note :- 1)The cement content considered in this item @ 330 kg / cum. Excess / less cement used as per design mix is payable / recoverable separately.2) Fly ash confirming to grade I of IS 3812)Part-1) only be used as part replacement of OPC as per IS: 456. Uniform blending with cement to be ensured in accordance with clauses 5.2 and 5.2.1 of IS:456-2000 in the items of and RMC.		
3.2.1		All works upto plinth level	Cum	1048
3.2.2		All works above plinth level.	Cum	3061

3.2.3		Extra for RCC/ BMC/ RMC work above floor Vth level for each 4 floors or part thereof.		
3.2.4		Extra for providing richer mixes for all floor levels		
3.2.4.1		Proving M30 grade concrete instead of M25 grade concrete BMC / RMC .	Cum	366
3.2.4.2		Proving M35 grade concrete instead of M25 grade concrete BMC / RMC .	Cum	366
3.3		Steel reinforcemnt work for RCC including straightening, cutting, bending, placing in position and binding all complete upto plinth level.		
i)		Thermo mechanically Treated bars of grade Fe 500D or more.	kg	112760.14
3.4		Steel reinforcemnt work for RCC including straightening, cutting, bending, placing in position and binding all complete above plinth level.		
i)		Thermo mechanically Treated bars of grade Fe 500D or more.	kg	497356.37
		TOTAL		
4		**FORM WORK**		
4.1		Centering and shuttering including strutting, propping etc and removal of forms of all heights.		
4.1.1		Foundations, footings, bases of columns, etc for mass concrete.	Sqm	189
4.1.2		Walls (of any thickness) including attached plasters, buttresses, plinth and string courses etc.	Sqm	
4.1.3		Suspended floors, roofs, landings, balconies and access platforms.	Sqm	10900
4.1.4		Lintels, Beams, plinth beams , girders , bressumers, cantilevers.	Sqm	7146

4.1.5		Columns, Pillars, Piers, Abutments, Posts and Struts.	Sqm	9900
4.1.6		Stair (excluding landing) except spiral stair.	Sqm	1360
4.2		Extra for additional height in centering, shuttering where ever required with adequate bracing, propping etc., including cost of de-shuttering and decentering at all levels, over a height of 3.50 meter for every additional height of 1 meter or part thereof (Plan area to be measured).		
		Suspended floors, roofs, landings, beams and balconies (Plan area to be measured).	Sqm	750
4.0		**TOTAL FOR STRUCTURAL STEEL**		
5.0		**BRICK WORK**		
5.01	a)	Brick work with bricks of class designation 75 in foundation and in foundation up to plinth in cement mortar 1:6 (1 cement : 6 coarse sand) for all levels	Cum	240.0
	b)	Same as item 4.01a) for plinth to Fourth Floor level	Cum	758.0
	c)	Same as item 4.01a) for Fifth to Tenth Floor Level	Cum	993.8
5.02	a)	Half brick masonry with bricks of class designation 75 in superstructure in cement mortar 1:4 (1 cement : 4 coarse sand) for all floors and levels including providing and placing in position 2 No. 6 mm dia MS bars at every third course.	Sqm	20.0
	b)	Same as item 4.02a) for plinth to Fourth Floor level	Sqm	740.0
	c)	Same as item 4.02a) for Fifth to Tenth Floor Level	Sqm	889.0
		Alternative Item		
5.0		**TOTAL OF BRICK WORK**		

6		***WOOD WORK***		
6.01		Providing, Making and fixing in position wood work in frames of doors including making rebate and edge chamfering as per design etc complete including grouting M.S hold fast made out of 35X5 M.S flat in CC 1:2:4 etc. complete i/c cost one wood primer.		
	1	Seasoned first class **Marandi wood**	***Cum***	30

6		***TOTAL WOOD WORK***		
7.0		**CIVIL FINISHING**		
7.01		6 mm thick cement **external finishing plaster** 1:2:2 (1 cement : 2 coarse sand : 2 fine sand) to ceiling and other RCC work.	Sqm	7475.0
7.02		Add for plaster drip course in plastered surface of moulding to RCC projection.	Rm	880.0
7.03		13 mm to 15 mm gypsum plaster thickness with coverage of 65m3/1000 kgs with a very smooth and off-white colour surface finish with bulk density of 650Kg./m3, to be well compacted to a density of 1050Kg/m3 with settling time of about 30-35 mintutes	Sqm	22545.0
7.04		18 mm cement external plaster in two coats under layer 12 mm thick cement plaster 1:5 (1 cement : 5 coarse sand) finished with a top layer 6 mm thick cement plaster 1:6:6 (1 cement : 6 coarse sand :6 fine sand) to walls including cost of 24 gauge 8 mm size galvanised chicken wire mesh of approved width at junctions of concrete and brick work including necessary laps and U shape galvanised wire nails.	Sqm	1050.0
7.05		Making 10 x 10 grooves in the external plaster by using suitable temporary wooden batten/ al channel.	Rm	2610
7.06		Providing and laying 15mm **waterproof water - tight smooth cement finished plaster** in cement mortar 1:4 (1cement: 4 coarse sand) and adding water-proofing agent of approved quality (Cico or approved equivalent), 1 kg per bag of cement or as per manufacturer's specification and to ensure water repellant quality, finished smooth in line,level and plumb including curing, scaffolding, hacking RCCsurfaces, raking joints etc. complete at all levels as directed and specified.	Sqm	
7.07		Cement Plaster with a floating coat of neat cement or neat cement punning:		
	a)	12mm CP of Mix CM 1:4	Sqm	
	b)	15mm CP of mix CM 1:4	Sqm	
	c)	20mm CP of mix CM 1:4	Sqm	

7.0		**TOTAL FOR CIVIL FINISHING**		
8.0		**WATER PROOFING**		
		Note :		
	a)	*All water-proofing works are to be quoted for complete work in all respects as per manufacturer's specifications and recommendations. The item descriptions given below is only a broad description of the works and in no way limits the contractor's responsibilty to follow the manufacturer's specifications and recommendations to the full and without charging anything extra to the client. The rate to be quoted for all heights and depths.*		
	b)	*All Subcontractors to be appointed by the Contractor shall have to be approved by the Project Manager / Architect.*		
	c)	*All water-proofing works to be executed by specialist agencies to be approved by Architect / PMC with a performance guarantee bond for 10 years and a bank guarantee for 5 years.*		
8.01		Providing and laying integral cement based **water proofing treatment (Brick Bat Coba)** of average 110mm thickness with brick aggregate and admixture of water proofing etc. Necessary gradient for easy flow of water shall be provided and the job completed including round vatas and khurras including preparation of surface as required for treatment of roofs, balconies, terraces etc.. Consisting of following operations. **(Only Plan area shall be measured for making payment to the contractor)**	Sqm	668
	a)	Applying and grouting a slurry coat of neat cement using 2.75 kg/sqm of cement admixed with proprietary water proofing compound (Cico / Accoproof or approved equivalent) confirming to IS 2645 over the RCC slab including cleaning the surface before treatment.		
	b)	Laying cement concrete using broken bricks / brick bats 25mm to 100mm size with 50% of cement mortar 1 : 5 (1 cement : 5 coarse sand) admixed with water proofing compound to required slope and treating similarly the the adjoining walls upto 300mm height including rounding of walls and slabs.		
	c)	After 2 days of proper curing applying a second coat of cement slurry admixed with approved water proofing compound.		
	d)	Finishing the surface with 20mm thick jointless cement mortar 1 : 4 (1 cement : 4 coarse sand) admixed with proprietary water proofing compound and finally finishing with trowel with neat cement slurry, making square panels of 300 x 300 mm in 10 x 2mm deep threaded lines including making gola & khurras.		
	e)	The whole terrace so finished shall be flooded with water for a minimum period of two weeks for curing and for final test. The complete methodology and specifications to be approved by the Project Manager		

8.0		**TOTAL FOR WATERPROOFING & INSULATION**		
9.0		**TERRACE FINISHING**		
9.01		Making khurras 45 x 45 cm with average minimum thickness of 5 cm cement concrete 1:2:4 (1 cement : 2 coarse sand : 4 graded stone aggregate of 20 mm nominal size)over PVC sheet 1 m x 1 m 400 micron finished with 12 mm cement plaster 1:3 (1 cement : 3 coarse sand) and a coat of neat cement, rounding of edges and making and finishing the outlet complete.	Nos	8
9.0		**TOTAL OF TERRACE FINISHING**		
10.0		**ELECTRICAL CONDUIT**		
10.01		Providing and fixing of	Sqm	
a)		Electrical Conduit Pipes		
		25mm	Metre	
		30mm	Metre	
		10mm	Metre	
b)		M.S. Fan Boxes	Nos.	
10.0		**TOTAL FOR ELECTRICAL CONDUIT**		
11.00		**ALUMINIUM WINDOWS DOOR**		
11.01		Aluminum windows doors to be provided by the owner. Fixing Aluminum window with anodized (20 Micron) in approved shade with all necessary pre-approved aluminium section. Rates to include for necessary fixtures and fastening, hinges, locking arrangement,	Sqm	1250

		weather bars, glazing clips, EPDM gasket, silicon sealant, inculding 5mm thick clear / frosted glass of Ashai/ Saint Gobain with all required screws and nuts as directed by Project Manager / Architect complete.		
11.02		Providing and fixing of 12 mm thick clear glass partition made out of 12mm toughened glass usingU channel of aluminium conealed in ground.		
11.00		**ALUMINIUM WINDOWS DOOR**		
12.00		**FLOORING & DADO WORKS**		
12.01		Providing, machine mixing and laying in approved panels of 40 mm thk **Indian Patent Floor** in cement concrete mix of of 1:2:4 well vibrated, compacted and finished smooth and cured by keeping surfaces well covered and protected aginst excess of any type (the contractor will provide for preparation of surface cleaning, hacking and exposing the aggregate to acheive the best bond and any curling, shifting or debonding noticed shall be rectified by the contractor at this cost) including providing and laying of PVC strips in the pannels,size of which not exceeding 1.5 Sqm in area all complete at all heights and leads to the satisifaction of the Project Manager	Sqm	
12.02		Fixing approved white / coloured **Vitrified tiles** of approx size 600mm x 600mm, in **flooring** to a pattern and including cement mortar 1:4 bedding with cement floating, including filling joints with white cement added with pigment curing etc. complete as ditected to the satisfaction of Project Manager. (total thickness of flooring 25-30mm thick)	Sqm	3000
12.03		Fixing approved white / coloured **ceramic tile in Flooring** as per the tile module in **toilets and kitchen**, including C.M. backing plaster 1:4 (1 Cement:4 Sand) with neat cement, including filling joints with white cement added with pigment curing, acid washing, etc. complete as directed to the satisfaction of the Project Manager.	Sqm	575
12.04		100 mm high skirting, edge rounding and normal polishing,over 15 mm thk. C.M. 1:4 backing or using approved adhesive such that the tile surace is flushed to the wall finish complete to the satisfaction of the Project Manager.	Rmt	625
12.05		Fixing approved white / coloured **ceramic tile in Dado** as per the tile module and upto specified height, **in toilets and kitchen and lift lobby wall**, including C.M. backing plaster 1:4 (1 Cement:4 Sand) with neat cement, including filling joints with white cement added with pigment curing, acid washing, etc. complete as directed to the satisfaction of the Project Manager.	Sqm	4685

12.06		Providing & fixing machine cut/machine pre-polished 20 mm thk. Cheema grey **granite kitchen platform/toilet counters** with end vertical polished granite stone, providing 25mm PVC dia sleeve for gas pipes, granite facia, granite edge rounding and mirror polishing, fixing S S sink with drain board/wash basin supplied by the client including sealing the junction of granite and kitchen sink with suitable sealant, MS Brackets required for supporting the same to be provided by the contractor and its cost to be included in this item etc. complete as directed by the Project Manager. (Plan area will be measured with deduction for sink area)	Sqm	325

