ADDIS ABABA UNIVERSITY

COLLEGE OF TECHNOLOGY & BUILT ENVIRONMENT

SCHOOL OF BUILT ENVIRONMENT

ASSESSMENT OF ROOFTOP RAINWATER HARVESTING POTENTIAL AS AN ALTERNATIVE WATER SOURCE FOR THE COMMERCIAL BUILDINGS IN MERKATO, ADDIS ABABA

BY

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ADDIS ABABA, ETHIOPIA

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I hereby declare that all information in this document has been obtained and presented by academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this study.

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ABSTRACT

Rapid urbanization and increasing commercial activity in Addis Ababa have put high pressure on the already struggling urban water supply system of AAWSA. This challenge is particularly evident in Merkato, where commercial buildings experience frequent water shortages and supply interruptions. In this context, rooftop rainwater harvesting presents a promising supplementary water source. Therefore, this study assessed the potential of rooftop rainwater harvesting for commercial buildings in Merkato, Addis Ababa. Both qualitative and quantitative research approaches are employed. A census survey was conducted on 34 commercial buildings. The findings showed that municipal water remains the dominant source of supply. However, the AAWSA water supply is unreliable. All buildings use storage tank as coping mechanism for the shortage. The recorded municipal water consumption ranged from 65.28 m³/year to 8352.00 m³/year. Non-potable activities represented the dominant category of water use. 79.4% of buildings used water primarily for activities such as toilet cleaning and floor cleaning. All surveyed buildings are physically suitable for RRWH with gutters and roof materials favorable for runoff collection. The estimated annual RRWH potential ranged from 192.64 m³/year to 3693.43 m³/year with a contribution to existing municipal water consumption varying from 6.07% to 169.20%. The analysis of monthly variation revealed that RRWH potential is highly seasonal, with the highest yields occurring during July and August, while minimal contributions are observed in December and January. The study concludes that RRWH has significant potential to reduce dependence on AAWSA and improve water security in commercial buildings in Merkato. Promoting its use, particularly for non-potable applications, can therefore contribute meaningfully to strengthening the urban water supply system.

Keywords: Rooftop rainwater harvesting, commercial buildings, Non-potable water use, Water supply, Merkato.

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AAWSA	Addis Ababa water and sewerage authority
BGI	Blue-green infrastructure
EMI	Ethiopian Meteorology Institute
GI	Green infrastructure
IDW	Inverse distance weighting
RRWH	Rooftop rainwater harvesting
RWH	Rainwater harvesting
WSUD	Water sensitive urban design

CHAPTER ONE
INTRODUCTION

1.1 Background of the study

Water is essential for human survival, socioeconomic development, and environmental well-being (Meskele et al., 2024). However, rapid population growth, urbanization, industrialization, and changing lifestyles have intensified pressure on freshwater resources worldwide, resulting in a global water crisis (UN-HABITAT, 2005). According to Alves et al. (2025) it is estimated that 44 countries will face extremely high or high levels of water stress by 2040. In developing countries, the lack of access to safe water remains significant and it is predicted that one-third of the population will face critical water shortages (Adugna et al., 2018; Assefa, 2018). In Ethiopia, the situation is particularly critical, as centralized water supply systems struggle to meet growing demand due to the mismatch between rapid population growth and the extent of existing water supply infrastructure (Adugna et al., 2018).

In Addis Ababa, these challenges are more pronounced in high-density commercial areas such as Merkato. The concentration of active commercial activities, coupled with rapid urbanization and population growth, has significantly increased water demand in the area. However, the existing water supply system relies heavily on centralized municipal services provided by the Addis Ababa Water and Sewerage Authority (AAWSA), which often struggles to meet urban water demand. Consequently, when combined with the impacts of climate change, these factors raise concerns about the long-term sustainability of water supply in Merkato.

Against this backdrop, commercial buildings play a significant role in shaping urban water demand patterns in the area. commercial buildings represent a major source of urban water demand due the large number of people it hosts. Water use in commercial buildings accounts for up to 20% of total water withdrawal in urban areas with significant portions dedicated to non-potable purposes (Ferreira et al., 2023; Karim et al., 2021). This creates an opportunity to substitute a significant portion of non-potable water use with alternative sources such as Rainwater harvesting which eases the burden on centralized supply system and reduces demand on municipal water systems.(Karim et al., 2021).

Rainwater harvesting (RWH) has emerged as a practical, decentralized, and environment friendly strategy to fill the gap between water demand and available supply (Meskele et al., 2024; UN-HABITAT, 2005). Rainwater harvesting is a technology that has been practiced for more than 4,000 years and involves collecting, conveying, and storing rainwater from relatively clean surfaces such as rooftops for later use (Khoury-Nolde, n.d.-a).

Studies conducted in Addis Ababa has shown that RRWH can supplement water supply systems. However, these studies focused on residential and institutional buildings which leaves the commercial buildings untouched. So, an understanding of how rooftop rainwater harvesting can be adapted for commercial buildings in densely populated urban market areas is required (Alves et al., 2025; Ferreira et al., 2023). Therefore, this study aims to assess the potential of rooftop rainwater harvesting as an alternative water source for commercial buildings (G+4 and above) in the Merkato area. This research seeks to provide the contribution of rainwater harvesting by assessing factors like source and supply of water, water usage patterns, water consumption, rainfall patterns and rooftop areas.

1.2 Statement of the problem

Merkato is the main commercial area in Addis Ababa. And it’s also one of the largest and densely populated commercial area in the city. The area is characterized by a high concentration of markets that accommodate a large number of people including traders, customers, and visitors. This intense concentration of commercial activities and population creates considerable water demand for various uses. However, the existing centralized water supply system has struggled to meet this growing demand. The water shortage is a persistent challenge in the area due to frequent supply interruptions, limited-service coverage and growing demand.

The growing demand is caused by rapid urbanization and the expansion of commercial buildings in Merkato. In a place such as Merkato, the inequity between water demand and available water supply makes the challenge even worse because a large number of people depend on a limited and often unreliable water source. This situation affects the functioning of commercial buildings and indicates the growing need for alternative water sources that can enhance water availability and reduce the reliability on the existing water supply system. At the same time Merkato receives considerable rainfall during the wet season. However, this rainwater remains unutilized. The predominantly covering rooftops and other impervious surfaces causes a large portion of rainfall to become surface runoff rather than being captured for productive uses. And this unutilized rain during raining creates runoff and contributes to localized flooding, disrupts movement within the area, and places additional pressure on the drainage system. In a highly built-up commercial area where impervious surfaces exceed 80–90%, and roof areas are extensive, this unutilized rainfall represents a potentially valuable water resource.

Rooftop rainwater harvesting has been widely recognized as a practical and sustainable alternative water supply option in urban areas. Yet, there is no significant research in this context. Therefore, the main problem addressed in this study is the lack of assessment of rooftop rainwater harvesting potential for commercial buildings in Merkato, Addis Ababa. Without such an assessment, it is difficult to determine whether available rooftop areas and local rainfall can provide a meaningful supplementary water source to reduce pressure on the urban supply system. This knowledge gap forms the basis of this study which seeks to determine the potential of rooftop rainwater harvesting as an alternative water source for the commercial buildings of Merkato.

1.3 Objective of the study

General objective:

- To assess the potential of rooftop rainwater harvesting as an alternative water source for the commercial buildings of Merkato, Addis Ababa

Specific objectives:

1. To assess the current water source and water supply conditions for the commercial buildings in Merkato, Addis Ababa
2. To quantify the water consumption and water use patterns within the commercial buildings
3. To estimate the rooftop rainwater harvesting potential of the commercial buildings and assess its contribution to the building water consumption

1.4 Research questions

General research question

- ✓ What is the potential of rooftop rainwater harvesting as an alternative water source for commercial buildings in Merkato, Addis Ababa?

Specific research questions

1. What are the current water sources and water supply conditions for the commercial buildings of Merkato, Addis Ababa?
2. What is the current water consumption, and what usage patterns exist within these Commercial buildings?
3. How much rainwater can potentially be harvested from the rooftops of commercial buildings in Merkato, and to what extent can it contribute to the building water consumption?

1.5 Scope of the study

This study focuses on the commercial buildings of Merkato in Addis Ababa. The research was conducted on commercial buildings starting from 5 stories (G+4) and above because the research aimed to assess rooftop rainwater harvesting potential in highly dense commercial environments. G+4 and above buildings were selected as a condition to represent densely populated and highly concentrated commercial developments within Merkato. 34 buildings were identified within the study area and considered suitable for the study. And the study is limited to assessing the potential of rooftop rainwater harvesting as an alternative water source and to what extent it can contribute to the current water consumptions.

It primarily focuses on the quantitative aspect of rainwater harvesting, specifically the estimation of the volume of rainwater that can be collected from building rooftops. Qualitative aspects related to water potable uses, such as water quality and treatment requirements, are not within the scope of this study. Therefore, the research focuses on the use of harvested rainwater for non-potable purposes, such as cleaning toilets and cleaning floors.

1.6 Significance of the study

This study is significant as it contributes to sustainable water management practices in marketplaces such as Merkato. By finding out the rooftop rainwater harvesting potential of the area, then using that as an alternative water source for commercial buildings in Merkato. As water scarcity becomes an increasing challenge in densely populated areas like Merkato, this research proposes a potential solution by giving a sustainable and decentralized option for non-potable purposes, such as cleaning toilets and cleaning floors. This can reduce pressure on existing water supply systems and promote environmental conservation.

Furthermore, the study addresses a critical research gap in the existing literature by extending the application of rooftop rainwater harvesting to commercial buildings in Addis Ababa, Ethiopia. Previous studies have largely focused on residential and institutional buildings, with limited attention given to commercial sectors despite their high-water demand. In this regard, the study provides empirical insight into the potential and practical applicability of RRWH in commercial building contexts, thereby contributing to the broader understanding of urban water management strategies.

In addition to that, capturing and utilizing rainwater in the commercial zone of Merkato can mitigate flooding that happens repeatedly in the rainy season and reduce stormwater runoff in the area. So, this will significantly contribute to improved drainage systems and flood risk in the study area

1.7 Limitations of the study

This study has several limitations that should be considered when interpreting its findings. First, the analysis was limited to commercial buildings of G+4 and above. This may limit the interpretation of the findings to lower-rise commercial buildings and other building typologies within the study area.

Second, the study was constrained by the unavailability of borehole water consumption data for buildings that rely on groundwater sources. As a result, the contribution of borehole water to total water consumption could not be fully quantified. This affects the completeness of the overall water demand analysis for some buildings.

Third, the study primarily focused on assessing rooftop rainwater harvesting potential and its contribution to existing water demand, rather than evaluating full system implementation aspects. Elements such as system design optimization, installation requirements, operation, and maintenance considerations were not examined.

Fourth, the assessment of water quality was limited, as the study emphasized quantity-based analysis rather than detailed physical chemical, and microbiological characteristics of harvested rainwater. This limit conclusions regarding the suitability of harvested rainwater for specific end uses without further treatment assessment.

Finally, the study did not include an economic evaluation of rooftop rainwater harvesting systems, such as cost-benefit analysis, payback period estimation or lifecycle cost assessment. Consequently, the economic feasibility of implementing such systems was not addressed.

1.8 Organization of the study

This study is organized into five chapters. Chapter one is introduction which includes the background of the study, problem statement, research objectives, research questions and the scope and significance of the study. Chapter two is literature review covering both theoretical and contextual reviews and the conceptual framework of the study. Chapter three is research methodology. It presents the study area, research design, data types, data collection methods, sampling techniques, and data analysis procedures employed. Chapter Four is results and discussion. It presents the findings of the study and comparison with existing literature. The Final chapter is Chapter five. Chapter Five presents the conclusions and recommendations for practice and future research.

CHAPTER TWO

LITERATURE REVIEW

This chapter presents a comprehensive review of literature relevant to rooftop rainwater harvesting and urban water management. The chapter is organized into theoretical, contextual, and empirical reviews. The chapter also presents the research gap and the conceptual framework guiding the study.

2.1 Theoretical review

2.1.1 Urban spatial planning

Urban spatial planning refers to the strategic organization and management of land use, infrastructure, urban growth, and spatial development patterns to achieve sustainable, functional, and resilient cities. It provides a framework for coordinating land-use activities, infrastructure provision, and resource allocation while balancing environmental, economic, and social objectives (Hurlimann & Wilson, 2018). Spatial planning extends beyond conventional land-use regulation by integrating multiple urban sectors such as transportation, housing, infrastructure, environmental management, and water resources into long-term development strategies (Moglia & Cook, 2019).

Urban spatial planning significantly influences urban form, building density, land-use patterns, and infrastructure distribution, which directly affect water demand, runoff generation, and opportunities for alternative water supply systems (Hurlimann & Wilson, 2018). Rapid urbanization and increasing building density often create pressure on centralized water supply systems, making spatial planning an important mechanism for managing resource allocation and infrastructure efficiency (Moglia & Cook, 2019). Through land-use control, zoning regulations, and infrastructure planning, spatial planning frameworks can shape water consumption patterns and influence the feasibility of decentralized water management approaches.

Furthermore, integrating water management objectives into spatial planning has become increasingly important for promoting sustainable urban development and climate adaptation. Spatial planning supports resilient urban systems by linking infrastructure development with environmental management and resource efficiency strategies (Hurlimann & Wilson, 2018).

2.1.2 Sustainable water management

Sustainable water management is a key component of sustainable development. It is defined as the use of water resources in a way that meets current ecological, social, and economic needs without compromising the ability of future generations to meet the same needs. It requires integrated and collaborative management approaches that go beyond administrative boundaries to enhance resilience and reduce risks in water systems. Water plays a crucial role in sustainable development. Because water is linked to energy, food production, health, peace, and poverty reduction. Therefore, access to safe and reliable water is a fundamental requirement for socioeconomic development. (Russo et al., 2014; United Nations Secretariat, 2023).

Despite water being a renewable natural resource, its usable portion is very limited. Water covers approximately two- third of the earth but only about 2% is freshwater suitable for human use. Smaller proportion is directly accessible for drinking and irrigation. This shows the importance of efficient water management for sustainable utilization of available resources. Groundwater stored in aquifers represents a major source of usable freshwater, and its recharge is an important indicator of water availability and sustainability (Andualem et al., 2019).

The complex nature of urban areas made water management in the urban setting complex. This is because urban areas are characterized by rapid population growth, urbanization, climate change, and environmental degradation. As the urban setting expands the demand for clean water increases with it and the existing traditional centralized water supply systems face significant pressure. This pressure is more severe in developing countries where urban expansion is often informal and unplanned. Because it makes the forecasting of water demand difficult (Russo et al., 2014; Siddique,2021). A systematic, long-term and forward-looking urban development and capacity development is crucial for the complex issues of urban water. This requires local ownership if it is to be sustainable beyond any one initiative. And it is an iterative process for lifelong learning that enables societal change (United Nations Secretariat, 2023).