12.00		**FLOORING & DADO WORKS**		
13.00		**PAINTING**		
12.01		Providing and applying three or more coats of **Oil Bound Distemper paint** In walls and ceiling of approved brand, manufacturer and shade to give a smooth finish over a coat of approved primer including the cost of preparing the surfaces with filling materials (putty), along with sand papering wherever required, scaffolding etc. complete. as per satisfaction of Project manger	Sqm	10385
12.02		Providing & applying 2 or more coats of **Acrylic External Paint** of approved shade on the externalplastered surfaces. Rate to include for preparing surface and providing & erecting scaffolding etc. all complete as per the manufacturer's specification and to the satisfaction of Project Manager. Approved makes Spectrum, Acro, Berger Exterior grade	Sqm	7475
13.00		**PAINTING**		
13.00		**OTHER GENERAL ITEMS**		
13.01		Constructing brick masonry open surface drain with bricks of class designation 75 in cement mortar 1 : 4(I Cement : 4 Fine sand) including earth excavation, 10 cm thick bed concrete 1 : 5 : 10 (I Cement : 5 Fine sand : 10 Graded stone aggregate 40 mm nominal size) and 25 mm thick cement concrete 1 : 2 : 4 (1 Cemnet : 2 Coarse Sand : 4 Graded stone aggregate 12.5 mm nominal size) for filling haunches including 12 mm cement plaster 1 : 4 (1 Cement : 4 Coarse sand with a floating coat of neat cement inside the drain its top and exposed side including disposal of surplus earth complete as per standard design with F.P.S. bricks.		
	a)	**30 cm drain 30 cm average depth**	**m**	
	b)	**30 cm drain 45 cm average depth**	**m**	
	c)	**45 cm drain 60 cm average depth**	**m**	
13.02		**Extra for every additional 15 cm average depth of drain.**	**m**	
13.02		Providing & Fabricating and fixing M.S. insert plates including necessary lugs, welding etc. all complete as directed.	Kg	

13.04		Providing and fixing in position M.S. staircase/ balcony railing as per detail drawings, including applying a priming coat of approved steel primer	Kg	30000
13.00		**TOTAL FOR OTHER GENERAL ITEMS**		

Case Study 2

Sno.	Particulars	Unit	Cumulative Qty.
Next			
	ITEMS AS PER CONTRACT		
A.	**EARTH WORK**		
1	**Site Clearance** Clearing the site / areas of shrubs, vegetation, grass, trees and saplings of girth up to 30cm (measured at 1m height from ground level) including removal of roots to a minimum depth of 60cm and disposal of rubbish outside the periphery. all lead and lift complete as directed by Engineer-in-charge.	Sqm	1,887.10
2	Earth work in excavation in foundation trenches or drains including dressing of sides and ramming of bottoms, lift up to required depth Including taking out the excavated soil and depositing and refilling of jhiri with watering and ramming and disposal of surplus excavated soil as directed within a lead of 50 Mtr.		-
	All kind of soils.		-
a	Depth up to 1.5m	cum	5,952.16
b	Depth 1.5 m to 3m	cum	-
c	Depth 3m to 4.5m	cum	-
3	Filling with available excavated earth (excluding rock) in trenches, plinth side of foundation etc. in layers. In depth, consolidating each deposited layer by ramming and watering including.	cum	677.14
4	**Ant termite treatment (with proprietary guarantee for 10 years)** Providing and applying, injecting Anti-termite (chloropyriphos) treatment as per IS 6313 supported by Manufacturer's specification for "pre-constructional " Anti - termite treatment creating a continuous chemical barrier, under the foundation Raft slab and pile caps and all around the column pits, all excavated trenches, top surface of plinth filling junction of wall and floor, external perimeter of the building	Sqm	1,451.00

	(minimum of 1m width) expansion joints, top surface of consolidated earth for flooring etc. complete as per technical specification or as directed by the engineer in charge. (Plinth area of the ground floor level only shall be measured for payment).		
Next			-
	Total of A		
Next			-
B.	**PLAIN CONCRETE WORK**		-
5	Providing & laying in position plain cement concrete including curing compaction etc. complete in specified grade excluding the cost of centering and shuttering		-
a	1:3:6 (1 cement: 3 Coarse sand:6 graded stone aggregate 20mm nominal size)	cum	307.41
Next			-
	Total of B		
Next			-
C.	**REINFORCED CONCRETE WORK**		-
	Form Work		-
6	Providing & fixing centering & shuttering with plywood or steel sheets for all heights level including shuttering, steel propings, bracing bothway & removal of form work for :-		-
a	Foundations, footings, bases of columns etc. for mass concrete.	Sqm	187.11
b	Columns, Pillars, Piers, Abutments, Posts and Struts with all floors	sqm	1,656.77
C.	Retaining Wall & Lift Wall	Sqm	1,242.70
7	Suspended floors roofs, landings, balconies, staircases, sills, chhajjas, access platform, Lintels, beams, plinth beams, girders and cantilevers,Fins, Facia, louvers, including edges with all floors.	sqm	8,244.61
	Concrete work		-
8	Providing and laying reinforced cement concrete in raft, wall footings and column footings, excluding the cost of centring, shuttering and reinforcement steel. (As per Design Mix) **M-25** Grade concrete. (RMC Mix) Including Cement	cum	622.00

9	Providing and laying reinforced cement concrete at all ht in Columns, retaining walls (any thickness), Lift wall, Under ground & Overhead water tanks,Lift Machine Room Etc. excluding the cost of centring, shuttering and reinforcement steel.(As per Design Mix) **M-30** grade concrete. (RMC Mix) Including Cement	Cum	-
9.1	Providing and laying reinforced cement concrete at all ht in Columns, retaining walls (any thickness), Lift wall, Under ground & Overhead water tanks,Lift Machine Room Etc. excluding the cost of centring, shuttering, Cement and reinforcement steel.(As per Design Mix) **M-30** grade concrete. (In-Situ Mix)	Cum	-
10	Providing and laying reinforced cement concrete works at all ht in suspended floors, roofs, landings, beams,lintels, stair waist slab, counter slabs etc. but excluding the cost of centring shuttering and reinforcement steel in (As per Design Mix) **M:25** Grade Concrete. (RMC Mix) Including Cement	Cum	1,056.00
10.1	Providing and laying reinforced cement concrete works at all ht in suspended floors, roofs, landings, beams,lintels, stair waist slab, counter slabs etc. but excluding the cost of centring shuttering , Cement and reinforcement steel in (As per Design Mix) **M:25** Grade Concrete. (In-Situ Mix)	Cum	415.33
	Reinforcement		-
11	Providing and laying steel reinforcement in all reinforced concrete work including supply, handling, cutting, removal of rust if required by wire brush, coating of cement slurry in inhibitor solution, bending, fabricating and placing in position to the shape and profile required as per drawing, tying with 16 SWG annealed steel wire and cost of binding with proper cover blocks, supports, chairs, spacer bars etc. as per specifications and complete in all respects for all heights.		-
	High yield strength deformed bars of grade 500 D(confirming to IS 1786) thermo mechanically treaated with minimum 14.5% elongation.	KG	285,779.71
Next			-
	Total of C		
Next			-
D.	**Masonry Work**		-
12	Providing Random rubble stone masnory type for foundation and plinth in cement sand mortar equal or above 30 cm. Thick wall in :-		-
	In cement mortar 1:6 (1 cement : 6 sand)	Cum	29.60
13	Providing & Fixing Red/Flyash 9" Brick masonry for superstructure with bricks of class desiganation 75 in :		-
	Cement mortar 1:6 (1 Cement : 6 coarse sand)		-
	All Floors	Cum	391.25
14	Add Extra in 9" Red Brick Work for Exposed Brick Work. Providing & fixing 230 mm exposed brick masonary (outer side exposed) thick masonary in super structure with locally available first quality bricks having a minium crushing strength 75 Kg/Sq Cm and water absorption	Sqm	-

	maximum 20% in cement mortar 1:6 Cement Mortar laid in specified courses of approved bond and including raking out joints, curing, doing independent double legged scaffolding, all complete as per specification etc at all heights & leads all as directed by site in-charge to his entire satisfaction for all height and level.		
15	Providing Half Red/Flyash Brick masonry for superstructure using bricks of designiation 75 in		-
	Cement mortar 1:4 and 50 mm thick concrete band having reinforcement of 8 mm 2 nos. At every 1m ht. (1 cement : 4 coarse sand)		-
	All Floor	Sqm	2,593.53
Next			-
	Total of D		
Next			-
E	**Plaster Work**		-
16	12 mm to 15 mm thick cement plaster in cement mortar 1:6 (1 cement : 6 sand, 50% coarse sand and 50% fine sand) on brickwork. Including Providing & Fixing of Fibre mesh on RCC & Brick Masonry joints & mixing of polypropylene fibre reinforcement for plaster to prevent shrinkage cracks etc. as per manufacturer's specifications (Recron). At all hieght & levels with scaffolding.	Sqm	-
17	Providing and applying 15 mm thick cement plaster in 1:4 (1 cement : 6 coarse sand) to external wall including scaffolding, water-proofing compound, Fixing of Fibre mesh, polypropylene fibres (Recron) curing etc. and forming uniform horizontal & vertical grooves as desired by architects at all heights and levels, including making chases in brick work and R.C.C. work wherever required, removal of wooden battens, repairs to edges of plaster panels, finishing grooves, providing drips on all horizontal projecting surfaces as per drawings and details. all complete	Sqm	7,685.22
18	Providing & applying cement plaster with neat plaster finish 1:3, 15mm in toilet, sump, lift pit etc including adding approved quality and brand waterproofing compound as per the manufactures approved specification etc.complete.as per the drawing and technical specifications or as directed by the engineer in charge.	Sqm	-
Next			-
	Total of E		
Next			**-**
F	**Flooring Work**		-
	Floor Sub Base		-

19	Random rubble dry stone soling 8" thick under floor. With filling the voids using sand of approved quality.		-
	(a) Ground Floor	Sqm	1,227.77
20	Providing and laying 75mm thick (average thickness) M20 grade ready mixed concrete for non slippery, **Vacuum Dewatered Flooring** including cleaning, trimming, watering the surface, laying in strips to required levels, trowelling, smoothening curing , groove cutting etc.complete. Also Providing vacuum de-watered flooring operation consisting of providing side shuttering with MS channels, angles to the required levels. Vibrating the concrete by using screed vibrator, de-watering using vacuum pumps by suction method and finishing the top surface to required level and grade using skim float/discs/power trowels. Covering the finished concrete surface with 200 micron thick polythene sheet and curing etc., complete.	Sqm	1,140.00
21.1	Extra for filling the groove with approved bitumen joint filler	Rmt	454.60
21.2	Extra for filling the groove with approved polysulphide joint filler	Rmt	-
Next			-
	Total of F		
Next			-
G	**Water Proofing & Terracing**		-
22	**Brick bat coba waterproofing**		-
	Providing and laying integral cement based water proofing treatment including preparation of surface as required for treatment of roofs, terraces etc consisting of following operations. (a) Applying and grouting a slurry coat of neat cement using 2.75 kg/sqm. of cement admixed with proprietary water proofing compound conforming to IS. 2645 over the RCC slab including cleaning the surface before treatment. (b) Laying cement concrete using broken bricks/brick bats 25 mm to 150mm size with 50% of cement mortar 1:4 (1 cement : 4 coarse sand) admixed with proprietary water proofing compound conforming to IS : 2645 over 20 to 25 mm thick layer of cement mortar of mix 1:4 (1 cement :4 coarse sand) admixed with proprietary water proofing compound conforming to IS : 2645 to required slope and treating similarly the adjoining walls upto 300 mm height including rounding of junctions of walls and slabs.		-
	(c) After two days of proper curing applying a second coat of cement slurry admixed with proprietary water proofing compound conforming to IS : 2645. (d) Finishing the surface with 20 mm thick joint less cement mortar of mix 1:4 (1 cement :4 coarse sand) admixed with proprietary water proofing compound conforming to IS : 2645 and finally finishing the surface with trowel with neat cement slurry and making of 300x300xmm square (e) The whole terrace so finished shall be flooded with water for a minimum period of two weeks for curing and for final test. All above operations to be done in order and as directed and specified by the Engineer-in-Charge.		-
	With average thickness of 120mm and minimum thickness at khurra as 65 mm. (Plan area will be measured and paid)	Sqm	739.61
23.1	**Khurras**		-
	Making khurras 450mm x 450mm with average minimum thickness of 50mm cement concrete 1:2:4 finished with 12mm cement plaster 1:3 (1 cement : 3 coarse sand) and a coat of neat cement rounding the edges & finishing the outlet complete including providing suitable M.S.Iron grating.	each	-

23.2	Providing gola 75 x 75 mm in cement concrete (1:2:4) including with cement mortar 1:3 as per standard design.	Rmt	250.98
Next			-
	Total of G		
Next			-
H	**Miscellaneous -**		-
24	Filling of sunk portion of roof with earthen pots of required height including filling voids with 1:3:6 light concrete.	CUM	10.69
25	Providing mixing and laying 52 mm thick **Indian Patent Stone (IPS) flooring** with "hardcrete" concrete hardener toping under layer 40 mm thick 1:2:4 mix concrete with 20mm and down size graded crushed aggregate and top layer 12mm thick hard crete cement hardener consisting of mix 1:2(1 harderner mix : 2 stone agreegates 6 mm nominal size) by volume with hard crete hardening compound of Snowcem India Ltd or equivalent is mixd a @ 2l hardcrete per 50 Kg of cement including providing and fixing glass strips in1 metre x 1 metre panels, casting the concrete compacting and finishing the surface smooth using cement slurry.	SQM	902.89
Next			
	Total of H		
Next Next			
26	Total tiles Flooring/Marble Flooring	SQFT	45650
27	Internal Gypsum Plaster	SQft	84090.90909

Appendix G: Site Water Consumption Records

Case Study 2

S.no.	Date	Opening reading	Closing reading	Consumption	Usage
1	13/08/2019	116,908.00	117,284.00	376.00	Labour
2	14/08/2019	117,284.00	118,786.00	1,502.00	Labour
3	15/08/2019	118,786.00	119,236.00	450.00	Labour
4	16/08/2019	119,236.00	120,087.00	851.00	Labour
5	17/08/2019	120,087.00	120,306.00	219.00	Labour
6	18/08/2019	120,306.00	121,209.00	903.00	Labour
7	19/08/2019	121,209.00	122,507.00	1,298.00	Labour
8	20/08/2019	122,507.00	123,128.00	621.00	Labour
9	21/08/2019	123,128.00	124,987.00	1,859.00	Labour
10	22/08/2019	124,987.00	126,807.00	1,820.00	Labour
11	23/08/2019	126,807.00	128,019.00	1,212.00	Labour
12	24/08/2019	128,019.00	129,113.00	1,094.00	Labour
13	25/08/2019	129,113.00	130,208.00	1,095.00	Labour
14	26/08/2019	130,208.00	131,034.00	826.00	Labour
15	27/08/2019	131,034.00	132,711.00	1,677.00	Labour
16	28/08/2019	132,711.00	133,421.00	710.00	Labour
17	29/08/2019	133,421.00	134,604.00	1,183.00	Labour
18	30/08/2019	134,604.00	135,302.00	698.00	Labour

19	31/08/2019	135,302.00	136,706.00	1,404.00	Slab casting/ labour
20	01/09/2019	136,706.00	137,908.00	1,202.00	Slab curing/ labour
21	02/09/2019	137,908.00	140,102.00	2,194.00	Slab curing/ labour
22	03/09/2019	140,102.00	142,517.00	2,415.00	Slab curing/ labour
23	04/09/2019	142,517.00	144,121.00	1,604.00	Column curing/ labour
24	05/09/2019	144,121.00	145,917.00	1,796.00	Column curing/ labour
25	06/09/2019	145,917.00	147,801.00	1,884.00	Column curing/ labour
26	07/09/2019	147,801.00	149,009.00	1,208.00	Column curing/ labour
27	08/09/2019	149,009.00	151,901.00	2,892.00	Column curing/ labour
28	09/09/2019	151,901.00	153,408.00	1,507.00	Column curing/ labour
29	10/09/2019	153,408.00	155,203.00	1,795.00	Column curing/ labour
30	11/09/2019	155,203.00	157,003.00	1,800.00	Soiling/ labour
31	12/09/2019	157,003.00	158,982.00	1,979.00	Soiling/ labour
32	13/09/2019	158,982.00	160,279.00	1,297.00	Soiling/ labour
33	14/09/2019	160,279.00	161,484.00	1,205.00	Soiling/ labour
34	15/09/2019	161,484.00	163,487.00	2,003.00	Soiling/ labour
35	16/09/2019	163,487.00	165,982.00	2,495.00	Soiling/ labour
36	17/09/2019	165,982.00	168,019.00	2,037.00	Soiling/ labour
37	18/09/2019	168,019.00	170,780.00	2,761.00	Soiling/ labour
38	19/09/2019	170,780.00	172,324.00	1,544.00	Soiling/ labour
39	20/09/2019	172,324.00	174,682.00	2,358.00	PCC soiling / Labour
40	21/09/2019	174,682.00	175,002.00	320.00	PCC soiling / Labour
41	22/09/2019	175,002.00	177,006.00	2,004.00	PCC soiling / Labour
42	23/09/2019	177,006.00	178,970.00	1,964.00	Soiling / Labour

43	24/09/2019	178,970.00	180,100.00	1,130.00	Soiling / Labour
44	25/09/2019	180,100.00	181,984.00	1,884.00	Soiling / Labour
45	26/09/2019	181,984.00	183,142.00	1,158.00	Soiling / Labour
46	27/09/2019	183,142.00	184,138.00	996.00	Soiling / Labour
47	28/09/2019	184,138.00	185,008.00	870.00	Soiling / Labour
48	29/09/2019	185,008.00	185,781.00	773.00	Soiling / Labour
49	30/09/2019	185,781.00	185,957.00	176.00	Column casting / Labour
50	01/10/2019	185,957.00	187,007.00	1,050.00	Column casting / Labour
51	02/10/2019	187,007.00	189,408.00	2,401.00	Column curing / Labour
52	03/10/2019	189,408.00	191,304.00	1,896.00	Column curing / Labour
53	04/10/2019	191,304.00	193,101.00	1,797.00	Column curing / Labour
54	05/10/2019	193,101.00	194,983.00	1,882.00	Column curing / Labour
55	06/10/2019	194,983.00	196,782.00	1,799.00	PCC /curing
56	07/10/2019	196,782.00	198,130.00	1,348.00	PCC /curing
57	08/10/2019	198,130.00	199,817.00	1,687.00	PCC /curing
58	09/10/2019	199,817.00	201,997.00	2,180.00	curing
59	10/10/2019	201,997.00	204,844.00	2,847.00	curing
60	11/10/2019	204,844.00	206,866.00	2,022.00	curing
61	12/10/2019	206,866.00	208,504.00	1,638.00	curing
62	13/10/2019	208,504.00	209,448.00	944.00	Labour
63	14/10/2019	209,448.00	210,337.00	889.00	Labour
64	15/10/2019	210,337.00	211,640.00	1,303.00	Labour
65	16/10/2019	211,640.00	212,320.00	680.00	Labour
66	17/10/2019	212,320.00	213,173.00	853.00	Labour

67	18/10/2019	213,173.00	214,980.00	1,807.00	Labour
68	19/10/2019	214,980.00	216,004.00	1,024.00	Labour
69	20/10/2019	216,004.00	217,240.00	1,236.00	Labour
70	21/10/2019	217,240.00	218,128.00	888.00	Labour
71	22/10/2019	218,128.00	219,528.00	1,400.00	Labour
72	23/10/2019	219,528.00	220,348.00	820.00	Labour
73	24/10/2019	220,348.00	221,226.00	878.00	Labour
74	25/10/2019	221,226.00	222,440.00	1,214.00	Labour
75	26/10/2019	222,440.00	224,900.00	2,460.00	Labour
76	27/10/2019	224,900.00	225,117.00	217.00	Amawas
77	28/10/2019	225,117.00	226,009.00	892.00	Labour
78	29/10/2019	226,009.00	227,117.00	1,108.00	Labour
79	30/10/2019	227,117.00	228,310.00	1,193.00	Labour
80	31/10/2019	228,310.00	229,670.00	1,360.00	Labour
81	01/11/2019	229,670.00	230,250.00	580.00	Labour
82	02/11/2019	230,250.00	231,897.00	1,647.00	Labour
83	03/11/2019	231,897.00	232,660.00	763.00	Labour
84	04/11/2019	232,660.00	233,548.00	888.00	Labour
85	05/11/2019	233,548.00	234,920.00	1,372.00	Brick masonary /Labour
86	06/11/2019	234,920.00	236,008.00	1,088.00	Brick masonary /Labour
87	07/11/2019	236,008.00	237,113.00	1,105.00	Brick masonary /Labour
88	08/11/2019	237,113.00	238,510.00	1,397.00	Labour
89	09/11/2019	238,510.00	239,410.00	900.00	Labour
90	10/11/2019	239,410.00	240,342.00	932.00	Slab curing

91	11/11/2019	240,342.00	241,008.00	666.00	Slab curing
92	12/11/2019	241,008.00	242,120.00	1,112.00	Slab curing
93	13/11/2019	242,120.00	243,380.00	1,260.00	Slab curing
94	14/11/2019	243,380.00	245,120.00	1,740.00	Concrete / curing
95	15/11/2019	245,120.00	246,830.00	1,710.00	Concrete / curing
96	16/11/2019	246,830.00	248,490.00	1,660.00	Concrete / curing
97	17/11/2019	248,490.00	250,320.00	1,830.00	Concrete / curing
98	18/11/2019	250,320.00	252,009.00	1,689.00	Concrete / curing
99	19/11/2019	252,009.00	253,710.00	1,701.00	Concrete / curing
100	20/11/2019	253,710.00	255,310.00	1,600.00	Concrete / curing
101	21/11/2019	255,310.00	257,653.00	2,343.00	Concrete / curing
102	22/11/2019	257,653.00	259,641.00	1,988.00	Column casting / curing
103	23/11/2019	259,641.00	260,381.00	740.00	Column casting / curing
104	24/11/2019	260,381.00	261,401.00	1,020.00	Column casting / curing
105	25/11/2019	261,401.00	262,125.00	724.00	Column casting / curing
106	26/11/2019	262,125.00	265,230.00	3,105.00	Curing
107	27/11/2019	265,230.00	265,445.00	215.00	Curing
108	28/11/2019	265,445.00	266,320.00	875.00	Curing
109	29/11/2019	266,320.00	267,100.00	780.00	Curing
110	30/11/2019	267,100.00	268,570.00	1,470.00	Curing
111	01/12/2019	268,570.00	268,918.00	348.00	Only labour
112	02/12/2019	268,918.00	269,318.00	400.00	Only labour
113	03/12/2019	269,318.00	270,401.00	1,083.00	Only labour
114	04/12/2019	270,401.00	271,903.00	1,502.00	Only labour