The world needs to transform to sustainable water management more than ever. It needs better ways to manage its water resources and delivers water and sanitation services for billions of people. Urgent action is needed to overcome this global water crisis because it is affecting all countries around the world in every aspect. It is affecting them socially, economically and environmentally

(United Nations, 2015). Figure 2.1 shows the smart water resource management and it is presented below.

Figure 2.1 Smart water resource management

(Source: United Nations, 2015)

While sustainable water management establishes the principles for efficient and equitable resource utilization, increasing urban water demand and limitations of conventional supply systems require practical approaches for implementation. This creates the need for integrated urban water strategies that address both supply challenges and water-sensitive urban development.

2.1.3 Water supply and demand in urban setting

The Sustainable Development Goals of united nation is linked to access to water, the reliability of the water supply, impacts on shared water resources and innovations to support the co-management of shared water resources in a way that does not diminish the ability of current and future generations to benefit from this fragile resource (United Nations Secretariat, 2023).

Currently, the existing water supply systems have improved but the demand is increasing. And it is due to the population growth and expansion in urbanization, industrialization and irrigated agricultural. The lengthy dry period due to climate change can be considered as another factor affecting water supply. The available water resources are limited which made the experts working in the water sector to search for solution to the water shortage (Che-Ani et al., 2009). Figure 2.2 shows the water flow within the urban setting including the input, the system and the output.

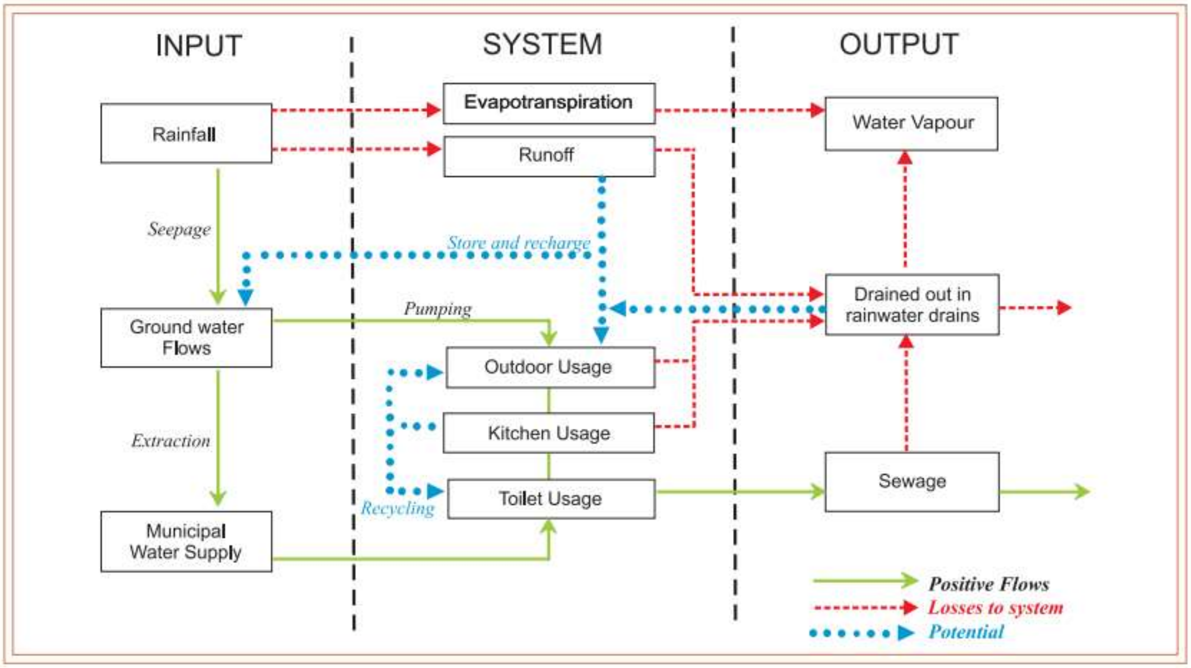

Figure 2.2 Water flows within the urban setting

(Source: UN-HABITAT, 2005)

Urban water systems often struggle to keep pace with rising demand. The growing demand for water is caused by population growth, increased food production, and industrial growth coupled with improved living standards. In addition to that climate change and environmental pollution affect the availability of water resources to meet this growing demand. The shortage of conventional water sources like surface and ground water joined with low water use efficiency are gradually threatening the security of water in urban, environmental and agricultural water needs (Rathnayaka et al., 2016).

Currently 2.2 billion people lack access to safely managed potable water and more than 4.2 billion people lack safely managed sanitation (United Nations, 2015). Therefore, Water supply is a major challenge all over the world in terms of quantity and quality. Water management is a priority in urban settings where the population is expected to rise up to 70% by 2050 (United Nations, 2012).

2.1.4 Water sensitive urban design (WSUD)

Water sensitive urban design (WSUD) represents a paradigm shift from conventional urban water management, advocating for the integrated management of land and water resources to incorporate rainwater into the urban landscape as a valuable resource rather than a waste product to be conveyed away (Ameen et al., 2020). Emerging from Australia in the 1990s, WSUD seeks to manage the urban water cycle holistically by minimizing potable water demand, reducing stormwater runoff, protecting water quality, and enhancing the ecological function of urban environments (Ameen et al., 2020). This approach aligns with broader frameworks of water sensitive cities, which benchmark urban water performance across governance, community capital, infrastructure resilience, and ecological health (Rogers et al., 2020).

Central to WSUD is the deployment of nature-based solutions and distributed infrastructure including rainwater harvesting, green roofs, permeable pavements, swales, and biofiltration systems that enable local infiltration, storage, and reuse of rainwater within the built fabric (Mguni et al., 2022; Siddique, 2021; Thomson & Newman, 2021). WSUD offers a framework for integrating rooftop rainwater harvesting as a deliberate design intervention capturing runoff from roof areas to offset water demand, reduce pressure on municipal supply, and contribute to urban water resilience (Ameen et al., 2020; Thomson & Newman, 2021).

Urban resilience in the context of water management refers to the capacity of urban water systems to anticipate, absorb, adapt to, and recover from shocks and stresses including droughts, floods, and supply disruptions while maintaining essential functions and transitioning toward more sustainable configurations (Takin et al., 2023; Thomson & Newman, 2021). Garrido-Baserba et al. (2024) further show that decentralized water systems when coupled with rainwater harvesting, vertical farming, and photovoltaic energy generation at the city-block scale can serve as a cost-effective cornerstone for enhancing both resource efficiency and urban resilience. Central to this transition is the shift from a linear extract and discharge model to a circular water economy that prioritizes water reuse, recycling, and localized capture (Siddique, 2021).

2.1.5 Green infrastructure and Blue-green Systems

Green infrastructure (GI) and blue-green systems refer to a strategically planned network of natural and semi-natural areas encompassing both green (land) and blue (water) spaces designed to deliver ecosystem services that replace or complement conventional grey infrastructure (Thomson & Newman, 2021). The European Commission defines GI as a network that provides water purification, climate mitigation and adaptation, and improved environmental quality, while Thomson and Newman (2021) further characterize it as the use of ecological systems to manage water, air, waste, and open space within the urban fabric.

Blue-green infrastructure (BGI) extends this concept by focusing specifically on nature-based approaches that integrate water elements such as swales, bioretention cells, infiltration trenches, permeable pavements, green roofs, and rainwater harvesting systems to mitigate flood hazards, improve water quality, and enhance urban livability (McNabb et al., 2024; Thomson & Newman, 2021). Unlike traditional drainage systems that convey stormwater away as waste, BGI promotes local infiltration, retention, and reuse, thereby reducing peak runoff, recharging groundwater, and building climate resilience (Siddique, 2021; Thomson & Newman, 2021)

Research demonstrates that spatially distributed rainwater harvesting as a core BGI measure that can reduce total flood volume by 16–45% and flood duration by 18–24% in urban drainage systems, while coupled green roof and rainwater harvesting installations achieve discharge reductions of 5–15% at city scale (Cristiano et al., 2021). The co-benefits extend beyond hydrology to include urban heat island mitigation, enhanced biodiversity, improved mental and physical wellbeing, and strengthened social-ecological connections livability (McNabb et al., 2024; Thomson & Newman, 2021).

2.1.6 Rainwater harvesting

Rain is the first form of water in the hydrological cycle and therefore represents the primary source of freshwater (UN-HABITAT, 2005). Surface water and groundwater resources, including rivers, lakes, and aquifers, are considered secondary sources because they are replenished by rainfall. However, modern water supply systems largely depend on these secondary sources, often overlooking the potential of rainwater as a direct water resource. Figure 2.3 demonstrates primary and secondary sources of water.

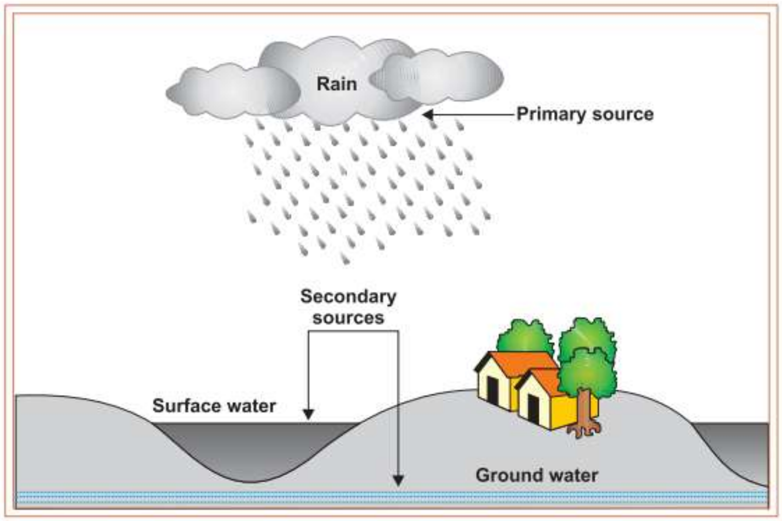

Figure 2.3 Water sources

(Source: UN-HABITAT, 2005)

Rainwater harvesting promotes the efficient utilization of rainfall at the point where it occurs, thereby enhancing water self-sufficiency and reducing dependence on conventional water supply sources (UN-HABITAT, 2005).

Rainwater harvesting has been widely discussed in the literature as a decentralized, environmentally sustainable, and cost-effective water management approach capable of reducing pressure on urban water supply and drainage systems, even under climate stress conditions (Alves et al., 2025; Andualem et al., 2019; Khoury-Nolde, n.d.-a; Siddique, 2021).

Rainwater harvesting involves the collection and storage of rainfall from different catchment surfaces, particularly rooftops, for future use. Rather than allowing rainfall to become surface runoff, harvested water can be stored for direct use or utilized for groundwater recharge, thereby improving long-term water availability and groundwater levels. This practice reduces dependence on conventional water supply systems and contributes to sustainable water management (Andualem et al., 2019).

As Medina (2016) stated Rainwater can be harvested for a couple of uses which are potable and non-potable.

- **Non-potable uses:** toilet flushing, cleaning activities, irrigation, vehicle washing, parking lot cleaning, and other domestic or commercial activities.
- **Potable uses:** drinking water and food preparation. However, these uses require appropriate treatment to ensure compliance with health and water quality standards.

Based on the catchment surface, rainwater harvesting systems can generally be classified into two categories:

- **Roof-based rainwater harvesting**: collection of runoffs from roof surfaces.
- **Land-based rainwater harvesting**: collection of runoffs from land surfaces such as ponds, reservoirs, and open areas.

Roof-based rainwater harvesting generally produces cleaner water compared to land-based systems because roof runoff is exposed to fewer contaminants, making it more suitable for domestic applications and easier to treat for potable use (Khoury-Nolde, n.d.).

Components rainwater harvesting system

According to UN-HABITAT (2005), All rainwater-harvesting systems includes six basic components regardless of the size of the rainwater harvesting system.

1. Catchment area

Catchment area can be roof or surfaces. And it is the part where the water harvesting happens and the rainfall is directly received. The catchment surfaces can be a paved area like building's terrace or an unpaved area like a lawn or open ground. Temporary structures like sloping sheds can also act as catchments areas. When a roof serves as a catchment area, the roof has to be appropriately sloped and preferably towards the direction of storage and recharge. There are three important aspects in this component.

- ✓ Catchment Area size - This is the size of a roof catchment area which is the building’s footprint under the roof structure. And it is limited to the area of the roof which is guttered.
- ✓ Run-off - Runoff is the term applied to the water that flows away from a catchment after falling on its surface in the form of rain. Runoff can be generated from both paved and unpaved catchment areas of buildings.
- ✓ Runoff Coefficient - Runoff coefficient is the factor that accounts for the fact that not all the rainfall falling on a catchment can be collected. Different material has different run off

coefficients. It is assigned based on the roof material type to account for collection losses due to leakage, wetting, infiltration, evaporation and spillage.

Table 2.1 Runoff coefficient values for various roof types

Type of roof	Runoff coefficient
Galvanized iron sheet	0.90
Asbestos sheet	0.80
Tiled roof	0.75
Concrete roof	0.70

(Source: Anchan & Shiva Prasad, 2021)

When a building is composed of different materials, a mixed runoff coefficient is calculated. The overall runoff coefficient was determined by weighting the runoff coefficient of each roof material according to its proportion of the total roof area (Anchan & Shiva Prasad, 2021; Khoury-Nolde, n.d.).

2. Gutters and Downspouts

The second component is Gutters and Downspouts. These are the transport channels from catchment surface to storage. Gutters and Downpipes have to be designed depending on site, rainfall characteristics and roof characteristics.

3. Leaf screens and roof washers.

These is the system that remove contaminants and debris. A first rain separator has to be put in place to divert and manage the first 2.5 mm of rain. First Flush is a device that make sure the runoff from the first spell of rain is flushed out and does not enter the system. This needs to be done because the first spell of rain carries a relatively higher number of pollutants from the air and catchment surface.

4. Cisterns or storage tanks

It is where the collected rainwater is safely stored or recharges the groundwater through open wells, bore wells or percolation pits.

5. Conveying system.

This system conveys the treated rainwater to the desired place. It can work either by gravity or pump.

6. Water treatment

This system filters the rainwater to remove solids and organic material and equipment. It uses additives to settle, filter, and disinfect the rain water harvested.

2.1.7 Benefits of rainwater harvesting

Rainwater harvesting provides multiple environmental, economic, and social benefits, making it an important strategy for sustainable water resource management. One of its major advantages is water conservation through the substitution of potable water with harvested rainwater for non-potable purposes such as toilet flushing, cleaning, washing, irrigation, and gardening activities (Alves et al., 2025; Andualem et al., 2019; Khoury-Nolde, n.d.). This substitution reduces the pressure on centralized potable water supply systems and improves overall water use efficiency.

Another important benefit of rainwater harvesting is its contribution to improving water security and diversifying water sources. In areas experiencing water scarcity or unreliable supply systems, harvested rainwater serves as an alternative and supplementary source of water that reduces dependence on conventional supplies (Khoury-Nolde, n.d.; UN-HABITAT, 2005). This benefit is particularly important in rapidly urbanizing and densely populated areas where water demand continues to increase.