115	05/12/2019	271,903.00	272,508.00	605.00	Only labour
116	06/12/2019	272,508.00	273,609.00	1,101.00	Only labour
117	07/12/2019	273,609.00	274,117.00	508.00	Only labour
118	08/12/2019	274,117.00	274,632.00	515.00	Labour/Masonary
119	09/12/2019	274,632.00	275,293.00	661.00	Labour/Masonary
120	10/12/2019	275,293.00	275,739.00	446.00	Labour
121	11/12/2019	275,739.00	276,542.00	803.00	Labour
122	12/12/2019	276,542.00	277,471.00	929.00	Labour
123	13/12/2019	277,471.00	278,328.00	857.00	Column casting / curing
124	14/12/2019	278,328.00	279,285.00	957.00	Curing
125	15/12/2019	279,285.00	280,128.00	843.00	Curing
126	16/12/2019	280,128.00	281,187.00	1,059.00	Curing
127	17/12/2019	281,187.00	281,571.00	384.00	Column casting / curing
128	18/12/2019	281,571.00	281,860.00	289.00	Curing
129	19/12/2019	281,860.00	282,101.00	241.00	Curing
130	20/12/2019	282,101.00	282,560.00	459.00	Curing
131	21/12/2019	282,560.00	284,136.00	1,576.00	Curing
132	22/12/2019	284,136.00	286,120.00	1,984.00	Curing/ concreting
133	23/12/2019	286,120.00	288,324.00	2,204.00	Curing/ concreting
134	24/12/2019	288,324.00	290,594.00	2,270.00	Curing/ concreting
135	25/12/2019	290,594.00	291,699.00	1,105.00	Curing/ concreting
136	26/12/2019	291,699.00	292,295.00	596.00	Curing/ concreting
137	27/12/2019	292,295.00	292,712.00	417.00	Curing/ concreting
138	28/12/2019	292,712.00	292,949.00	237.00	Curing/ concreting

139	29/12/2019	292,949.00	293,149.00	200.00	Curing/ concreting
140	30/12/2019	293,149.00	294,871.00	1,722.00	Column casting
141	31/12/2019	294,871.00	295,013.00	142.00	Curing/ labour
142	01/01/2020	295,013.00	295,463.00	450.00	Curing/ labour
143	02/01/2020	295,463.00	295,900.00	437.00	Curing/ labour
144	03/01/2020	295,900.00	296,251.00	351.00	Labour
145	04/01/2020	296,251.00	297,351.00	1,100.00	Labour
146	05/01/2020	297,351.00	299,895.00	2,544.00	Labour
147	06/01/2020	299,895.00	300,045.00	150.00	Labour
148	07/01/2020	300,045.00	300,105.00	60.00	Curing/ concreting
149	08/01/2020	300,105.00	300,200.00	95.00	Curing/ concreting
150	09/01/2020	300,200.00	301,649.00	1,449.00	Curing/ concreting
151	10/01/2020	301,649.00	302,343.00	694.00	Curing/ concreting
152	11/01/2020	302,343.00	303,494.00	1,151.00	Curing/ concreting
153	12/01/2020	303,494.00	305,006.00	1,512.00	Curing/ concreting
154	13/01/2020	305,006.00	306,539.00	1,533.00	Curing/ concreting
155	14/01/2020	306,539.00	308,046.00	1,507.00	Curing/ concreting
156	15/01/2020	308,046.00	309,948.00	1,902.00	Column casting
157	16/01/2020	309,948.00	310,097.00	149.00	Curing/ labour
158	17/01/2020	310,097.00	310,948.00	851.00	Curing/ labour
159	18/01/2020	310,948.00	312,251.00	1,303.00	Curing/ labour
160	19/01/2020	312,251.00	313,045.00	794.00	Labour
161	20/01/2020	313,045.00	314,151.00	1,106.00	Labour
162	21/01/2020	314,151.00	315,500.00	1,349.00	Labour

163	22/01/2020	315,500.00	317,009.00	1,509.00	Labour
164	23/01/2020	317,009.00	318,508.00	1,499.00	Curing/ concreting
165	24/01/2020	318,508.00	320,189.00	1,681.00	Curing/ concreting
166	25/01/2020	320,189.00	321,694.00	1,505.00	Curing/ concreting
167	26/01/2020	321,694.00	323,187.00	1,493.00	Curing/ concreting
168	27/01/2020	323,187.00	324,634.00	1,447.00	Curing/ concreting
169	28/01/2020	324,634.00	326,293.00	1,659.00	Curing/ concreting
170	29/01/2020	326,293.00	327,808.00	1,515.00	Curing/ concreting
171	30/01/2020	327,808.00	329,299.00	1,491.00	Curing/ concreting
172	31/01/2020	329,299.00	331,137.00	1,838.00	Column casting
173	01/02/2020	331,137.00	332,655.00	1,518.00	Curing/ labour
174	02/02/2020	332,655.00	334,230.00	1,575.00	Curing/ labour
175	03/02/2020	334,230.00	335,612.00	1,382.00	Curing/ labour
176	04/02/2020	335,612.00	337,251.00	1,639.00	Labour
177	05/02/2020	337,251.00	338,762.00	1,511.00	Labour
178	06/02/2020	338,762.00	340,220.00	1,458.00	Labour
179	07/02/2020	340,220.00	341,726.00	1,506.00	Labour
180	08/02/2020	341,726.00	343,100.00	1,374.00	Curing/ concreting
181	09/02/2020	343,100.00	344,631.00	1,531.00	Curing/ concreting
182	10/02/2020	344,631.00	346,143.00	1,512.00	Curing/ concreting
183	11/02/2020	346,143.00	347,602.00	1,459.00	Curing/ concreting
184	12/02/2020	347,602.00	349,121.00	1,519.00	Curing/ concreting
185	13/02/2020	349,121.00	350,651.00	1,530.00	Curing/ concreting
186	14/02/2020	350,651.00	352,231.00	1,580.00	Curing/ concreting

187	15/02/2020	352,231.00	353,654.00	1,423.00	Curing/ concreting
188	16/02/2020	353,654.00	355,183.00	1,529.00	Column casting
189	17/02/2020	355,183.00	358,530.00	3,347.00	Curing/ labour
190	18/02/2020	358,530.00	359,036.00	506.00	Curing/ labour
191	19/02/2020	359,036.00	360,365.00	1,329.00	Curing/ labour
192	20/02/2020	360,365.00	363,185.00	2,820.00	Labour
193	21/02/2020	363,185.00	365,034.00	1,849.00	Labour
194	22/02/2020	365,034.00	366,587.00	1,553.00	Labour
195	23/02/2020	366,587.00	367,042.00	455.00	Labour
196	24/02/2020	367,042.00	368,092.00	1,050.00	Curing/ concreting
197	25/02/2020	368,092.00	369,112.00	1,020.00	Curing/ concreting
198	26/02/2020	369,112.00	369,203.00	91.00	Curing/ concreting
199	27/02/2020	369,203.00	370,006.00	803.00	Curing/ concreting
200	28/02/2020	370,006.00	371,500.00	1,494.00	Curing/ concreting
201	29/02/2020	371,500.00	373,097.00	1,597.00	Curing/ concreting
202	01/03/2020	373,097.00	374,389.00	1,292.00	Curing/ concreting
203	02/03/2020	374,389.00	376,143.00	1,754.00	Curing/ concreting
204	03/03/2020	376,143.00	378,942.00	2,799.00	Column casting
205	04/03/2020	378,942.00	380,782.00	1,840.00	Curing/ labour
206	05/03/2020	380,782.00	382,142.00	1,360.00	Curing/ labour
207	06/03/2020	382,142.00	384,187.00	2,045.00	Curing/ labour
208	07/03/2020	384,187.00	386,312.00	2,125.00	Labour
209	08/03/2020	386,312.00	388,921.00	2,609.00	Labour
210	09/03/2020	388,921.00	394,786.00	5,865.00	Labour

211	10/03/2020	394,786.00	396,101.00	1,315.00	Labour
212	11/03/2020	396,101.00	398,987.00	2,886.00	Curing/ concreting
213	12/03/2020	398,987.00	401,368.00	2,381.00	Curing/ concreting
214	13/03/2020	401,368.00	405,989.00	4,621.00	Curing/ concreting
215	14/03/2020	405,989.00	409,138.00	3,149.00	Curing/ concreting
216	15/03/2020	409,138.00	411,048.00	1,910.00	Curing/ concreting
217	16/03/2020	411,048.00	413,241.00	2,193.00	Curing/ concreting
218	17/03/2020	413,241.00	415,831.00	2,590.00	Curing/ concreting
219	18/03/2020	415,831.00	417,137.00	1,306.00	Curing/ concreting
220	19/03/2020	417,137.00	419,439.00	2,302.00	Column casting
221	20/03/2020	419,439.00	421,789.00	2,350.00	Curing/ labour
222	21/03/2020	421,789.00	423,187.00	1,398.00	Curing/ labour
223	22/03/2020	423,187.00	425,381.00	2,194.00	Curing/ labour
224	23/03/2020				Lockdown
225	24/03/2020				Lockdown
226	25/03/2020				Lockdown
227	26/03/2020				Lockdown
228	27/03/2020				Lockdown
229	28/03/2020				Lockdown
230	29/03/2020				Lockdown
231	30/03/2020				Lockdown
232	31/03/2020				Lockdown
233	01/04/2020				Lockdown
234	02/04/2020				Lockdown

235	03/04/2020				Lockdown
236	04/04/2020				Lockdown
237	05/04/2020				Lockdown
238	06/04/2020				Lockdown
239	07/04/2020				Lockdown
240	08/04/2020				Lockdown
241	09/04/2020				Lockdown
242	10/04/2020				Lockdown
243	11/04/2020				Lockdown
244	12/04/2020				Lockdown
245	13/04/2020				Lockdown
246	14/04/2020				Lockdown
247	15/04/2020				Lockdown
248	16/04/2020				Lockdown
249	17/04/2020				Lockdown
250	18/04/2020				Lockdown
251	19/04/2020				Lockdown
252	20/04/2020				Lockdown
253	21/04/2020				Lockdown
254	22/04/2020				Lockdown
255	23/04/2020				Lockdown
256	24/04/2020				Lockdown
257	25/04/2020				Lockdown
258	26/04/2020				Lockdown

259	27/04/2020				Lockdown
260	28/04/2020				Lockdown
261	29/04/2020				Lockdown
262	30/04/2020				Lockdown
263	01/05/2020				Lockdown
264	02/05/2020				Lockdown
265	03/05/2020				Lockdown
266	04/05/2020	430,189.00	430,941.00	752.00	Curing/ concreting
267	05/05/2020	430,941.00	431,742.00	801.00	Curing/ concreting
268	06/05/2020	431,742.00	434,193.00	2,451.00	Curing/ concreting
269	07/05/2020	434,193.00	437,842.00	3,649.00	Curing/ concreting
270	08/05/2020	437,842.00	439,178.00	1,336.00	Curing/ concreting
271	09/05/2020	439,178.00	441,738.00	2,560.00	Curing/ concreting
272	10/05/2020	441,738.00	443,783.00	2,045.00	Curing/ concreting
273	11/05/2020	443,783.00	445,083.00	1,300.00	Curing/ concreting
274	12/05/2020	445,083.00	447,780.00	2,697.00	Curing/ concreting
275	13/05/2020	447,780.00	449,089.00	1,309.00	Curing/ concreting
276	14/05/2020	449,089.00	453,582.00	4,493.00	Curing/ concreting
277	15/05/2020	453,582.00	455,936.00	2,354.00	Curing/ concreting
278	16/05/2020	455,936.00	457,136.00	1,200.00	Curing/ concreting
279	17/05/2020	457,136.00	459,112.00	1,976.00	Curing/ concreting
280	18/05/2020	459,112.00	461,323.00	2,211.00	Curing/ concreting
281	19/05/2020	461,323.00	463,117.00	1,794.00	Curing/ concreting
282	20/05/2020	463,117.00	465,081.00	1,964.00	Curing