Rainwater harvesting also contributes significantly to groundwater management and long-term water sustainability. It supports groundwater recharge, improves groundwater quality, and can increase groundwater levels in wells and boreholes, thereby strengthening long-term water availability (UN-HABITAT, 2005). Additionally, the practice reduces stormwater runoff, which lowers the burden on urban drainage systems and minimizes flooding risks, particularly in highly built urban environments (Teston et al., 2018; UN-HABITAT, 2005).

From an environmental and economic perspective, rainwater harvesting is considered a sustainable and cost-effective water management solution. Since water is collected close to the point of use, the need for energy-intensive water extraction, transportation, and treatment processes is minimized, resulting in lower energy consumption and operational costs (Alves et al., 2025; Khoury-Nolde, n.d.; Teston et al., 2018). Furthermore, rainwater harvesting uses naturally available on-site resources and can be implemented through relatively simple and flexible technologies, making it an environmentally responsible approach to urban water management.

2.2 Contextual review

2.2.1 Ethiopia and Addis Ababa water supply and demand

Ethiopia faces a mismatch between water resources and service access. Even though the country has significant untapped water potential. Literature shows that only about 0.2 million hectares are under irrigation and less than 25% of the population has access to potable water. This shows that the supply coverage in the country remains limited relative to demand (Alem, 1999). This same literature explains that centralized water supply is difficult in rural part of Ethiopia. The rugged terrain and scattered settlements make the centralized water supply costly and impracticable (Alem, 1999).

Urban demand is rising faster than supply. In the capital city of Ethiopia, Addis Ababa where most of the country administrative, diplomatic, and commercial activities are concentrated, the city has experienced rapid growth and urban expansion. The city faces a severe water shortage due to those causes. Water problem in the city is worsening time to time by rapid growth and urbanization which put pressure on the water infrastructure (Haddis, 2021).

Literatures shows that other city within the country also demonstrate same water supply and demand gap. In Hosaena City, the demand of the city is unmet by the existing water sources. The study concluded that rooftop rainwater harvesting could help reduce the water shortage within the city (Meskele et al., 2024). Another case is Woldia city, water demand increased after university expansion then the supply remained the same which caused severe shortages. (Andavar et al., 2020).

Water is an issue across the cities of the country. So, it indicates that critical water condition exists in Ethiopia. Because the preferred approach is centralized water supply. This approach fails to address the needs of the country. And there is mismatch between the rapid population growth and the existing water supply infrastructure (Adugna et al., 2018).

Addis Ababa currently gets its water from two sources namely surface water source and ground water source. There are three surface water sources Gefersa, Lagadadi, and Dire dams which are located outside of the city and groundwater sources are Akaki well fields and small boreholes dispersed in different parts of the city. The current total water supply is 580,000 m^3 per day despite the city demand being 1.1 million m^3 per day. And about 450,000 m^3 /day is sourced from surface and groundwater. From the produced 450,000 m^3 /day about 36.5 % of the water is lost during conveyance via leakage and other system problems. And the per capita distribution is around 40 liters/day which well under the city's goal which is 110 liters/ day (The Resilience Shift et al., n.d.).

Higher living standards and pressure of rapid population growth are among the factor that caused an increase in water demand per capita. There is a rise in water demand from industrial, commercial, and construction sectors which is greatly impacted by rapidly expanding economy and unprecedented construction boom. On the contrary of demand growth in every major sector, the availability and supply of water is declining. The causes for that are intensive groundwater development, natural resource degradation and climate change. Because of the imbalance between water demand and water availability, there is water shortage in the city. And city-wide water rationing is common in city (The Resilience Shift et al., n.d.).

2.2.2 Water demand and usage patterns in commercial buildings

As literatures stated the water demand in the commercial buildings is predominantly non-potable. This non-potable use includes the water used for floor cleaning, toilet cleaning and flushing, parking lots washing and so on. These uses do not require water to meet the water quality as drinking water (Karim et al., 2021). Figure 2.4 shows the typical Commercial building layout and the model assumption in a non-potable water supply system.

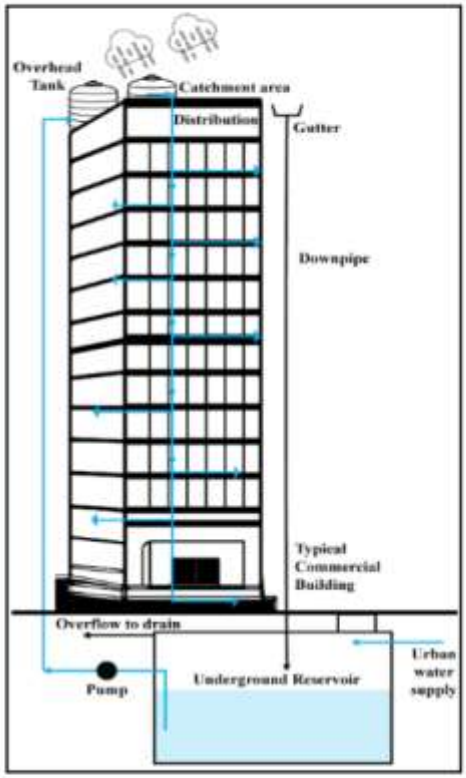

Figure 2.4 Typical Commercial Building Layout
(Source: Karim et al., 2021)

The amount of water demanded in commercial building is higher (Ferreira et al., 2023). Studies conducted on commercial and retail buildings have shown that the non-potable consumption figure reaching about 70 to 90 percent of the total consumption of the building. The main non-potable water use included general cleaning, toilet cleaning and flushing, and carpark washing (Ferreira et al., 2023; Fulazzaky et al., 2021).

A case study conducted on commercial building found out that the main water consuming activities was toilet flushing and pavement washing (Alves et al., 2025). Therefore, this regular and recurring pattern in the usage of water in commercial buildings gives an opportunity for rooftop rainwater harvesting. Because a large portion of their water demand does not require potable water quality (Ferreira et al., 2023).

2.2.3 Rainwater harvesting potential for commercial buildings

Rainwater harvesting have long history which dated back to the pre-Axumite period around 560 BC. In ancient Ethiopia, rainwater was collected and stored in ponds for agriculture and water supply. In Axum, historical evidence was found which shows the existence of roof water harvesting structures. Similarly, water harvesting systems in old Gondar castles and monasteries was evident. On top of that, rainwater capturing to support sorghum production under harsh rainfall conditions among the Konso people is used for long period of time. And these indigenous systems existed for centuries. But the importance of rainwater harvesting was not widely recognized until the drought and famine of the 1980s. But after that incident rainwater harvesting which started to receive more policy and institutional consideration as suitable water supply strategy (Alem, 1999; Roba et al., 2022).

The rainwater harvesting association established a guideline to encourage rainwater harvesting in Addis Ababa in 1999. The practicability of the guideline is questionable because it is applied only at an insignificant level. And it is only practiced by few and in household level with its traditional features. And this few uses only use in for non-potable purposes. This limited practice is the scenario despite all water-demanding activities (Adugna et al., 2018).

Commercial building is often characterized by large roof areas, concentrated water demand, and significant non-potable water uses. These features make them a suitable candidate for rainwater harvesting. For a high-density commercial district like Merkato, where impervious surfaces dominate and space for conventional GI is limited, rooftop-based blue-green interventions particularly rainwater harvesting coupled with green roof elements offer a feasible pathway to integrate stormwater management, non-potable water supply, and urban resilience within the existing built fabric (Thomson & Newman, 2021).

Study conducted in Malaysia on commercial building found out that rainwater harvesting in commercial buildings can contribute to more effective water management (Fulazzaky et al., 2021). Another study on a commercial building case study focused on water and energy efficiency also showed that an optimal rainwater harvesting system could be designed by matching non-potable water demand with storage volume. And taking in to consideration that the energy needed for pumping, distribution and storage (Alves et al., 2025).

Rainwater collected from rooftops in commercial buildings can therefore be stored or reused for non-potable purposes. Lowering potable water consumption can help significantly reduce the dependency on municipal supply (Ferreira et al., 2023). Many studies have shown that measurable water saving can be achieved by rooftop rainwater harvesting. Among those studies one of them showed that harvested rainwater can contribute approximately 10.8% of the actual municipal water supply and another study on a large public institution found that rooftop harvesting could supply up to 2.3 percent of annual potable water demand of the city (Adugna et al., 2018; Meskele et al., 2024). On building scale, this means the potential can be substantial when roof area, non-potable consumption and rainfall are well matched (Teston et al., 2018). At the same time commercial-building rainwater harvesting also reduces stormwater runoff and drainage pressure (Khoury-Nolde, n.d; Teston et al., 2018).

2.2.4 Rooftop rainwater harvesting storage systems in high-density urban areas

Storage represents the largest capital investment in a rainwater harvesting system, and its design becomes especially critical where space is limited (UN-HABITAT, 2005). Tanks may be positioned above ground, partly underground, or fully underground depending on site conditions (Khoury-Nolde, n.d.). In dense urban settings such as Merkato, the literature identifies underground storage as the most practical solution, as it preserves surface space for commercial activity while protecting stored water from temperature fluctuations, UV exposure, and algal growth. Underground reinforced concrete or masonry tanks can be installed within a building's basement or beneath its footprint, and pre-fabricated modular geocellular systems offer high storage capacity in compact configurations with reported void ratios of up to 95% and load-bearing capacity suitable for trafficable surfaces. For above-ground applications in narrow spaces, slimline tanks designed to fit against walls or in side passages are commercially available in capacities ranging from roughly 2,000 to 4,000 litres and can be connected in series to increase total volume. The University of Dar es Salaam case study provides a practical model for commercial buildings: rainwater from corrugated iron roofs is first diverted through small foul tanks (70 litres each) for first-flush removal, then conveyed to underground storage tanks with a total capacity of 80,000 litres, from which it is pumped to a roof-level distribution tank connected to the building's plumbing (UN-HABITAT, 2005). This staged approach combines minimal above-ground space use with reliable system performance, making it relevant for commercial zones where ground-level area is at a premium.

2.3 Empirical Review

2.3.1 Water savings potential of rooftop rainwater harvesting

Numerous empirical studies worldwide have demonstrated the substantial water-saving potential of rooftop rainwater harvesting (RWH) systems in commercial and institutional buildings, although performance varies according to local conditions, building characteristics, and demand patterns. Teston et al. (2018), reviewing 158 cases across residential, commercial, and public buildings in Brazil, reported an average potable water savings potential of 53%, with commercial and public buildings showing greater feasibility due to higher non-potable water demand. Similarly, Ferreira et al. (2023) estimated that a 100 m³ storage tank in a retail building in southern Portugal could achieve total water savings of 32–36%, while Silva et al. (2023) reported non-potable water savings of 64.47% for an industrial building with a 4,638 m² roof area using a 70 m³ storage tank.

Further evidence suggests that larger commercial systems can achieve substantial substitution of municipal supply. Alves et al. (2025) found that storage volumes of 78–152 m³ in a Portuguese shopping center enabled harvested rainwater to satisfy 116–139% of designated non-potable demand under different scenarios, indicating surplus harvesting potential in some periods. Likewise, Fulazzaky et al. (2021) reported favorable economic performance for large-scale commercial systems in Malaysia when integrated during construction, while Thebuwena et al. (2024) found that combining RWH systems with water-efficient fixtures in office buildings could achieve overall water efficiency improvements of up to 73%. Collectively, these findings indicate that commercial and institutional buildings offer substantial opportunities for reducing dependence on municipal water supply through rooftop rainwater harvesting systems.

2.3.2 Economic feasibility and payback periods

Economic viability has been a central consideration in evaluating rooftop rainwater harvesting (RWH) systems, with payback periods varying considerably depending on building type, system scale, water tariffs, and financing conditions. Teston et al. (2018) reported payback periods ranging from 0.5 years to more than 25 years across residential, public, and commercial buildings in Brazil, concluding that commercial buildings generally achieve shorter payback periods due to higher non-potable water demand. Similarly, Alves et al. (2025) reported payback periods ranging from 3 years and 11 months to 6 years and 1 month for shopping center scenarios, while Thebuwena et al. (2024) estimated an approximate 10-year payback period for office buildings. Although efficient fixture replacement generated greater water savings, its payback period exceeded 15 years. Fulazzaky et al. (2022) further noted that integrating RWH systems during the construction phase provides better economic returns than post-construction retrofitting. Previous studies also indicate that storage infrastructure represents a significant portion of capital costs, while economic performance is strongly influenced by water tariffs, rainfall characteristics, and roof catchment area (Teston et al., 2018).

2.3.3 Reliability and system performance

Reliability refers to the proportion of time during which harvested rainwater can meet water demand, while efficiency measures the extent to which available runoff is effectively utilized. Empirical studies have assessed these indicators to evaluate rooftop rainwater harvesting (RWH) system performance. Teston et al. (2018), through a review of nine Brazilian studies, found that although 60% of systems satisfied demand more than 65% of the time, only 11% achieved reliability levels above 76%, largely due to high water demand relative to collection capacity. Since storage capacity strongly influences water availability, storage optimization plays an important role in improving system reliability.

Beyond water supply performance, RWH systems also provide stormwater management benefits. Mugume et al. (2024) demonstrated that spatially distributed RWH systems in Kampala reduced total flood volumes by 16–45% and average flood duration by 18–24% within urban drainage networks. Similarly, Cristiano et al. (2021) found that large-scale deployment of RWH systems combined with green roofs across nine cities reduced total runoff discharge by 5–15%, even during extreme rainfall events. These findings indicate that properly designed RWH systems can enhance both water supply reliability and urban stormwater management performance.

2.3.4 Storage tank sizing and optimization studies

Storage tank sizing is widely recognized as one of the most important design parameters in rooftop rainwater harvesting systems because it strongly influences both system reliability and economic feasibility. Oversized tanks may increase capital costs without proportional benefits, whereas undersized tanks can lead to frequent overflow and supply shortages (Adity, 2023). Several sizing methodologies have been empirically validated. Alves et al. (2025), using the Rippl mass curve method for a Portuguese shopping center, identified optimal storage volumes ranging from 78–152 m^3 depending on demand scenarios. Similarly, Ferreira et al. (2023) used mass-balance simulation and found that a 100 m^3 tank was optimal for a retail store, while Silva et al. (2023) reported an optimal tank size of 70 m^3 for an industrial building with a roof area of 4,638 m^2. Ruso et al. (2024) applied a daily linear programming model in Northern Cyprus and identified optimum residential tank sizes of 2–6 m^3, achieving reliability levels of up to 20%, while emphasizing that daily time-step analysis provides more realistic sizing outcomes than monthly approaches. These findings suggest that appropriate tank sizing depends on local rainfall conditions, roof characteristics, and water demand patterns, making storage design a key consideration for technically reliable and economically feasible rooftop RWH systems.

2.3.5 Empirical evidence from the Ethiopian context

Empirical studies within Ethiopia provide important local evidence regarding rooftop rainwater harvesting (RRWH) potential and implementation challenges. Mulu (2020) estimated that rooftop catchments in the Tulu-Dimtu condominium area of Addis Ababa could generate approximately 125,172 m^3 of harvestable rainwater annually, satisfying about 18.13% of toilet flushing demand. Similarly, Meskele et al. (2024) found that harvested rainwater from public buildings in Hosaena City could contribute between 0.073% and 1.8% of municipal supply without storage systems, while storage integration increased potential contributions to as high as 28.41% of institutional demand and approximately 10.8% of annual city water supply.

Studies in institutional settings suggest even greater potential. Adugna et al. (2018) reported that rooftop rainwater harvesting could satisfy between 0.9% and 649% of institutional water demand depending on building characteristics, rainfall conditions, and storage capacity. Likewise, Kanno et al. (2021) showed that institutional systems in Dilla Town could satisfy approximately 24–155.7% of emergency handwashing demand, highlighting the importance of decentralized water systems during crisis periods.

Beyond technical potential, social studies indicate high public acceptance but low implementation. Yilma et al. (2026) found that most respondents in Addis Ababa recognized the economic and water-saving benefits of RRWH, yet adoption remained constrained by financial limitations, inadequate institutional support, technological barriers, and limited infrastructure. Collectively, these findings indicate that while rooftop rainwater harvesting demonstrates considerable technical and social potential in Ethiopia, implementation remains influenced by storage availability, institutional support, economic conditions, and building characteristics.

Collectively, these findings indicate that rooftop rainwater harvesting has considerable technical and social potential in Ethiopia, although implementation and performance vary depending on building characteristics, storage conditions, and institutional and economic factors

2.4 Research gap

Although previous studies have demonstrated the technical feasibility of rooftop rainwater harvesting in residential, institutional, and public-sector buildings, limited research has specifically examined high-density commercial buildings, where water demand characteristics and usage patterns may differ considerably. Existing studies in Ethiopia have primarily focused on public institutions, residential settings, and city-scale assessments, with limited empirical evidence from highly dense commercial districts such as Merkato. Therefore, this study addresses sectoral and geographical gaps by assessing rooftop rainwater harvesting potential and its contribution to water demand reduction among G+4 and above commercial buildings in Merkato, Addis Ababa.

2.5 Conceptual framework of the study

The conceptual framework of the study was developed from the reviewed literature to illustrate the study variables and their relationships The conceptual framework demonstrates that rooftop rainwater harvesting potential is influenced by physical factors such as roof catchment characteristics and rainfall characteristics, while water consumption is shaped by building characteristics and usage patterns. The comparison between estimated harvesting potential and building water consumption determines the contribution of harvested rainwater toward meeting commercial building water consumption. Figure 2.5 shows the conceptual framework of the study and it is presented below.

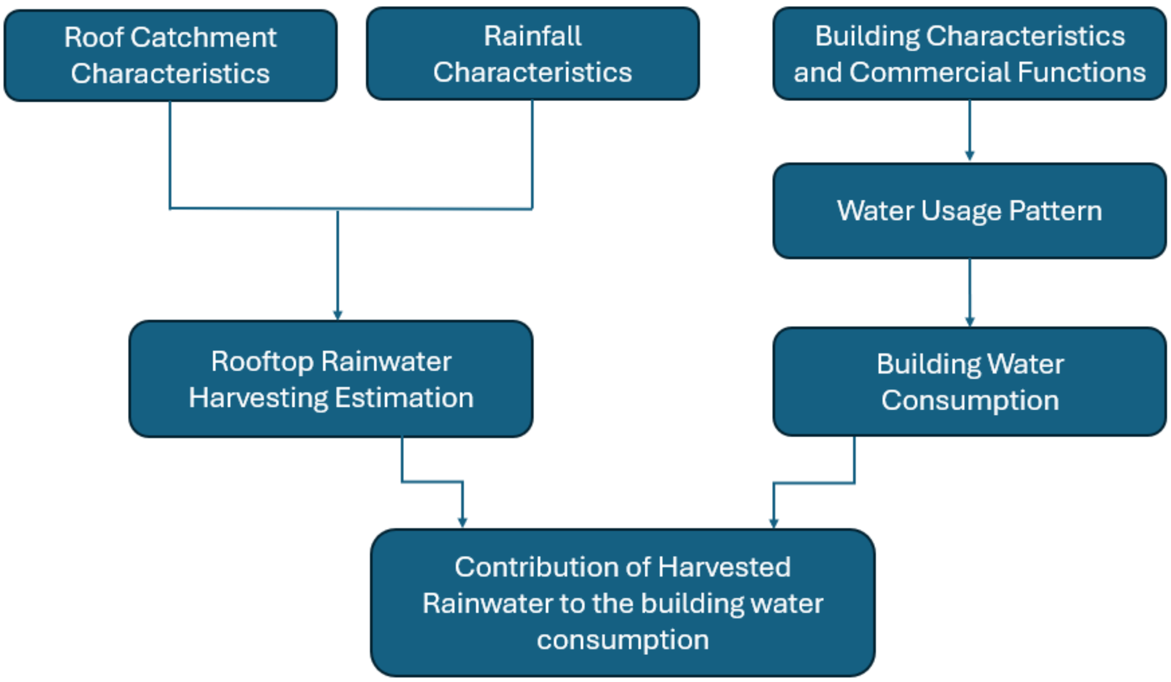

Figure 2.5 Conceptual framework of the study

CHAPTER THREE

MATERIALS AND METHODS

This chapter presents the research methodology used in this study. This includes various sections such as study area description, research design, data type and source, sampling design, and a brief process of how the data was analyzed.

3.1 Study area description

The study area is commercial zone of Merkato which is located in Addis Ababa. It is located in the capital city of Ethiopia. The city is characterized by its political, economic, and symbolic role in the country. (Haddis, 2021). The study area Merkato is a large marketplace in the capital city and it is the main market of the city which makes it host different types of trade and vibrant commercial activities. And within this area there are a number of commercial building and this study is conducted on them.

Geographically, Addis Ababa is located between 8°50' N to 9°5' N and 38°38' E to 38°54'E. The average annual rainfall is 1184mm. It has a subtropical highland climate with precipitation varying considerably by the month. The city has a complex mix of alpine climate zones, with temperature differences of up to 10 °C (18 °F). Summers are much rainier which is June up to September. The average maximum and minimum temperatures range between 10.2 °C and 22.9 °C (Feyissa et al., 2018).

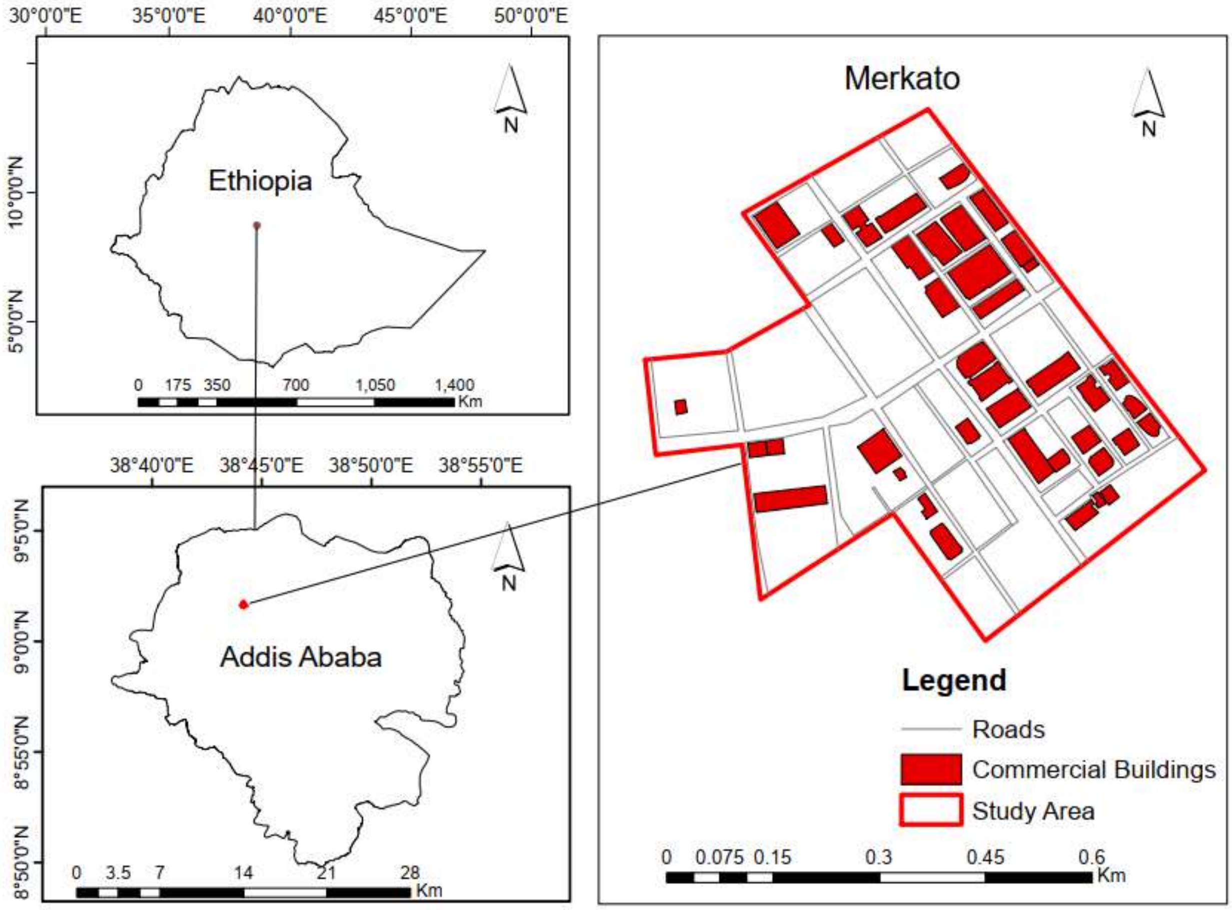

Figure 3.1 Location Map

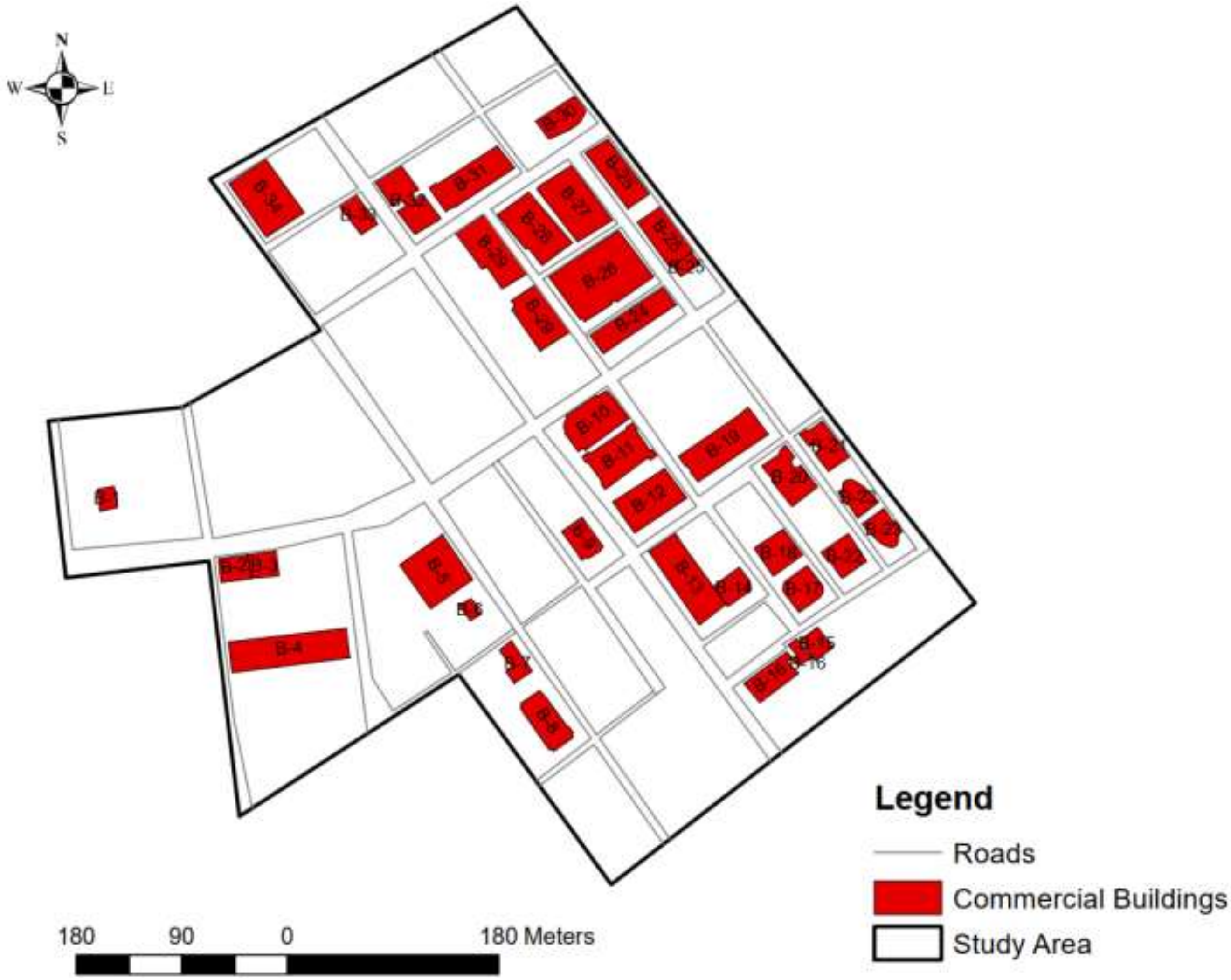

Figure 3.2 Study Area

3.2 Research design

The research design used for this study is mixed research approach. And the research method used a combination of descriptive and analytical approaches. Both qualitative and quantitative research types are employed to collect and analyze relevant data for the study. A face-to-face questionnaire survey with the commercial building administrators was conducted. Desk study and field observations are the methodologies that are used to achieve the objective of this study.

3.3 Type and source of data

This research used both primary and secondary data sources. The relevant data for the study were obtained using a building survey. This included building observation and building administrators' face-to-face questionnaire survey. Desk study within this topic area and review of different documents from governmental organizations, official reports, books, journals, and published research was done.

Primary data related to water consumption and usage patterns of the study buildings were collected through building surveys and interviews with building administrators. A face-to-face interview approach was employed to obtain detailed and reliable information on the subject matter which is water supply conditions and consumption patterns. Field observations (building survey) were carried out to gather essential physical and technical information, including the number of commercial services that require water per building and the type of the roofs. These observations supported both the assessment of water usage pattern and the evaluation of rooftop rainwater harvesting potential.