283	21/05/2020	465,081.00	468,782.00	3,701.00	Curing
284	22/05/2020	468,782.00	471,008.00	2,226.00	Curing
285	23/05/2020	471,008.00	473,101.00	2,093.00	Curing
286	24/05/2020	473,101.00	475,911.00	2,810.00	Curing
287	25/05/2020	475,911.00	477,991.00	2,080.00	Curing
288	26/05/2020	477,991.00	481,361.00	3,370.00	Curing
289	27/05/2020	481,361.00	483,768.00	2,407.00	Curing
290	28/05/2020	483,768.00	485,181.00	1,413.00	Curing
291	29/05/2020	485,181.00	487,319.00	2,138.00	Curing
292	30/05/2020	487,319.00	491,728.00	4,409.00	Curing
293	31/05/2020	491,728.00	493,219.00	1,491.00	Curing
294	01/06/2020	498,113.00	501,128.00	3,015.00	Curing
295	02/06/2020	501,128.00	503,982.00	2,854.00	Curing
296	03/06/2020	503,982.00	507,381.00	3,399.00	Curing
297	04/06/2020	507,381.00	510,988.00	3,607.00	Curing
298	05/06/2020	510,988.00	513,087.00	2,099.00	Curing
299	06/06/2020	513,087.00	515,011.00	1,924.00	Curing
300	07/06/2020	515,011.00	517,387.00	2,376.00	Curing
301	08/06/2020	517,387.00	519,168.00	1,781.00	Curing/ concreting
302	09/06/2020	519,168.00	521,386.00	2,218.00	Curing/ concreting
303	10/06/2020	521,386.00	523,138.00	1,752.00	Curing/ concreting
304	11/06/2020	523,138.00	525,712.00	2,574.00	Curing/ concreting
305	12/06/2020	525,712.00	527,013.00	1,301.00	Curing/ concreting
306	13/06/2020	527,013.00	529,834.00	2,821.00	Curing/ concreting

307	14/06/2020	529,834.00	531,786.00	1,952.00	Curing/ concreting
308	15/06/2020	531,786.00	533,289.00	1,503.00	Curing/ concreting
309	16/06/2020	533,289.00	535,186.00	1,897.00	Curing/ concreting
310	17/06/2020	535,186.00	539,138.00	3,952.00	Curing/ concreting
311	18/06/2020	539,138.00	541,011.00	1,873.00	Curing/ concreting
312	19/06/2020	541,011.00	543,138.00	2,127.00	Curing/ concreting
313	20/06/2020	543,138.00	546,007.00	2,869.00	Curing/ concreting
314	21/06/2020	546,007.00	548,721.00	2,714.00	Curing/ concreting
315	22/06/2020	548,721.00	551,032.00	2,311.00	Curing/ concreting
316	23/06/2020	551,032.00	554,971.00	3,939.00	Curing/ concreting
317	24/06/2020	554,971.00	557,386.00	2,415.00	Curing/ concreting
318	25/06/2020	557,386.00	559,186.00	1,800.00	Curing/ concreting
319	26/06/2020	559,186.00	562,319.00	3,133.00	Curing/ concreting
320	27/06/2020	562,319.00	565,187.00	2,868.00	Curing/ concreting
321	28/06/2020	565,187.00	567,971.00	2,784.00	Curing/ concreting
322	29/06/2020	567,971.00	571,382.00	3,411.00	Curing/ concreting
323	30/06/2020	571,382.00	573,771.00	2,389.00	Curing/ concreting
324	01/07/2020	573,771.00	576,138.00	2,367.00	Curing/ concreting
325	02/07/2020	576,138.00	579,786.00	3,648.00	Curing/ concreting
326	03/07/2020	579,786.00	583,182.00	3,396.00	Curing/ concreting
327	04/07/2020	583,182.00	588,136.00	4,954.00	Curing/ concreting
328	05/07/2020	588,136.00	591,321.00	3,185.00	Curing/ concreting
329	06/07/2020	591,321.00	596,451.00	5,130.00	Curing/ concreting
330	07/07/2020	596,451.00	602,139.00	5,688.00	Curing/ concreting

331	08/07/2020	602,139.00	608,286.00	6,147.00	Curing/ concreting
332	09/07/2020	608,286.00	614,328.00	6,042.00	Curing/ concreting
333	10/07/2020	614,328.00	619,419.00	5,091.00	Curing/ concreting
334	11/07/2020	619,419.00	625,128.00	5,709.00	Masonary / labour/ curing
335	12/07/2020	625,128.00	630,154.00	5,026.00	Masonary / labour/ curing
336	13/07/2020	630,154.00	635,981.00	5,827.00	Masonary / labour/ curing
337	14/07/2020	635,981.00	639,781.00	3,800.00	Masonary / labour/ curing
338	15/07/2020	639,781.00	644,127.00	4,346.00	Masonary / labour/ curing
339	16/07/2020	644,127.00	648,092.00	3,965.00	Masonary / labour/ curing/concreting
340	17/07/2020	648,092.00	655,429.00	7,337.00	Masonary / labour/ curing/concreting
341	18/07/2020	655,429.00	661,368.00	5,939.00	Masonary / labour/ curing/concreting
342	19/07/2020	661,368.00	667,219.00	5,851.00	Masonary / labour/ curing/concreting
343	20/07/2020	667,219.00	672,486.00	5,267.00	Masonary / labour/ curing/concreting
344	21/07/2020	672,486.00	681,336.00	8,850.00	Masonary / labour/ curing/concreting
345	22/07/2020	681,336.00	685,129.00	3,793.00	Masonary / labour/ curing/concreting
346	23/07/2020	685,129.00	691,973.00	6,844.00	Masonary / labour/ curing/concreting
347	24/07/2020	691,973.00	699,982.00	8,009.00	Masonary / labour/ curing/concreting
348	25/07/2020	699,982.00	706,219.00	6,237.00	Masonary / labour/ curing/concreting
349	26/07/2020	706,219.00	711,368.00	5,149.00	Masonary / labour/ curing/concreting
350	27/07/2020	711,368.00	716,259.00	4,891.00	Masonary / labour/ curing/concreting
351	28/07/2020	716,259.00	720,089.00	3,830.00	Masonary / labour/ curing/concreting
352	29/07/2020	720,089.00	725,982.00	5,893.00	Masonary / labour/ curing/concreting
353	30/07/2020	725,982.00	730,329.00	4,347.00	Masonary / labour/ curing/concreting
354	31/07/2020	730,329.00	736,486.00	6,157.00	Masonary / labour/ curing/concreting

355	01/08/2020	736,486.00	741,782.00	5,296.00	Masonary / labour/ curing/concreting
356	02/08/2020	741,782.00	747,398.00	5,616.00	Masonary / labour/ curing/concreting
357	03/08/2020	747,398.00	752,032.00	4,634.00	Masonary / labour/ curing/concreting
358	04/08/2020	752,032.00	757,279.00	5,247.00	Masonary / labour/ curing/concreting
359	05/08/2020	757,279.00	761,123.00	3,844.00	Masonary / labour/ curing/concreting
360	06/08/2020	761,123.00	763,286.00	2,163.00	Masonary / labour/ curing/concreting
361	07/08/2020	763,286.00	765,785.00	2,499.00	Masonary / labour/ curing/concreting
362	08/08/2020	765,785.00	769,826.00	4,041.00	Gypsum, masonary, curing
363	09/08/2020	769,826.00	775,049.00	5,223.00	Gypsum, masonary, curing
364	10/08/2020	775,049.00	779,694.00	4,645.00	Gypsum, masonary, curing
365	11/08/2020	779,694.00	784,826.00	5,132.00	Gypsum, masonary, curing
366	12/08/2020	784,826.00	790,701.00	5,875.00	Gypsum, masonary, curing
367	13/08/2020	790,701.00	795,627.00	4,926.00	Gypsum, masonary, curing
368	14/08/2020	795,627.00	801,016.00	5,389.00	Gypsum, masonary, curing
369	15/08/2020	801,016.00	805,472.00	4,456.00	Gypsum, masonary, curing
370	16/08/2020	805,472.00	810,481.00	5,009.00	Gypsum, masonary, curing
371	17/08/2020	810,481.00	816,061.00	5,580.00	Gypsum, masonary, curing
372	18/08/2020	816,061.00	821,275.00	5,214.00	Gypsum, masonary, curing
373	19/08/2020	821,275.00	825,933.00	4,658.00	Gypsum, masonary, curing
374	20/08/2020	825,933.00	830,901.00	4,968.00	Gypsum, masonary, curing
375	21/08/2020	830,901.00	836,797.00	5,896.00	Gypsum, masonary, curing
376	22/08/2020	836,797.00	842,476.00	5,679.00	Gypsum, masonary, curing
377	23/08/2020	842,476.00	847,024.00	4,548.00	Gypsum, masonary, curing
378	24/08/2020	847,024.00	850,565.00	3,541.00	Gypsum, masonary, curing

379	25/08/2020	850,565.00	854,684.00	4,119.00	Gypsum, masonary, curing
380	26/08/2020	854,684.00	858,786.00	4,102.00	Gypsum, masonary, curing
381	27/08/2020	858,786.00	861,601.00	2,815.00	Gypsum, masonary, curing
382	28/08/2020	861,601.00	866,975.00	5,374.00	Gypsum, masonary, curing
383	29/08/2020	866,975.00	872,617.00	5,642.00	Gypsum, masonary, curing
384	30/08/2020	872,617.00	878,847.00	6,230.00	Gypsum, masonary, curing
385	31/08/2020	878,847.00	887,077.00	8,230.00	Gypsum, masonary, curing
386	01/09/2020	887,077.00	895,353.00	8,276.00	Gypsum, masonary, curing
387	02/09/2020	895,353.00	903,286.00	7,933.00	Gypsum, masonary, curing
388	03/09/2020	903,286.00	910,655.00	7,369.00	Gypsum, masonary, curing
389	04/09/2020	910,655.00	919,213.00	8,558.00	Gypsum, masonary, curing
390	05/09/2020	919,213.00	927,059.00	7,846.00	Gypsum, masonary, curing
391	06/09/2020	927,059.00	936,203.00	9,144.00	Gypsum, masonary, curing
392	07/09/2020	936,203.00	943,002.00	6,799.00	Gypsum, masonary, curing
393	08/09/2020	943,002.00	948,574.00	5,572.00	Gypsum, masonary, curing
394	09/09/2020	948,574.00	953,718.00	5,144.00	Gypsum, masonary, curing
395	10/09/2020	953,718.00	958,482.00	4,764.00	Gypsum, masonary, curing
396	11/09/2020	958,482.00	965,825.00	7,343.00	Gypsum, masonary, curing
397	12/09/2020	965,825.00	973,071.00	7,246.00	Gypsum, masonary, curing
398	13/09/2020	973,071.00	981,012.00	7,941.00	Gypsum, masonary, curing
399	14/09/2020	981,012.00	982,715.00	1,703.00	Gypsum, masonary, curing
400	15/09/2020	982,715.00	985,064.00	2,349.00	Gypsum, masonary, curing
401	16/09/2020	985,064.00	990,007.00	4,943.00	Gypsum, masonary, curing
402	17/09/2020			-	