Secondary data were collected from relevant institutions and published sources. These included rainfall data obtained from the Ethiopian Meteorology Institute and technical parameters such as runoff coefficients from relevant literature. These data were used to estimate the rooftop rainwater harvesting potential. The daily recorded rainfall data from 7 stations near the study area were collected from the Ethiopian Meteorology Institute. The stations are Abssinia School, Addis Ababa Obs, Medhanalem School, Yekatit 23 School, Ayertena, Intoto, and Kolfe Keranio School. Moreover, the current water consumption levels were obtained from Addis Ababa water and sewerage agency (AAWSA) which enabled consistency and accuracy in the collected information.

3.4 Sampling design

3.4.1 sampling techniques

This study employed a census approach. All identified Commercial building above G+4 was included in the survey. Since the total number of commercial buildings in the study area is manageable. The data for the study building were collected from each building rather than selecting a sample. This approach enhances the accuracy and reliability of the results. Because it eliminates sampling error and ensuring full representation of the study area.

3.4.2 Sampling population

The sampling population of this study consists commercial buildings above G+4 located in the Merkato area. A total of 34 commercial buildings suitable for this research were identified within the study area.

3.4.3 Sample size

The sample size of the study is equal to the total population, which is 34 buildings. All identified commercial buildings (G+4 and above) were included in the survey. This was done to improve the precision of the analysis related to water consumption, water usage pattern and rooftop rainwater harvesting potential.

3.5 Method of data analysis

3.5.1 Building survey

A building survey was done via a face-to-face questionnaire survey with each of the building administrators to gather information about basic building characteristics. This includes water usage patterns and rainwater harvesting potential. The questionnaire generally addresses building characteristics, source of water, shortage coping mechanisms, usage patterns, and roof characteristics. And an additional building observation was done for each building to verify data such as water usage pattern and roof material.

3.5.2 Water consumption

To determine the average annual water consumption of the building, three years of monthly water consumption records were collected from AAWSA for each building. The average of these three years is taken as the average annual water consumption of these buildings. And for the monthly water consumption the average of the three years were taken.

3.5.3 Roof catchment

Roof catchment materials and rainwater drainage systems were obtained through interviews with the building administrators and verified by building observation. And the roof catchment area was obtained by digitizing the study area buildings using ArcMap.

3.5.4 Rainfall data

Seven meteorology stations near the study area are used to interpolate the annual and monthly average rainfall of the study area. Accordingly, 15 to 33 years of daily rainfall data from the seven stations were obtained from the Ethiopian Meteorology Institute (EMI).

The arithmetic mean method was used to fill missing rainfall data. This method was selected because, it is a simple and transparent technique that performs reasonably well when nearby stations have similar rainfall behavior. Additionally, Because of its low computational requirements and acceptable accuracy it is widely used as a baseline method in hydrological studies (De Silva et al., 2007; Sattari et al., 2017; Yogafanny & Legono, 2022). After filling in the missing values, it is converted to monthly and annual average rainfall. Then ArcMap was used to perform Inverse distance weighting (IDW) interpolation method. The monthly and annual average rainfall of the study area are obtained using the IDW interpolation method.

3.5.5 Rooftop rainwater harvest potential

The calculation of rooftop rainwater harvesting potential depends mainly on three measurable inputs: roof area, local rainfall, and the runoff coefficient of the roof surface (Dwivedi & Shrivastava, 2021; Schuster-Wallace et al., 2022). As per the objective of the study the calculation of the annual and monthly rain water harvesting potential was performed. And for the rooftop rainwater harvesting potential estimation the following formula is used:

$$V = A \times R \times C / 1000$$

Where V = the harvested rainwater volume in m^3

A= roof catchment area in m^2

R = rainfall depth in mm/y or rainfall depth in mm/month

C = runoff coefficient

1000 is a conversion rate to m^3

3.6 Validation and reliability

To make sure the validity of the data, the gathered data was verified by building survey. And the census approach used in this study enhances the accuracy and reliability of the results by eliminating sampling error and ensuring full representation of the commercial buildings.

CHAPTER FOUR
RESULTS AND DISCUSSION

This chapter presents the findings and discussion of the study conducted on 34 commercial buildings located in Merkato. The analysis is organized according to the objectives of the study. So, the chapter presents general building characteristics, Existing water supply conditions of the surveyed buildings, the water consumption and water usage patterns of the surveyed buildings and the rooftop rainwater harvesting potential of each building and its contribution to the existing water consumption.

4.1 Findings

4.1.1 General building characteristics

34 commercial buildings within the active commercial area of Merkato were included in this study. These buildings range from five stories (G+4) up to eleven stories (G+10). 27 of the surveyed buildings fall within the G+4 to G+6 range, while only 7 of them fall under G+8 to G+10. The roof areas of the buildings vary significantly, ranging from 185 m^2 to 3547 m^2. This variation will impact the volume of rainwater that can potentially be harvested from each building. A building code name ranging from B-1 to B-34 is assigned for the surveyed building in order to promote ease of analysis and presentation in the study. Table 4.1 shows the general characteristics of the buildings in the study area including their name, building code assigned, number of stories and roof area of each building. Figure 4.1 illustrates the distribution of surveyed buildings by height category.

Table 4.1 General characteristics of the buildings in the study area

No.	Name of the Building	Building Code	Stories	Roof Area(m^2)
1	Zelela Commercial Building	B-1	G+10	280
2	Jabulani commercial Building	B-2	G+5	518
3	Soblani Business Center	B-3	G+5	490
4	Merkato Shema Tera Market Center	B-4	G+4	2605
5	Mehal Mercato Real Estate Share Company	B-5	G+5	2036
6	Chalot Market Center	B-6	G+5	185
7	Telelan Business Center	B-7	G+6	466
8	Afia Commercial Center	B-8	G+5	1160
9	Addis Fana Private limited company	B-9	G+8	670
10	Dire tera share company	B-10	G+4	1617
11	Dire Building P.L.C	B-11	G+4	1615
12	Africa commercial Center	B-12	G+4	1688
13	Tewekel share company	B-13	G+4	2094
14	Agenbi Building Construction P.L.C	B-14	G+5	584
15	ATAA Construction Share Company	B-15	G+6	399
16	Zeway Commercial Building	B-16	G+4	1101
17	Rahey Be Sidamo Tera Lemat Nigid Share Company	B-17	G+5	813
18	Sidamo Building Share Company B3	B-18	G+7	860
19	Adamas zemenay share Company	B-19	G+6	1996
20	Sidamo Building Share Company B1	B-20	G+10	1141
21	Sidamo Building Share Company B2	B-21	G+10	825
22	Metesaseb Le Edeget General Trading	B-22	G+6	757
23	Cinema Ras Building Share Company	B-23	G+4	1215
24	Mars Commercial Center	B-24	G+8	1410
25	Addis Ababa Market Center	B-25	G+4	2711
26	Military Tera Negadioch Share Company C	B-26	G+5	3547
27	Military Tera Negadioch Share Company B	B-27	G+4	2052
28	Military Tera Negadioch Share Company A	B-28	G+4	1884
29	Mesert Hiwot Share Company A and B	B-29	G+4	3098
30	Siket Commercial Center	B-30	G+7	818
31	Addis Adamas Commercial Center	B-31	G+6	1672
32	Yedigit Meselale Commercial Building	B-32	G+5	1369
33	Antsbaraki Share Company	B-33	G+4	524
34	Nigat Birhane share company	B-34	G+4	2138

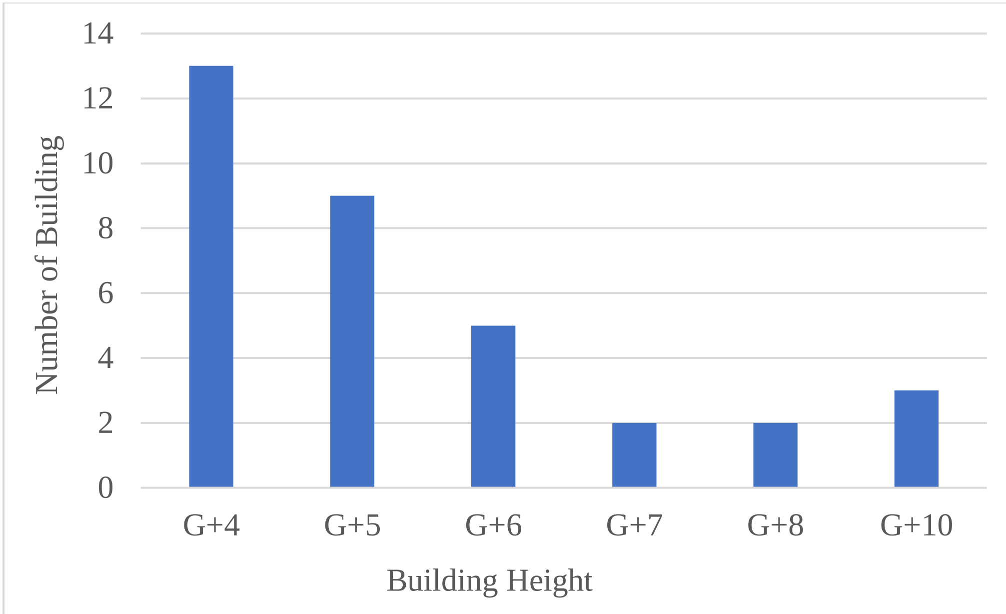

Figure 4.1 Buildings with their heights

4.1.2 Existing water supply conditions

4.1.2.1 Source of water supply

The dominate water source in the surveyed buildings is municipal water supply by the Addis Ababa Water and Sewerage Authority (AAWSA). Out of the 34 surveyed buildings, 27 depend mainly on municipal water supply from AAWSA, 6 use a combination of AAWSA and borehole water, and 1 depends mainly on borehole water. In addition to that three of the surveyed buildings, namely B-26, B-27, and B-28 share a single municipal water meter provided by the AAWSA. Figure 4.2 illustrates the percentile coverage of each water supply source and Figure 4.3 shows the distribution of the water source among the surveyed buildings.

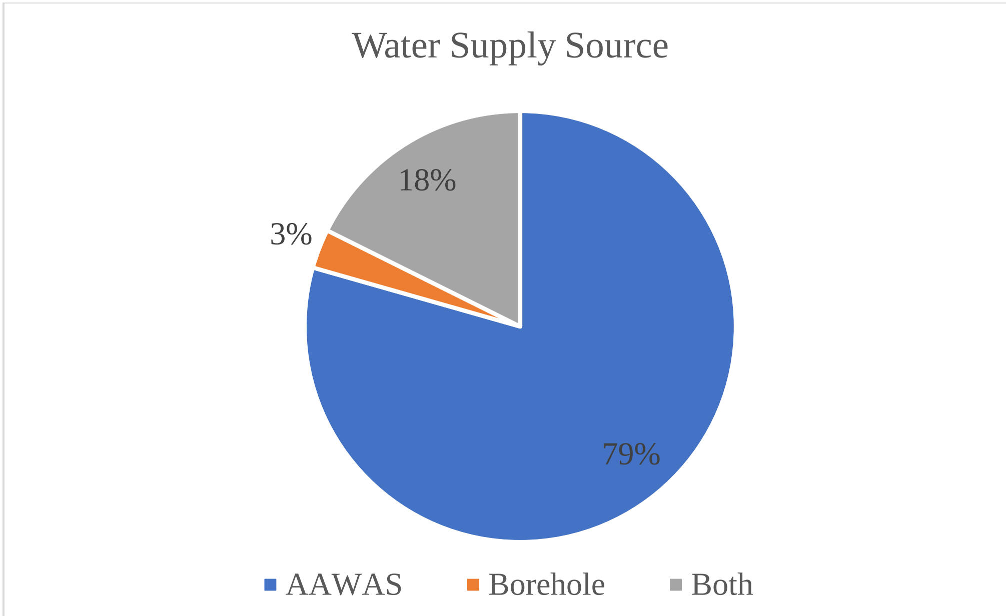

Figure 4.2 Source of Water Supply

Figure 4.3 Buildings with their source of water

4.1.2.2 Water supply reliability

Water shortage was found to be a major issue among the surveyed buildings. Out of the 34 buildings, 88.2% reported experiencing water shortage, and only 11.8% reported no shortage. Frequent shortages occur in the area and municipal water is available only 2 or 3 days per week.

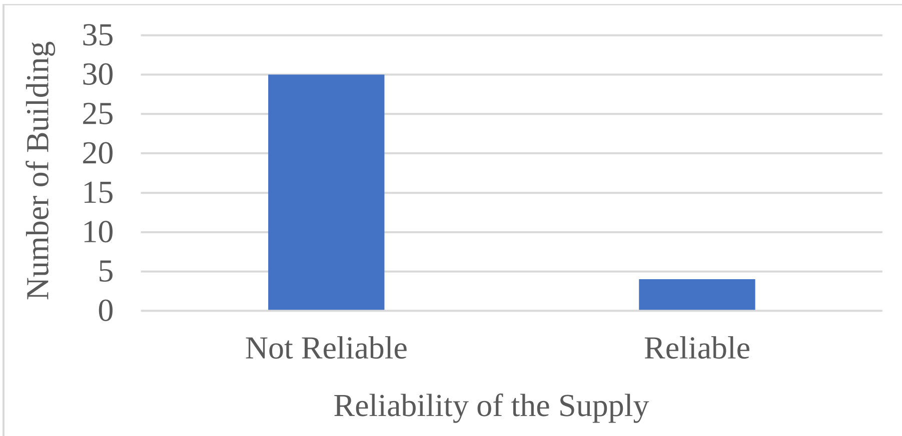

Figure 4.4 Reliability of supply

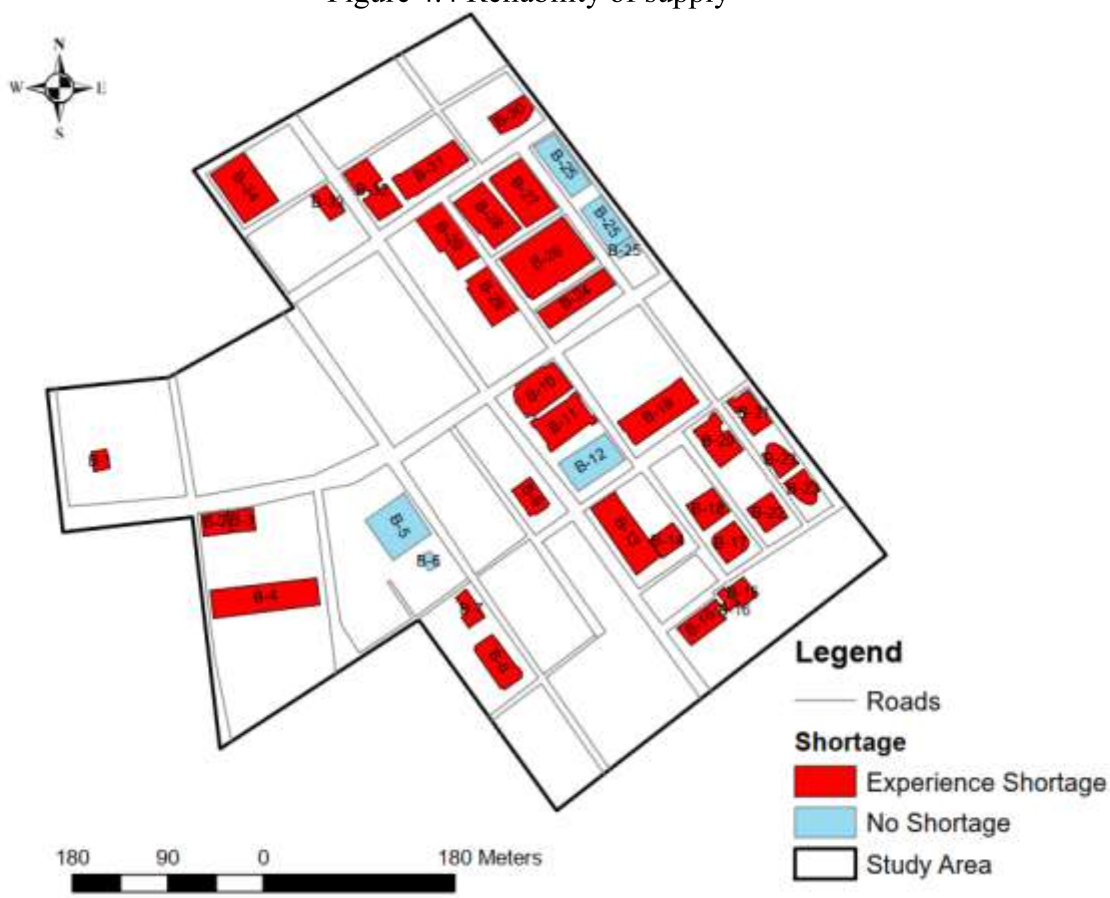

Figure 4.5 Shortage Occurrence

4.1.2.3 Alternative sources during shortage

Shortage is a major problem in the surveyed buildings. So, the surveyed buildings use different alternatives to cope up with the shortage. From those alternatives the most common alternatives reported include: storage tank, purchased water, private borehole and, in a few cases, rainwater use. All surveyed buildings store water in tanks as a coping mechanism during supply interruptions, and some buildings additionally purchase tanker-delivered water when stored water becomes insufficient and some have private borehole for non-potable use. Out of the 34 buildings about 20% of the surveyed buildings additionally purchase water whenever municipal supply and stored water become insufficient. And B-4 and B-11 use rainwater for floor cleaning in the rainy season.

4.1.2.4 Storage capacity

All surveyed buildings use storage tank to cope up with shortage. The storage total capacity ranges from 10,000 liters to 96,000 liters per building. The buildings were classified into five storage capacity categories ranging from 1,000 – 20,000 liters to 80,001 – 100,000 liters. Table 4.2 shows the number of buildings fall under each category and it is presented below.

Table 4.2 Storage capacity category

Storage Capacity Category (L)	Number of Buildings
1,000 – 20,000	7
20,001 – 40,000	15
40,001 – 60,000	8
60,001 – 80,000	2
80,001 – 100,000	2

Figure 4.6 demonstrates the distribution of storage capacity category among the surveyed buildings.

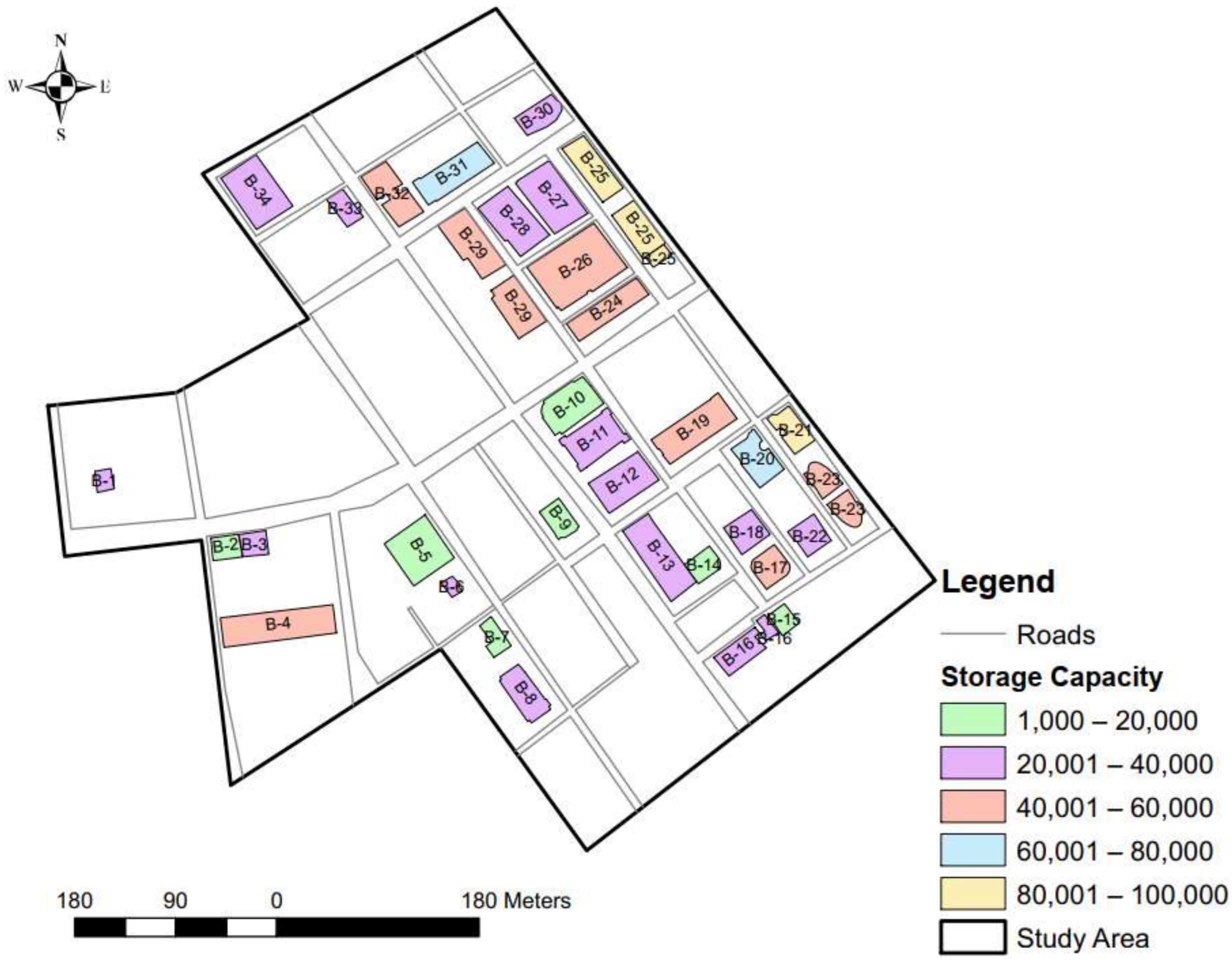

Figure 4.6 Storage Capacity

B-21 and B-25 were identified under the highest storage capacity category, indicating that these buildings possess relatively larger water storage volumes compared to other surveyed buildings. In contrast, B-2, B-5, B-7, B-9, B-10, B-14, and B-15 were categorized under the lowest storage category, showing relatively limited storage volumes. The spatial distribution map further reveals noticeable variation in storage capacity among the surveyed buildings across the study area.

4.1.3 Water consumption and water use patterns

4.1.3.1 Recorded municipal water consumption

Average monthly and annual municipal water consumption was calculated for each surveyed building. The results indicate considerable variation in water consumption among buildings. Differences were observed in both monthly and annual consumption levels across the study area.

Table 4.3 shows the annual minimum, maximum and average recorded water consumption among the surveyed buildings.

Table 4.3 Summary of recorded annual municipal water consumption

Indicators	Value
Number of Municipal Water Meter	31
Minimum Recorded Water Consumption	65.28 m^3 / Year
Maximum Recorded Water Consumption	8352 m^3 / Year
Average Recorded Water Consumption	3021.21 m^3 / Year

The statistics on Table 4.3 are based on 31 municipal meter records obtained from the AAWSA. The study used 31 water meter out of 34 building surveyed because B-24 entirely relies on borehole water and three buildings namely B-26, B-27 and B-28 share a municipal water meter so the study took that as 1 municipal record.

Based on the annual consumption records, B-29 recorded the highest annual municipal water consumption at approximately 8,352 m^3/year, while B-5 recorded the lowest annual municipal water consumption at 65.28 m^3/year. The average annual municipal water consumption among the surveyed buildings was approximately 3,021.21 m^3/year. These findings demonstrate substantial variation in municipal water consumption across the surveyed buildings.

Table 4.4 shows the annual water consumption statistics among buildings entirely dependent on AAWSA.

Table 4.4 Summary of annual water consumption for buildings entirely dependent on AAWSA

Indicators	Value
Number of Municipal Water Meter	27
Minimum Recorded Water Consumption	759.67 m3 / Year
Maximum Recorded Water Consumption	8352 m3 / Year
Average Recorded Water Consumption	3269.94 m3 / Year

Among buildings entirely dependent on AAWSA, B-23 recorded the lowest annual municipal water consumption with 759.67 m^3/year. The average monthly consumption of buildings entirely dependent on AAWSA is presented in Table 4.5.

Table 4.5 Average monthly consumption of buildings entirely dependent on AAWSA

Months	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Average Monthly Consumption in m^3	260.63	277.53	268.12	298.33	306.04	278.09	313.56	302.12	267.00	301.61	164.25	232.66

Figure 4.7 shows the pattern of the average monthly consumption of buildings entirely dependent on AAWSA.

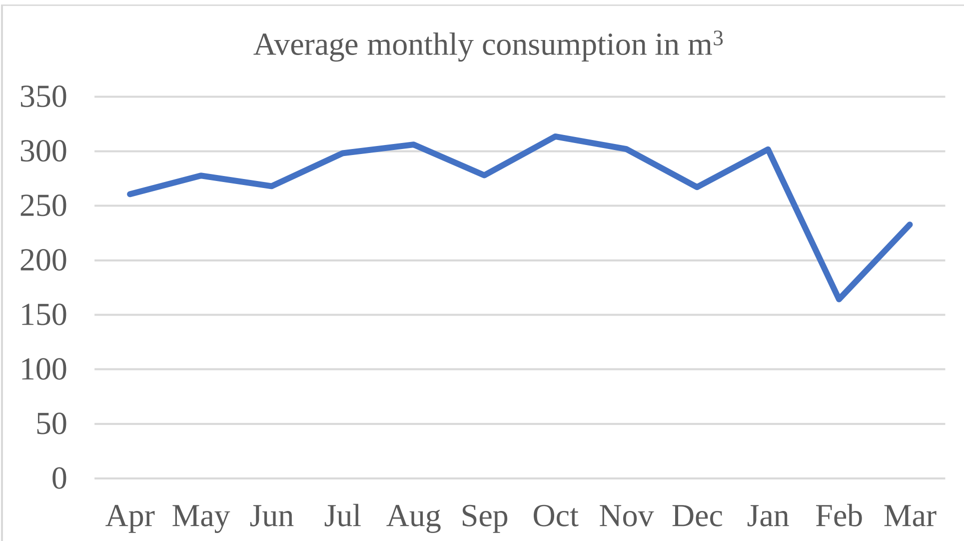

Figure 4.7 Average monthly consumption of buildings entirely dependent on AAWSA

The monthly municipal water consumption data show a clear fluctuation pattern throughout the year among the surveyed commercial buildings. The pattern demonstrates that municipal water demand in the commercial buildings is not constant throughout the year. The pattern suggests moderate seasonal variation, with relatively higher consumption during July to November and lower consumption during February and March.

4.1.3.2 Main use of water

Water use for non-potable purpose is dominant in the surveyed buildings. In this study out of the 34 surveyed buildings, 27 buildings reported non-potable use only, while only 7 buildings reported the use of water for both potable and non-potable purposes. Figure 4.8 illustrates the percentile coverage of the water use in surveyed buildings and Figure 4.9 shows the distribution of potability based water use among the surveyed buildings.