403	18/09/2020	990,007.00	995,821.00	5,814.00	Gypsum, masonary, curing
404	19/09/2020	995,821.00	1,002,571.00	6,750.00	Gypsum, masonary, curing
405	21/09/2020	1,002,571.00	1,005,827.00	3,256.00	Gypsum, masonary, curing
406	22/09/2020	1,005,827.00	1,008,089.00	2,262.00	Gypsum, masonary, curing
407	23/09/2020	1,008,089.00	1,009,149.00	1,060.00	Gypsum, masonary, curing
408	24/09/2020	1,009,149.00	1,010,574.00	1,425.00	Gypsum, masonary, curing
409	25/09/2020	1,010,574.00	1,012,137.00	1,563.00	Gypsum, masonary, curing
410	26/09/2020	1,012,137.00	1,014,370.00	2,233.00	Gypsum, masonary, curing
411	27/09/2020	1,014,370.00	1,016,059.00	1,689.00	Gypsum, masonary, curing
412	28/09/2020	1,016,059.00	1,019,829.00	3,770.00	Gypsum, masonary, curing
413	29/09/2020	1,019,829.00	1,022,622.00	2,793.00	Gypsum, masonary, curing
414	30/09/2020	1,022,622.00	1,028,254.00	5,632.00	Gypsum, masonary, curing
415	01/10/2020	1,028,254.00	1,030,054.00	1,800.00	Gypsum, masonary, curing, tile fixing
416	02/10/2020	1,030,054.00	1,034,157.00	4,103.00	Gypsum, masonary, curing, tile fixing
417	03/10/2020	1,034,157.00	1,039,387.00	5,230.00	Gypsum, masonary, curing, tile fixing
418	04/10/2020	1,039,387.00	1,044,980.00	5,593.00	Gypsum, masonary, curing, tile fixing
419	05/10/2020	1,044,980.00	1,050,254.00	5,274.00	Gypsum, masonary, curing, tile fixing
420	06/10/2020	1,050,254.00	1,054,485.00	4,231.00	Gypsum, masonary, curing, tile fixing
421	07/10/2020	1,054,485.00	1,058,310.00	3,825.00	Gypsum, masonary, curing, tile fixing
422	08/10/2020	1,058,310.00	1,062,958.00	4,648.00	Gypsum, masonary, curing, tile fixing
423	09/10/2020	1,062,958.00	1,064,159.00	1,201.00	Gypsum, masonary, curing, tile fixing
424	10/10/2020	1,064,159.00	1,071,147.00	6,988.00	Gypsum, masonary, curing, tile fixing
425	11/10/2020	1,071,147.00	1,075,602.00	4,455.00	Gypsum, masonary, curing, tile fixing
426	12/10/2020	1,075,602.00	1,081,074.00	5,472.00	Gypsum, masonary, curing, tile fixing

427	13/10/2020	1,081,074.00	1,085,556.00	4,482.00	Gypsum, masonary, curing, tile fixing
428	14/10/2020	1,085,556.00	1,089,549.00	3,993.00	Gypsum, masonary, curing, tile fixing
429	15/10/2020	1,089,549.00	1,092,351.00	2,802.00	Gypsum, masonary, curing, tile fixing
430	16/10/2020	1,092,351.00	1,096,209.00	3,858.00	Gypsum, masonary, curing, tile fixing
431	17/10/2020	1,096,209.00	1,102,019.00	5,810.00	Gypsum, masonary, curing, tile fixing
432	18/10/2020	1,102,019.00	1,109,158.00	7,139.00	Gypsum, masonary, curing, tile fixing
433	19/10/2020	1,109,158.00	1,111,599.00	2,441.00	Gypsum, masonary, curing, tile fixing
434	20/10/2020	1,111,599.00	1,113,572.00	1,973.00	Gypsum, masonary, curing, tile fixing
435	21/10/2020	1,113,572.00	1,116,145.00	2,573.00	Gypsum, masonary, curing, tile fixing
436	22/10/2020	1,116,145.00	1,119,756.00	3,611.00	Gypsum, masonary, curing, tile fixing
437	23/10/2020	1,119,756.00	1,124,205.00	4,449.00	Gypsum, masonary, curing, tile fixing
438	24/10/2020	1,124,205.00	1,128,102.00	3,897.00	Gypsum, masonary, curing, tile fixing
439	25/10/2020	1,128,102.00	1,132,710.00	4,608.00	Gypsum, masonary, curing, tile fixing
440	26/10/2020	1,132,710.00	1,136,205.00	3,495.00	Gypsum, masonary, curing, tile fixing
441	27/10/2020	1,136,205.00	1,137,711.00	1,506.00	Gypsum, masonary, curing, tile fixing
442	28/10/2020	1,137,711.00	1,138,171.00	460.00	Gypsum, masonary, curing, tile fixing
443	29/10/2020	1,138,171.00	1,139,520.00	1,349.00	Gypsum, masonary, curing, tile fixing
444	30/10/2020	1,139,520.00	1,140,227.00	707.00	Gypsum, masonary, curing, tile fixing
445	31/10/2020	1,140,227.00	1,143,127.00	2,900.00	Gypsum, masonary, curing, tile fixing
446	01/11/2020	1,143,127.00	1,144,235.00	1,108.00	Gypsum, masonary, curing, tile fixing
447	02/11/2020	1,144,235.00	1,145,320.00	1,085.00	Gypsum, masonary, curing, tile fixing
448	03/11/2020	1,145,320.00	1,146,599.00	1,279.00	Gypsum, masonary, curing, tile fixing
449	04/11/2020	1,146,599.00	1,147,074.00	475.00	Gypsum, masonary, curing, tile fixing
450	05/11/2020	1,147,074.00	1,148,663.00	1,589.00	Gypsum, masonary, curing, tile fixing

451	06/11/2020	1,148,663.00	1,151,413.00	2,750.00	Gypsum, masonary, curing, tile fixing
452	07/11/2020	1,151,413.00	1,153,682.00	2,269.00	Gypsum, masonary, curing, tile fixing
453	08/11/2020	1,153,682.00	1,155,721.00	2,039.00	Gypsum, masonary, curing, tile fixing
454	09/11/2020	1,155,721.00	1,158,456.00	2,735.00	Gypsum, masonary, curing, tile fixing
455	10/11/2020	1,158,456.00	1,159,236.00	780.00	Gypsum, masonary, curing, tile fixing
456	11/11/2020	1,159,236.00	1,161,231.00	1,995.00	Gypsum, masonary, curing, tile fixing
457	12/11/2020	1,161,231.00	1,163,389.00	2,158.00	Gypsum, masonary, curing, tile fixing
458	13/11/2020	1,163,389.00	1,165,145.00	1,756.00	Gypsum, masonary, curing, tile fixing
459	14/11/2020	1,165,145.00	1,167,315.00	2,170.00	Gypsum, masonary, curing, tile fixing
460	15/11/2020	1,167,315.00	1,169,456.00	2,141.00	Gypsum, masonary, curing, tile fixing
461	16/11/2020	1,169,456.00	1,171,725.00	2,269.00	Gypsum, masonary, curing, tile fixing
462	17/11/2020	1,171,725.00	1,173,856.00	2,131.00	Gypsum, masonary, curing, tile fixing
463	18/11/2020	1,173,856.00	1,175,205.00	1,349.00	Gypsum, masonary, curing, tile fixing
464	19/11/2020	1,175,205.00	1,177,102.00	1,897.00	Gypsum, masonary, curing, tile fixing
465	20/11/2020	1,177,102.00	1,179,201.00	2,099.00	Gypsum, masonary, curing, tile fixing
466	21/11/2020	1,179,201.00	1,181,923.00	2,722.00	Gypsum, masonary, curing, tile fixing
467	22/11/2020	1,181,923.00	1,183,171.00	1,248.00	Gypsum, masonary, curing, tile fixing
468	23/11/2020	1,183,171.00	1,185,520.00	2,349.00	Gypsum, masonary, curing, tile fixing
469	24/11/2020	1,185,520.00	1,187,811.00	2,291.00	Gypsum, masonary, curing, tile fixing
470	25/11/2020	1,187,811.00	1,189,074.00	1,263.00	Gypsum, masonary, curing, tile fixing
471	26/11/2020	1,189,074.00	1,191,208.00	2,134.00	Gypsum, masonary, curing, tile fixing
472	27/11/2020	1,191,208.00	1,193,209.00	2,001.00	Gypsum, masonary, curing, tile fixing
473	28/11/2020	1,193,209.00	1,196,923.00	3,714.00	Gypsum, masonary, curing, tile fixing
474	29/11/2020	1,196,923.00	1,198,700.00	1,777.00	Gypsum, masonary, curing, tile fixing

475	30/11/2020	1,198,700.00	1,200,895.00	2,195.00	Gypsum, masonary, curing, tile fixing
476	01/12/2020	1,200,895.00	1,201,492.00	597.00	Gypsum, masonary, curing, tile fixing
477	02/12/2020	1,201,492.00	1,203,722.00	2,230.00	Gypsum, masonary, curing, tile fixing
478	03/12/2020	1,203,722.00	1,204,867.00	1,145.00	Gypsum, masonary, curing, tile fixing
479	04/12/2020	1,204,867.00	1,206,710.00	1,843.00	Gypsum, masonary, curing, tile fixing
480	05/12/2020	1,206,710.00	1,208,236.00	1,526.00	Gypsum, masonary, curing, tile fixing
481	06/12/2020	1,208,236.00	1,210,913.00	2,677.00	Gypsum, masonary, curing, tile fixing
482	07/12/2020	1,210,913.00	1,211,810.00	897.00	Gypsum, masonary, curing, tile fixing
483	08/12/2020	1,211,810.00	1,212,645.00	835.00	Gypsum, masonary, curing, tile fixing
484	09/12/2020	1,212,645.00	1,213,730.00	1,085.00	Gypsum, masonary, curing, tile fixing
485	10/12/2020	1,213,730.00	1,214,617.00	887.00	Gypsum, masonary, curing, tile fixing
486	11/12/2020	1,214,617.00	1,216,983.00	2,366.00	Gypsum, masonary, curing, tile fixing
487	12/12/2020	1,216,983.00	1,217,812.00	829.00	Gypsum, masonary, curing, tile fixing
488	13/12/2020	1,217,812.00	1,219,819.00	2,007.00	Gypsum, masonary, curing, tile fixing
489	14/12/2020	1,219,819.00	1,220,112.00	293.00	Gypsum, masonary, curing, tile fixing
490	15/12/2020	1,220,112.00	1,222,629.00	2,517.00	Gypsum, masonary, curing, tile fixing
491	16/12/2020	1,222,629.00	1,224,788.00	2,159.00	Gypsum, plastering, curing, tile fixing
492	17/12/2020	1,224,788.00	1,226,821.00	2,033.00	Gypsum, plastering, curing, tile fixing
493	18/12/2020	1,226,821.00	1,228,606.00	1,785.00	Gypsum, plastering, curing, tile fixing
494	19/12/2020	1,228,606.00	1,229,567.00	961.00	Gypsum, plastering, curing, tile fixing
495	20/12/2020	1,229,567.00	1,230,101.00	534.00	Gypsum, plastering, curing, tile fixing
496	21/12/2020	1,230,101.00	1,232,762.00	2,661.00	Gypsum, plastering, curing, tile fixing
497	22/12/2020	1,232,762.00	1,233,209.00	447.00	Gypsum, plastering, curing, tile fixing
498	23/12/2020	1,233,209.00	1,234,231.00	1,022.00	Gypsum, plastering, curing, tile fixing