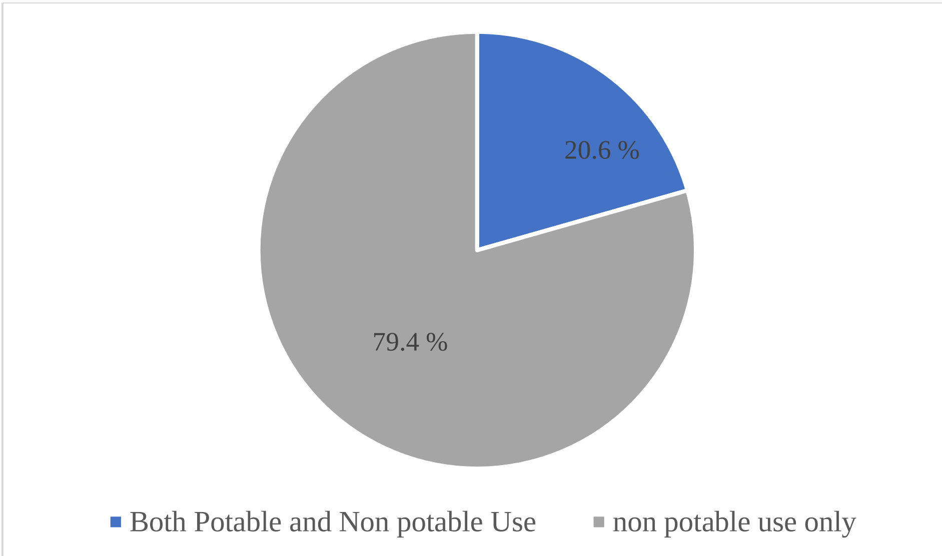

Figure 4.8 Water Use in the Surveyed building

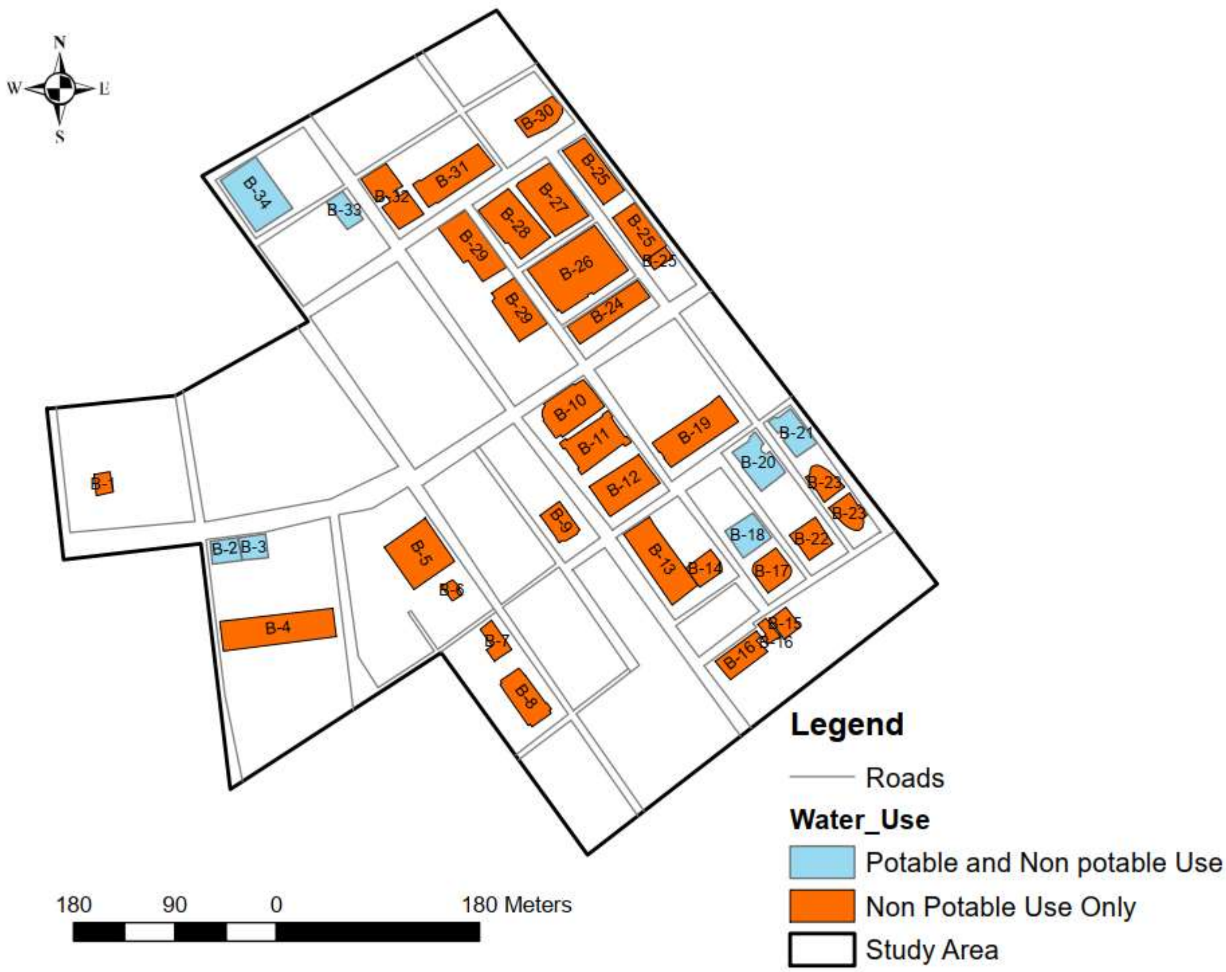

Figure 4.9 Potability Based Water Use

4.1.3.3 Major water-requiring activities

Non - potable water use is the major water use in the surveyed buildings. And from those non potable water use, there are activities in the building that take major share of it. And nearly on all surveyed buildings, the two dominant water-consuming activities are toilet cleaning and floor cleaning. These activities occur daily in every building and in some cases toilet cleaning may occur twice or more per day as required. And also, there are activities that occur in monthly basis such as window cleaning and since it is less frequent, its contribution is lower out of total water consumption of the building.

4.1.3.4 Commercial services that increase water consumption

Besides the water-consuming activities necessary for the general functioning of commercial buildings, the study identified several commercial services within the surveyed buildings that contribute to overall water consumption. The most commonly observed services were cafes and restaurants, public toilets, and hair salons. Additionally, only one surveyed building was found to provide hotel services. Buildings containing multiple service types generally exhibited higher overall water consumption levels. The existing service category is presented in Table 4.6.

Table 4.6 Existing water-consuming services category

Services Category	Building Code	Frequency	Percentage (%)
Cafe and Restaurant only	B-3, B-6, B-7, B-8, B-12, B-14, B-16 & B-28	8	23.53 %
Cafe and Restaurant + Hair Salon	B-2, B-10, B-19 & B-26	4	11.76 %
Cafe and Restaurant + Public Toilets	B-4, B-22 & B-25	3	8.82 %
Cafe and Restaurant + Hotel	B-9	1	2.94%
Public Toilet only	B-15, B-23 & B-24	3	8.82%

All Services	B-1, B-5, B-11, B-17, B-18, B-20, B-21, B-27, B-29, B-30, B-31, B-32, B-33, B-34	14	41.18%
None	B-13	1	2.94 %
Total		34	100%

Table 4.6 presents the distribution of existing water-consuming service categories within the surveyed commercial buildings. The classification was developed based on the presence or combination of major water-consuming activities identified during the building observation, including cafes and restaurants, hair salons, public toilets, and hotels. Buildings were grouped according to the service combinations they contained. The frequency values represent the number of buildings falling under each service category, while percentages were calculated by dividing the frequency of each category by the total number of surveyed buildings.

The results indicate that buildings with all service categories constituted the largest group (41.18%), followed by buildings containing only cafes and restaurants (23.53%). In contrast, only one building (2.94%) had no identified water-consuming services. Overall, the table shows that most surveyed buildings contain one or more water-intensive activities, with cafes and restaurants appearing either independently or in combination with other services.

4.1.4 Rainwater harvesting potential

4.1.4.1 Physical suitability of buildings

For the successful conveyance of rooftop rainwater to storage facilities, collection components such as gutters and downpipes are required. The survey results showed that all surveyed buildings were equipped with gutter systems, indicating that they possess the basic physical infrastructure required for rooftop runoff collection and conveyance.

Roof material is also an important factor influencing rooftop rainwater harvesting potential. Different roof materials were observed within the study area, with the predominant types being corrugated iron sheets, waterproofed concrete slabs, and combinations of polycarbonate skylight panels with corrugated iron sheets and waterproofed concrete slabs. Figure 4.10 shows the statistics of roof materials of the surveyed buildings.

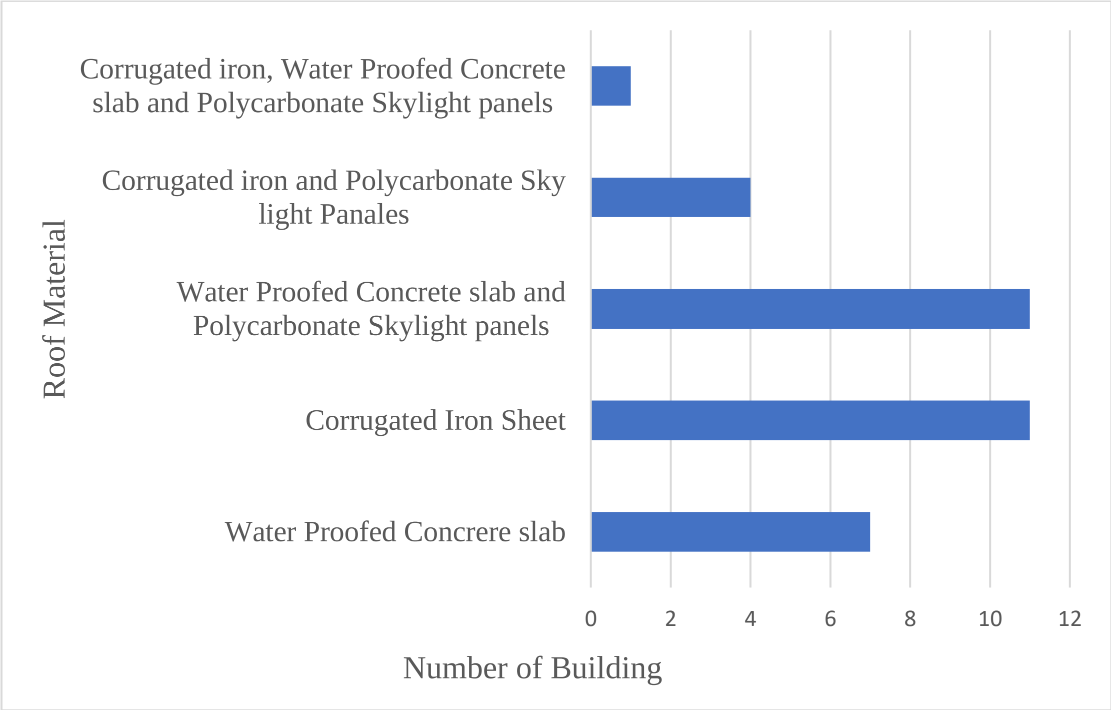

Figure 4.10 Roof materials of the surveyed buildings

4.1.4.2 Estimated harvesting potential

The calculation of monthly and annually rain water harvesting was performed. And for the rooftop rainwater harvesting potential estimation the following formula is used:

$$V = A \text{ x } R \text{ x } C / 1000$$

Where V = the harvested rainwater volume in m^3

A= roof catchment area in m^2

R = rainfall depth in mm/y or rainfall depth in mm/month

C = runoff coefficient

1000 is a conversion rate to m^3

Rainfall data used for the estimation were obtained from seven surrounding meteorological stations and it is shown in Table 4.7.

Table 4.7 Recorded annual rainfall value

No.	Station Name	Elevation (m)	Longitude (Deg)	Latitude (Deg)	Annual Average rainfall (mm)	Years
1	Abssinia School	2501	38.723333	9.044722	1182.45	20
2	Addis Ababa Obs	2386	38.7475	9.01891	1229.75	32
3	Medhanalem School	2539	38.727	9.059	994.13	18
4	Yekatit 23 School	2456	38.730556	9.0335	1273.40	23
5	Ayertena	2325	38.696389	8.983056	1322.33	20
6	Intoto	2903	38.725	9.083667	1289.65	33
7	Kolfe Keranio School	2413	38.702139	9.015361	1219.90	15

(Source : National Metrological Agency)

The annual rainfall depth of the study area was estimated using the Inverse Distance Weighting (IDW) interpolation method, resulting in an average annual rainfall value of 1244.59 mm. Monthly rainfall values used for estimating monthly harvesting potential are presented in Table 4.8.

Table 4.8 Monthly Rainfall Value of the study Area

Months	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Rainfall depth in mm	78.9	92	150.3	292.1	306.1	189.8	33.5	16.3	6.2	11.1	17.8	50.4

The rooftop area of the surveyed buildings varies from 185 m^2 to 3547 m^2. For the runoff coefficient, 0.85 is taken for each surveyed building because this value was considered appropriate for the roof materials observed in the study area which are corrugated iron sheets, waterproofed concrete slabs, and combinations of polycarbonate skylight panels with corrugated iron sheets and waterproofed concrete slabs. And these materials have higher runoff coefficients from previous studies (Khoury-Nolde, n.d.; Thebuwena et al., 2024). Therefore, by using the mentioned parameter accordingly the estimation of the total volume of rainwater that can be harvested from each building is calculated.

The estimated annual rooftop rainwater harvesting potential showed substantial variation among the surveyed buildings. The estimated annual harvesting potential ranged from 195.71 m^3/year to 3752.38 m^3/year. Similarly, monthly rooftop rainwater harvesting potential also varied considerably, ranging from 0.36 m^3/month to 922.95 m^3/month. The findings further indicate that B-26 recorded the highest estimated rooftop rainwater harvesting potential, while B-6 showed the lowest estimated potential among the surveyed buildings.

4.1.5 Contribution of rainwater to existing water consumption

To determine the contribution of rooftop rainwater harvesting to building water usage, the estimated harvesting potential was compared with the average recorded municipal water consumption of each surveyed building. The comparison was conducted for both monthly and annual harvesting potential. And the annual comparison showed substantial variation among the buildings ranging from low coverage to very high coverage. Buildings with low coverage are as follows

- ✓ B-1 – 6.07% of the total consumption of the building
- ✓ B-3 – 13.06% of the total consumption of the building
- ✓ B-6 - 11.96% of the total consumption of the building

And buildings with relatively high coverage are as follows

- ✓ B-23 -169.20% of the total consumption of the building
- ✓ B-19 – 91.76 % of the total consumption of the building
- ✓ B-11 – 74.36% of the total consumption of the building
- ✓ B-4 – 61.97% of the total consumption of the building

The monthly rooftop rainwater harvesting potential showed seasonal variation throughout the year. The highest harvesting potential was observed during the main rainy season from June to September, particularly in July and August, due to increased rainfall availability. During these months several surveyed buildings achieved substantially higher harvesting volumes and coverage percentages. Table 4.9 illustrates the summary of monthly rainwater harvesting contribution in the surveyed buildings.

Table 4.9 Summary of monthly rainwater harvesting contribution in the surveyed buildings

Observation	Building Code	Month	Coverage in Percentile
Highest monthly coverage recorded	B-23	August	488.89%
Lowest monthly coverage recorded	B-1	December	0.36%
Very low contribution period for most buildings	Most buildings	December–January	Below 10%
Buildings with consistently high monthly coverage	B-4, B-11, B-19 and B-23	June–September	High contribution
Buildings with consistently low monthly coverage	B-1, B-3 and B-6	Throughout the year	Low contribution
Peak harvesting season	All buildings	July and August	Maximum contribution
Lowest harvesting season	All buildings	December and January	Minimum contribution

The minimum annual coverage is 6.07% of the annual consumption of B-1 and maximum coverage is 169.20% of the annual consumption of B-23. Several surveyed buildings achieved substantially higher harvesting volumes and coverage percentages in rainy season. For instance, B-23 recorded the highest monthly coverage from harvested rainwater, reaching approximately 454.71% in July and 488.89% in August. Similarly, B-11, B-19, and B-4 also demonstrated high monthly coverage from harvested rainwater during peak rainfall periods. The minimum harvesting contribution was generally observed during December and January, where coverage percentages in several buildings dropped below 10%. Buildings such as B-1, B-3, and B-6 consistently exhibited low harvesting potential throughout the year.

4.2 Discussion

4.2.1 Existing water supply conditions

4.2.1.1 Municipal water supply and reliability

AAWSA is the dominant source of water in the study area. Out of the 34 surveyed buildings, 27 buildings depend mainly on AAWSA, 6 buildings use both AAWSA and borehole water, and 1 building depends mainly on borehole water. The findings indicate that municipal water supply remains the main source of water for commercial buildings in the study area. However, the growing reliance on alternative sources like private boreholes suggest that municipal water supply alone is not sufficient to meet the total water demand of the buildings.

The existing water supply in the study area is unreliable. 30 buildings reported experiencing water shortages and only 4 reported with no shortage. This high proportion indicates that water supply reliability remains a significant challenge in the study area. This shortage interrupts the normal functioning of commercial buildings such as availability of toilets and daily cleaning routine. And it also indicates that the existing municipal supply is not consistently meeting the demand of the surveyed building.

The overall result aligns with earlier studies that show the persistent challenge of urban water supply. Abraha et al. (2020) reported that 38% of water demand was unmet in the Adama city, confirming that water insecurity remains a serious urban problem in Ethiopia. Therefore, the findings suggest that municipal water supply alone cannot reliably satisfy water demand for many commercial buildings within the study area.