499	24/12/2020	1,234,231.00	1,235,810.00	1,579.00	Gypsum, plastering, curing, tile fixing
500	25/12/2020	1,235,810.00	1,236,473.00	663.00	Gypsum, plastering, curing, tile fixing
501	26/12/2020	1,236,473.00	1,238,727.00	2,254.00	Gypsum, plastering, curing, tile fixing
502	27/12/2020	1,238,727.00	1,240,171.00	1,444.00	Gypsum, plastering, curing, tile fixing
503	28/12/2020	1,240,171.00	1,241,627.00	1,456.00	Gypsum, plastering, curing, tile fixing
504	29/12/2020	1,241,627.00	1,242,950.00	1,323.00	Gypsum, plastering, curing, tile fixing
505	30/12/2020	1,242,950.00	1,244,299.00	1,349.00	Gypsum, plastering, curing, tile fixing
506	31/12/2020	1,244,299.00	1,245,498.00	1,199.00	Gypsum, plastering, curing, tile fixing
507	01/01/2021	1,245,498.00	1,247,241.00	1,743.00	Gypsum, plastering, curing, tile fixing
508	02/01/2021	1,247,241.00	1,248,895.00	1,654.00	Gypsum, plastering, curing, tile fixing
509	03/01/2021	1,248,895.00	1,249,292.00	397.00	Gypsum, plastering, curing, tile fixing
510	04/01/2021	1,249,292.00	1,251,521.00	2,229.00	Gypsum, plastering, curing, tile fixing
511	05/01/2021	1,251,521.00	1,253,320.00	1,799.00	Gypsum, plastering, curing, tile fixing
512	06/01/2021	1,253,320.00	1,254,730.00	1,410.00	Gypsum, plastering, curing, tile fixing
513	07/01/2021	1,254,730.00	1,255,688.00	958.00	Gypsum, plastering, curing, tile fixing
514	08/01/2021	1,255,688.00	1,257,227.00	1,539.00	Gypsum, plastering, curing, tile fixing
515	09/01/2021	1,257,227.00	1,260,235.00	3,008.00	Gypsum, plastering, curing, tile fixing
516	10/01/2021	1,260,235.00	1,262,910.00	2,675.00	Gypsum, plastering, curing, tile fixing
517	11/01/2021	1,262,910.00	1,264,567.00	1,657.00	Gypsum, plastering, curing, tile fixing
518	12/01/2021	1,264,567.00	1,266,616.00	2,049.00	Gypsum, plastering, curing, tile fixing
519	13/01/2021	1,266,616.00	1,268,100.00	1,484.00	Gypsum, plastering, curing, tile fixing
520	14/01/2021	1,268,100.00	1,270,412.00	2,312.00	Gypsum, plastering, curing, tile fixing
521	15/01/2021	1,270,412.00	1,272,775.00	2,363.00	Gypsum, plastering, curing, tile fixing
522	16/01/2021	1,272,775.00	1,274,200.00	1,425.00	Gypsum, plastering, curing, tile fixing

523	17/01/2021	1,274,200.00	1,276,223.00	2,023.00	Gypsum, plastering, curing, tile fixing
524	18/01/2021	1,276,223.00	1,278,721.00	2,498.00	Gypsum, plastering, curing, tile fixing
525	19/01/2021	1,278,721.00	1,280,912.00	2,191.00	Gypsum, plastering, curing, tile fixing
526	20/01/2021	1,280,912.00	1,282,212.00	1,300.00	Gypsum, plastering, curing, tile fixing
527	21/01/2021	1,282,212.00	1,284,171.00	1,959.00	Gypsum, plastering, curing, tile fixing
528	22/01/2021	1,284,171.00	1,286,209.00	2,038.00	Gypsum, plastering, curing, tile fixing
529	23/01/2021	1,286,209.00	1,288,231.00	2,022.00	Gypsum, plastering, curing, tile fixing
530	24/01/2021	1,288,231.00	1,290,953.00	2,722.00	Gypsum, plastering, curing, tile fixing
531	25/01/2021	1,290,953.00	1,292,124.00	1,171.00	Gypsum, plastering, curing, tile fixing
532	26/01/2021	1,292,124.00	1,294,818.00	2,694.00	Gypsum, plastering, curing, tile fixing
533	27/01/2021	1,294,818.00	1,296,119.00	1,301.00	Gypsum, plastering, curing, tile fixing
534	28/01/2021	1,296,119.00	1,298,277.00	2,158.00	Gypsum, plastering, curing, tile fixing
535	29/01/2021	1,298,277.00	1,300,980.00	2,703.00	Gypsum, plastering, curing, tile fixing
536	30/01/2021	1,300,980.00	1,302,255.00	1,275.00	Gypsum, plastering, curing, tile fixing
537	31/01/2021	1,302,255.00	1,304,588.00	2,333.00	Gypsum, plastering, curing, tile fixing
538	01/02/2021	1,304,588.00	1,306,123.00	1,535.00	Gypsum, plastering, curing, tile fixing
539	02/02/2021	1,306,123.00	1,308,787.00	2,664.00	Gypsum, plastering, curing, tile fixing
540	03/02/2021	1,308,787.00	1,310,321.00	1,534.00	Gypsum, plastering, curing, tile fixing
541	04/02/2021	1,310,321.00	1,312,997.00	2,676.00	Gypsum, plastering, curing, tile fixing
542	05/02/2021	1,312,997.00	1,314,211.00	1,214.00	Gypsum, plastering, curing, tile fixing
543	06/02/2021	1,314,211.00	1,316,799.00	2,588.00	Gypsum, plastering, curing, tile fixing
544	07/02/2021	1,316,799.00	1,318,067.00	1,268.00	Gypsum, plastering, curing, tile fixing
545	08/02/2021	1,318,067.00	1,320,566.00	2,499.00	Gypsum, plastering, curing, tile fixing
546	09/02/2021	1,320,566.00	1,322,917.00	2,351.00	Gypsum, plastering, curing, tile fixing

547	10/02/2021	1,322,917.00	1,324,331.00	1,414.00	Gypsum, plastering, curing, tile fixing
548	11/02/2021	1,324,331.00	1,326,825.00	2,494.00	Gypsum, plastering, curing, tile fixing
549	12/02/2021	1,326,825.00	1,328,207.00	1,382.00	Gypsum, plastering, curing, tile fixing
550	13/02/2021	1,328,207.00	1,330,125.00	1,918.00	Gypsum, plastering, curing, tile fixing
551	14/02/2021	1,330,125.00	1,332,250.00	2,125.00	Gypsum, plastering, curing, tile fixing
552	15/02/2021	1,332,250.00	1,334,002.00	1,752.00	Gypsum, plastering, curing, tile fixing
553	16/02/2021	1,334,002.00	1,336,111.00	2,109.00	Gypsum, plastering, curing, tile fixing
554	17/02/2021	1,336,111.00	1,338,433.00	2,322.00	Gypsum, plastering, curing, tile fixing
555	18/02/2021	1,338,433.00	1,340,289.00	1,856.00	Gypsum, plastering, curing, tile fixing
556	19/02/2021	1,340,289.00	1,342,680.00	2,391.00	Gypsum, plastering, curing, tile fixing
557	20/02/2021	1,342,680.00	1,344,964.00	2,284.00	Gypsum, plastering, curing, tile fixing
558	21/02/2021	1,344,964.00	1,346,767.00	1,803.00	Gypsum, plastering, curing, tile fixing
559	22/02/2021	1,346,767.00	1,348,223.00	1,456.00	Gypsum, plastering, curing, tile fixing
560	23/02/2021	1,348,223.00	1,350,199.00	1,976.00	Gypsum, plastering, curing, tile fixing
561	24/02/2021	1,350,199.00	1,352,123.00	1,924.00	Gypsum, plastering, curing, tile fixing
562	25/02/2021	1,352,123.00	1,354,466.00	2,343.00	Gypsum, plastering, curing, tile fixing
563	26/02/2021	1,354,466.00	1,357,891.00	3,425.00	Gypsum, plastering, curing, tile fixing
564	27/02/2021	1,357,891.00	1,359,345.00	1,454.00	Gypsum, plastering, curing, tile fixing
565	28/02/2021	1,359,345.00	1,361,541.00	2,196.00	Gypsum, plastering, curing, tile fixing
566	01/03/2021	1,361,541.00	1,363,835.00	2,294.00	Gypsum, plastering, curing, tile fixing
567	02/03/2021	1,363,835.00	1,365,716.00	1,881.00	Gypsum, plastering, curing, tile fixing
568	03/03/2021	1,365,716.00	1,367,413.00	1,697.00	Gypsum, plastering, curing, tile fixing
569	04/03/2021	1,367,413.00	1,370,154.00	2,741.00	Gypsum, plastering, curing, tile fixing
570	05/03/2021	1,370,154.00	1,372,528.00	2,374.00	Gypsum, plastering, curing, tile fixing

571	06/03/2021	1,372,528.00	1,374,321.00	1,793.00	Gypsum, plastering, curing, tile fixing
572	07/03/2021	1,374,321.00	1,376,626.00	2,305.00	Gypsum, plastering, curing, tile fixing
573	08/03/2021	1,376,626.00	1,378,761.00	2,135.00	Gypsum, plastering, curing, tile fixing
574	09/03/2021	1,378,761.00	1,380,017.00	1,256.00	Gypsum, plastering, curing, tile fixing
575	10/03/2021	1,380,017.00	1,382,633.00	2,616.00	Gypsum, plastering, curing, tile fixing
576	11/03/2021	1,382,633.00	1,384,525.00	1,892.00	Gypsum, plastering, curing, tile fixing
577	12/03/2021	1,384,525.00	1,386,111.00	1,586.00	Gypsum, plastering, curing, tile fixing
578	13/03/2021	1,386,111.00	1,388,313.00	2,202.00	Gypsum, plastering, curing, tile fixing
579	14/03/2021	1,388,313.00	1,390,777.00	2,464.00	Gypsum, plastering, curing, tile fixing
580	15/03/2021	1,390,777.00	1,392,015.00	1,238.00	Gypsum, plastering, curing, tile fixing
581	16/03/2021	1,392,015.00	1,394,455.00	2,440.00	Gypsum, plastering, curing, tile fixing
582	17/03/2021	1,394,455.00	1,396,313.00	1,858.00	Gypsum, plastering, curing, tile fixing
583	18/03/2021	1,396,313.00	1,398,977.00	2,664.00	Gypsum, plastering, curing, tile fixing
584	19/03/2021	1,398,977.00	1,400,738.00	1,761.00	Gypsum, plastering, curing, tile fixing
585	20/03/2021	1,400,738.00	1,401,611.00	873.00	Gypsum, plastering, curing, tile fixing
586	21/03/2021	1,401,611.00	1,403,980.00	2,369.00	Gypsum, plastering, curing, tile fixing
587	22/03/2021	1,403,980.00	1,405,138.00	1,158.00	Gypsum, plastering, curing, tile fixing
588	23/03/2021	1,405,138.00	1,407,334.00	2,196.00	Gypsum, plastering, curing, tile fixing
589	24/03/2021	1,407,334.00	1,409,553.00	2,219.00	Gypsum, plastering, curing, tile fixing
590	25/03/2021	1,409,553.00	1,411,449.00	1,896.00	Gypsum, plastering, curing, tile fixing
591	26/03/2021	1,411,449.00	1,413,857.00	2,408.00	Gypsum, plastering, curing, tile fixing
592	27/03/2021	1,413,857.00	1,415,447.00	1,590.00	Gypsum, plastering, curing, tile fixing
593	28/03/2021	1,415,447.00	1,417,372.00	1,925.00	Gypsum, plastering, curing, tile fixing
594	29/03/2021	1,417,372.00	1,419,047.00	1,675.00	Gypsum, plastering, curing, tile fixing

595	30/03/2021	1,419,047.00	1,421,033.00	1,986.00	Gypsum, plastering, curing, tile fixing
596	31/03/2021	1,421,033.00	1,423,071.00	2,038.00	Gypsum, plastering, curing, tile fixing
597	01/04/2021	1,423,071.00	1,425,034.00	1,963.00	Gypsum, plastering, curing, tile fixing
598	02/04/2021	1,425,034.00	1,427,277.00	2,243.00	Gypsum, plastering, curing, tile fixing
599	03/04/2021	1,427,277.00	1,429,312.00	2,035.00	Gypsum, plastering, curing, tile fixing
600	04/04/2021	1,429,312.00	1,431,653.00	2,341.00	Gypsum, plastering, curing, tile fixing
601	05/04/2021	1,431,653.00	1,433,602.00	1,949.00	Gypsum, plastering, curing, tile fixing
602	06/04/2021	1,433,602.00	1,434,997.00	1,395.00	Gypsum, plastering, curing, tile fixing
603	07/04/2021	1,434,997.00	1,437,111.00	2,114.00	Gypsum, plastering, curing, tile fixing
604	08/04/2021	1,437,111.00	1,439,613.00	2,502.00	Gypsum, plastering, curing, tile fixing
605	09/04/2021	1,439,613.00	1,441,791.00	2,178.00	Gypsum, plastering, curing, tile fixing
606	10/04/2021	1,441,791.00	1,443,376.00	1,585.00	Gypsum, plastering, curing, tile fixing
607	11/04/2021	1,443,376.00	1,445,839.00	2,463.00	Gypsum, plastering, curing, tile fixing
608	12/04/2021	1,445,839.00	1,447,780.00	1,941.00	Gypsum, plastering, curing, tile fixing
609	13/04/2021	1,447,780.00	1,449,183.00	1,403.00	Gypsum, plastering, curing, tile fixing
610	14/04/2021	1,449,183.00	1,451,466.00	2,283.00	Gypsum, plastering, curing, tile fixing
611	15/04/2021	1,451,466.00	1,453,375.00	1,909.00	Gypsum, plastering, curing, tile fixing
612	16/04/2021	1,453,375.00	1,456,107.00	2,732.00	Gypsum, plastering, curing, tile fixing
613	17/04/2021	1,456,107.00	1,458,556.00	2,449.00	Gypsum, plastering, curing, tile fixing
614	18/04/2021	1,458,556.00	1,460,814.00	2,258.00	Gypsum, plastering, curing, tile fixing
615	19/04/2021	1,460,814.00	1,462,293.00	1,479.00	Gypsum, plastering, curing, tile fixing
616	20/04/2021	1,462,293.00	1,464,272.00	1,979.00	Gypsum, plastering, curing, tile fixing
617	21/04/2021	1,464,272.00	1,466,033.00	1,761.00	Gypsum, plastering, curing, tile fixing
618	22/04/2021	1,466,033.00	1,468,302.00	2,269.00	Gypsum, plastering, curing, tile fixing

619	23/04/2021	1,468,302.00	1,470,412.00	2,110.00	Gypsum, plastering, curing, tile fixing
620	24/04/2021	1,470,412.00	1,472,403.00	1,991.00	Gypsum, plastering, curing, tile fixing
621	25/04/2021	New meter	3,466.00	3,466.00	Gypsum, plastering, curing, tile fixing
622	26/04/2021	3,466.00	6,832.00	3,366.00	Gypsum, plastering, curing, tile fixing
623	27/04/2021	6,832.00	9,123.00	2,291.00	Gypsum, plastering, curing, tile fixing
624	28/04/2021	9,123.00	12,255.00	3,132.00	Gypsum, plastering, curing, tile fixing
625	29/04/2021	12,255.00	16,683.00	4,428.00	Gypsum, plastering, curing, tile fixing
626	30/04/2021	16,683.00	19,736.00	3,053.00	Gypsum, plastering, curing, tile fixing
627	01/05/2021	19,736.00	22,863.00	3,127.00	Gypsum, plastering, curing, tile fixing
628	02/05/2021	22,863.00	25,992.00	3,129.00	Gypsum, plastering, curing, tile fixing
629	03/05/2021	25,992.00	30,479.00	4,487.00	Gypsum, plastering, curing, tile fixing
630	04/05/2021	30,479.00	34,351.00	3,872.00	Gypsum, plastering, curing, tile fixing
631	05/05/2021	34,351.00	38,258.00	3,907.00	Gypsum, plastering, curing, tile fixing
632	06/05/2021	38,258.00	41,741.00	3,483.00	Gypsum, plastering, curing, tile fixing
633	07/05/2021	41,741.00	44,952.00	3,211.00	Gypsum, plastering, curing, tile fixing
634	08/05/2021	44,952.00	48,456.00	3,504.00	Gypsum, plastering, curing, tile fixing
635	09/05/2021	48,456.00	52,638.00	4,182.00	Gypsum, plastering, curing, tile fixing
636	10/05/2021	52,638.00	57,963.00	5,325.00	Gypsum, plastering, curing, tile fixing
637	11/05/2021	57,963.00	61,173.00	3,210.00	Gypsum, plastering, curing, tile fixing
638	12/05/2021	61,173.00	65,546.00	4,373.00	Gypsum, plastering, curing, tile fixing
639	13/05/2021	65,546.00	70,349.00	4,803.00	Gypsum, plastering, curing, tile fixing
640	14/05/2021	70,349.00	74,423.00	4,074.00	Gypsum, plastering, curing, tile fixing
641	15/05/2021	74,423.00	79,479.00	5,056.00	Gypsum, plastering, curing, tile fixing
642	16/05/2021	79,479.00	83,927.00	4,448.00	Gypsum, plastering, curing, tile fixing

643	17/05/2021	83,927.00	88,590.00	4,663.00	Gypsum, plastering, curing, tile fixing
644	18/05/2021	88,590.00	92,298.00	3,708.00	Gypsum, plastering, curing, tile fixing
645	19/05/2021	92,298.00	97,557.00	5,259.00	Gypsum, plastering, curing, tile fixing
646	20/05/2021	97,557.00	101,397.00	3,840.00	Gypsum, plastering, curing, tile fixing
647	21/05/2021	101,397.00	105,668.00	4,271.00	Gypsum, plastering, curing, tile fixing
648	22/05/2021	105,668.00	110,252.00	4,584.00	Gypsum, plastering, curing, tile fixing
649	23/05/2021	110,252.00	115,529.00	5,277.00	Gypsum, plastering, curing, tile fixing
650	24/05/2021	115,529.00	120,439.00	4,910.00	Gypsum, plastering, curing, tile fixing
651	25/05/2021	120,439.00	125,696.00	5,257.00	Gypsum, plastering, curing, tile fixing
652	26/05/2021	125,696.00	128,019.00	2,323.00	Gypsum, plastering, curing, tile fixing
653	27/05/2021	128,019.00	131,952.00	3,933.00	Gypsum, plastering, curing, tile fixing
654	28/05/2021	131,952.00	134,149.00	2,197.00	Gypsum, plastering, curing, tile fixing
655	29/05/2021	134,149.00	138,437.00	4,288.00	Gypsum, plastering, curing, tile fixing
656	30/05/2021	138,437.00	140,529.00	2,092.00	Gypsum, plastering, curing, tile fixing
657	31/05/2021	140,529.00	144,213.00	3,684.00	Gypsum, plastering, curing, tile fixing
658	01/06/2021	144,213.00	148,213.00	4,000.00	Gypsum, plastering, curing, tile fixing
659	02/06/2021	148,213.00	152,753.00	4,540.00	Gypsum, plastering, curing, tile fixing
660	03/06/2021	152,753.00	158,706.00	5,953.00	Gypsum, plastering, curing, tile fixing
661	04/06/2021	158,706.00	165,602.00	6,896.00	Gypsum, plastering, curing, tile fixing
662	05/06/2021	165,602.00	170,319.00	4,717.00	Gypsum, plastering, curing, tile fixing
663	06/06/2021	170,319.00	180,461.00	10,142.00	Gypsum, plastering, curing, tile fixing
664	07/06/2021	180,461.00	190,115.00	9,654.00	vdc, tile fixing, gypsum
665	08/06/2021	190,115.00	200,716.00	10,601.00	vdc, tile fixing, gypsum
666	09/06/2021	200,716.00	210,752.00	10,036.00	vdc, tile fixing, gypsum

667	10/06/2021	210,752.00	220,317.00	9,565.00	vdc, tile fixing, gypsum
668	11/06/2021	220,317.00	231,516.00	11,199.00	vdc, tile fixing, gypsum
669	12/06/2021	231,516.00	246,893.00	15,377.00	vdc, tile fixing, gypsum
670	13/06/2021	246,893.00	260,128.00	13,235.00	vdc, tile fixing, gypsum
671	14/06/2021	260,128.00	265,527.00	5,399.00	vdc, tile fixing, gypsum
672	15/06/2021	265,527.00	270,845.00	5,318.00	vdc, tile fixing, gypsum
673	16/06/2021	270,845.00	274,189.00	3,344.00	vdc, tile fixing, gypsum
674	17/06/2021	274,189.00	277,236.00	3,047.00	vdc, tile fixing, gypsum
675	18/06/2021	277,236.00	280,188.00	2,952.00	vdc, tile fixing, gypsum
676	19/06/2021	280,188.00	295,323.00	15,135.00	ramp casting, curing, tile fixing, gypsum
677	20/06/2021	295,323.00	311,622.00	16,299.00	ramp casting, curing, tile fixing, gypsum
678	21/06/2021	311,622.00	326,669.00	15,047.00	ramp casting, curing, tile fixing, gypsum
679	22/06/2021	326,669.00	343,941.00	17,272.00	ramp casting, curing, tile fixing, gypsum
680	23/06/2021	343,941.00	356,238.00	12,297.00	ramp casting, curing, tile fixing, gypsum
681	24/06/2021	356,238.00	368,377.00	12,139.00	ramp casting, curing, tile fixing, gypsum
682	25/06/2021	368,377.00	373,803.00	5,426.00	ramp casting, curing, tile fixing, gypsum
683	26/06/2021	373,803.00	378,418.00	4,615.00	ramp casting, curing, tile fixing, gypsum
684	27/06/2021	378,418.00	383,423.00	5,005.00	ramp casting, curing, tile fixing, gypsum
685	28/06/2021	383,423.00	388,649.00	5,226.00	ramp casting, curing, tile fixing, gypsum
686	29/06/2021	388,649.00	394,351.00	5,702.00	ramp casting, curing, tile fixing, gypsum
687	30/06/2021	394,351.00	398,412.00	4,061.00	ramp casting, curing, tile fixing, gypsum
688	01/07/2021	398,412.00	402,307.00	3,895.00	ramp casting, curing, tile fixing, gypsum
689	02/07/2021	402,307.00	406,262.00	3,955.00	Gypsum, curing, tile fixing
690	03/07/2021	406,262.00	410,048.00	3,786.00	Gypsum, curing, tile fixing

691	04/07/2021	410,048.00	413,943.00	3,895.00	Gypsum, curing, tile fixing
692	05/07/2021	413,943.00	417,864.00	3,921.00	Gypsum, curing, tile fixing
693	06/07/2021	417,864.00	421,876.00	4,012.00	Gypsum, curing, tile fixing
694	07/07/2021	421,876.00	425,711.00	3,835.00	Gypsum, curing, tile fixing
695	08/07/2021	425,711.00	429,507.00	3,796.00	Gypsum, curing, tile fixing
696	09/07/2021	429,507.00	433,493.00	3,986.00	Gypsum, curing, tile fixing
697	10/07/2021	433,493.00	437,618.00	4,125.00	Gypsum, curing, tile fixing
698	11/07/2021	437,618.00	442,912.00	5,294.00	Gypsum, curing, tile fixing
699	12/07/2021	442,912.00	448,508.00	5,596.00	Gypsum, curing, tile fixing