4.2.1.2 Alternative water sources and coping mechanisms

Surveyed buildings adopted different alternatives to cope up with the shortage. From those alternatives the most common alternatives reported include: storage tank, purchased water, private borehole and, in a few cases, rainwater use. Despite the widespread water shortage observed in most buildings B-5, B-6, B-12 and B-25 did not report significant water shortage. They have different mitigating factors. B-5 and B-25 rely primarily on borehole water which reduced the dependency on the municipal water supply and provide sufficient water for their consumption.

In the case of B-6, the absence of water shortage was mainly associated with its relatively small building size and effective water management practices implemented by the building administration. B-12 contains commercial service like cafe and restaurant that demand water but they utilize their own separate water sources, while the building water supply mainly used for cleaning and sanitation purposes. These findings indicate that alternative water sources, lower water demand and effective water management practices contribute significantly to improved water supply reliability.

4.2.1.3 Water storage capacity

Storage is the main coping mechanism against supply interruptions. And all surveyed buildings have water storage tanks, with storage capacities ranging from 10,000 liters to 96,000 liters.
The relatively high storage capacities observed in B-21 and B-25 are associated with their physical characteristics and water demand requirements. B-21 is a high-rise building, while B-25 occupies a comparatively larger area, both of which likely require greater storage capacity to meet user demand and maintain water availability. It is consistent with literatures. Larger roof areas and higher daily water demand both drive greater ideal rainwater tank capacity, with a direct positive relationship between catchment area and required storage volume (Teston et al., 2018).Similarly, Fulazzaky et al. (2021) showed that for commercial buildings, the optimal storage tank volume is fundamentally determined by the balance between rooftop catchment area, water demand, and the length of dry periods to maintain supply reliability.

Conversely, buildings with lower storage capacities may face greater vulnerability during supply disruptions due to their limited ability to store sufficient water for continuous use. Fulazzaky et al. (2021) confirmed that undersized tanks result in rapid depletion and frequent empty-tank days, leaving buildings reliant on alternative sources or facing outright shortage. The observed spatial variation in storage capacity suggests differences in building characteristics, water demand patterns, and preparedness for unreliable municipal water supply conditions

4.2.2 Water consumption and water use patterns

4.2.2.1 Variation in municipal water consumption

The observed variation in municipal water consumption may be attributed to differences in building characteristics, including building size, type and intensity of commercial activities, occupancy levels, and reliance on alternative water sources such as boreholes. Buildings with supplementary water sources may exhibit lower dependence on municipal supply, while larger buildings with higher user demand are likely to consume greater volumes of water.

The exceptionally high annual municipal water consumption observed in B-29 suggests a relatively high-water demand and greater reliance on municipal water supply systems. In contrast, the low municipal water consumption recorded for B-5 associated with the use of alternative water sources, reducing dependence on municipal supply. The large variation in annual water consumption among buildings may reflect differences in building size, occupancy, commercial activities, and access to supplementary water sources.

The observed fluctuations in monthly municipal water consumption suggest the presence of seasonal variation in water demand patterns among commercial buildings. Higher consumption during July to November may be associated with increased commercial activities, greater occupancy levels, or changing water use behaviors during these months. Conversely, lower consumption during February and March may indicate reduced water demand or increased reliance on alternative water sources. These variations demonstrate that municipal water demand in commercial buildings is influenced by temporal factors and is not uniform throughout the year

4.2.2.2 Water use patterns and purpose of water use

The dominant water use in the study area is for non-potable purposes. 79.4% of the surveyed buildings using water only for non-potable activities. The remaining 21.6% use water for both potable and non-potable use namely B-2, B-3, B-18, B-20, B-21, B-33, and B-34. The remaining buildings utilize water only for non-potable purposes. Buildings that utilize water for potable purposes entirely depend on the municipal water supply. And potable use generally occurs only during periods when municipal water is available through the direct supply pipe, while stored water is not commonly used for potable purposes. The findings further reveal that buildings using borehole water as an alternative water source do not utilize it for potable purposes. This is mainly due to concerns regarding groundwater contamination and the unsafe condition of nearby sewerage infrastructure. As a result, borehole water is primarily used for non-potable activities.

This finding indicates that a significant portion of commercial building water use is related with uses that are non-potable and do not require potable-quality water. The tendency of commercial building using water for non- potable purposes is supported by the reviewed literatures, which shows that commercial and institutional buildings often large portion of their water for non-potable uses such as toilet cleaning and flushing, cleaning and related non-potable activities. Studies report non-potable shares of 69.6% and 63.15% in office buildings and municipal market building respectively (Ferreira et al., 2023; Thebuwena et al., 2024). This finding indicates that it is possible to substitute the existing water demand with rainwater harvesting.

4.2.2.3 Dominant water-consuming activities in commercial buildings

Among the non-potable use, the major water-consuming activities identified were toilet cleaning and floor cleaning. They occur on a daily basis. The occurrence of these dominant water consuming activities in the surveyed buildings is strongly supported by previous studies in the literature review. Studies shows that commercial and institutional buildings mainly consume non-potable water for sanitation and cleaning purposes. These studies are conducted on commercial and retail building from Malaysia and Portugal and it shows that toilet flushing, general cleaning, pavement washing, and other service-related uses are major components of building water consumption, while less frequent activities contribute a smaller share of the total consumption (Ferreira et al., 2023; Fulazzaky et al., 2021). This dominant use of water for this particular activities, toilet and floor cleaning suggests a common pattern in commercial buildings and this pattern makes these surveyed buildings suitable for rainwater harvesting as an alternative water source for these buildings.

4.2.2.4 Influence of commercial services on water consumption

The presence of commercial services within buildings contributes substantially to overall water demand due to their operational requirements. The most common water-consuming services identified in the surveyed buildings were cafes and restaurants, public toilets, and hair salons. Among the surveyed buildings, 41.18% hosted all of these services simultaneously. These services require frequent water use for activities such as cleaning, sanitation, food preparation, and customer-related services, which increases overall water consumption. Buildings with multiple service functions are therefore likely to experience higher water demand compared to buildings with fewer or less water-intensive services. These findings suggest that both the type and number of commercial services operating within a building influence water consumption pattern.

4.2.3 Rooftop rainwater harvesting and its contribution

4.2.3.1 Physical suitability of buildings for rooftop rainwater harvesting

The presence of gutters across all surveyed buildings suggests favorable physical conditions for implementing rooftop rainwater harvesting systems, as these components facilitate the collection and transfer of runoff to storage facilities. Additionally, the roof materials identified in the surveyed buildings support the feasibility of achieving the study objective because literature indicates that such materials are generally suitable for rainwater harvesting applications. Their relatively smooth surfaces improve runoff generation and enhance the efficient conveyance of collected rainwater to storage systems.

4.2.3.2 Rooftop rainwater harvesting potential

The variation in rooftop rainwater harvesting potential among buildings is primarily associated with differences in rooftop area and seasonal rainfall distribution. The highest harvesting potential was observed during the main rainy season from June to September, particularly in July and August, due to increased rainfall availability. Lowest monthly harvesting potential occurred during the dry season months from November to February. Buildings with larger roof catchment areas generate greater runoff volumes and therefore possess higher harvesting potential. This explains why B-26, which has the largest rooftop area (3547 m^2), recorded the highest estimated harvesting potential. In contrast, B-6 exhibited the lowest potential due to its relatively smaller rooftop area (185 m^2). The wide variation in monthly harvesting potential reflects the influence of seasonal rainfall patterns in the study area, where rainfall distribution is uneven throughout the year. These findings suggest that rooftop area and rainfall seasonality are important determinants of rainwater harvesting performance in highly dense commercial buildings

4.2.3.3 Contribution of rooftop rainwater harvesting to building water consumption

Contribution of estimated harvesting rainwater to the existing municipal water consumption showed that rooftop rainwater harvesting can cover a small up to larger portion of monthly and annually water Consumption. The large variation in the contribution of the total consumption of the buildings indicates that rooftop rainwater harvesting potential is influenced primarily by seasonal variation and its contribution affected by the relationship between roof catchment area and water consumption rather than by roof area alone.

For buildings with lower contribution percentages, RRWH may function primarily as a supplementary water source. In contrast, buildings with higher contribution percentages may utilize harvested rainwater as a major alternative source for non-potable applications. Overall, the findings indicate that rooftop rainwater harvesting can make a meaningful contribution to non-potable water consumption in many of the surveyed buildings. Figure 4.11 shows the comparison between the average monthly consumption and the average monthly harvesting potential.

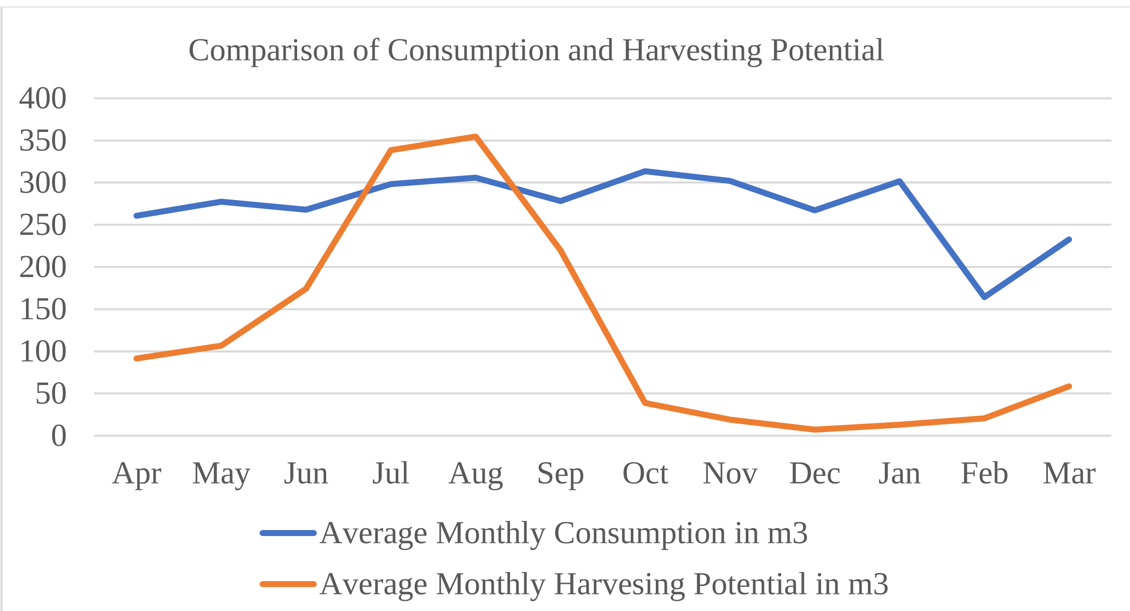

Figure 4.11 comparison of consumption and harvesting potential

The results further confirm that rooftop rainwater harvesting can significantly supplement water demand during rainy months when supported by adequate storage facilities. The comparison between average monthly water consumption and harvesting potential reveals a clear seasonal mismatch between water demand and rainwater availability. Water consumption remains relatively stable throughout the year, indicating continuous demand within commercial buildings, whereas harvesting potential varies with season. Harvesting potential increases significantly during the rainy months of July and August, where harvested volumes exceed average consumption, but declines sharply from October to February while demand remains relatively high.

This temporal imbalance highlights the importance of storage infrastructure in RRWH systems. During high rainfall periods, adequate storage capacity is necessary to capture surplus runoff that would otherwise be lost through overflow, while stored water can be utilized during dry months when harvesting potential is insufficient to meet demand. Therefore, storage systems play a critical role in improving reliability, increasing water supply continuity, and maximizing the contribution of RRWH toward reducing dependence on municipal water sources.

The findings are generally consistent with previous studies, although contribution percentages observed in some surveyed buildings exceeded those reported in many published case studies. This difference appears to be associated with variations in roof catchment area, building water demand, rainfall conditions, building functions, and methodological differences including rainfall estimation approaches, runoff coefficient assumptions, and building selection criteria.

For example, in Hosaena City, rooftop rainwater from medium to large public buildings was estimated to contribute only about 10.8 percent annually, which is much lower than high-coverage buildings such as B-23, B-19, and B-11 (Meskele et al., 2024). Similarly, Mulu (2020) 18.13 % coverage of toilet-flushing demand in Tulu Dimitu can be met by rainwater harvesting, while Adugna (2018) stated up to 649 percent of the water supply can be met by rooftop RWH from large public institutions in Addis Ababa under favorable conditions. A study from Malaysia on commercial-building shows same pattern appears, with non-potable demand, tank capacity, and water-use profile determining whether harvested rainwater can cover a small share or a large share of commercial building demand (Fulazzaky et al., 2021).

4.2.4 Summary of discussion

Overall, the discussion demonstrates that commercial buildings in Merkato experience unreliable municipal water supply, substantial variation in water demand, and considerable potential for RRWH. The findings suggest that RRWH can play an important role in supplementing existing water sources, particularly for non-potable uses, although its effectiveness depends on rooftop area, rainfall distribution, storage capacity, and building water demand characteristics.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents conclusion and recommendation of the study based on the findings. It presents conclusions regarding the potential of rooftop rainwater harvesting in the commercial buildings of the Merkato and provides recommendations for future practice and further research.

5.1 Conclusions

The study assessed the potential of rooftop rainwater harvesting on commercial buildings of Merkato, Addis Ababa. It focused on water supply conditions, water consumption, water use patterns, harvesting potential, and to what extent it could contribute to the existing water supply.

The finding showed that the municipal water supply from AAWSA is the main water source for the surveyed buildings. But the supply is unreliable and characterized by frequent shortages. Because of that, all buildings rely on water storage tanks.

The study found that the main water use in these commercial buildings is for non-potable purposes, mainly for cleaning toilets and floors. The estimated potential for rooftop rainwater harvesting varied among buildings due to roof area differences. And higher harvesting potential was observed during the main rainy season from June to September, while lower potential was observed during the main dry season months. The analysis further demonstrated that harvested rainwater can contribute from small portion up to more than the annual municipal water consumption. Buildings with relatively large roof area and lower consumption achieved the highest contribution percentages. The finding indicates that the contribution of rooftop rainwater harvesting is influenced mainly by the relationship between roof catchment area and water consumption rather than by roof size alone. Seasonal rainfall variation also significantly affects harvesting performance and coverage levels throughout the year.

Overall, the study concluded that rooftop rainwater harvesting has a potential to serve as a supplementary water source for the commercial buildings in Merkato, mainly for non-potable purposes. Integrating rooftop rainwater harvesting systems into these buildings can help reduce dependency on unreliable municipal water supply, reduce water shortages, and enhance urban water sustainability in the study area.

5.2 Recommendations

According to the conclusion and findings of this study. The following practical recommendations and recommendations for further study were proposed. And it is stated as follows

Practical Recommendations

1. Using and promoting rainwater harvesting as a supplementary source for non-potable uses within the commercial building

The study showed that majority of water consumption in the surveyed buildings is associated with non-potable activities, and all buildings showed suitable physical characteristics and harvested rainwater can satisfy a substantial proportion of water demand so it should be encouraged for uses such as toilet cleaning, floor cleaning, and related sanitation purposes.

2. Integrate rooftop rainwater harvesting into commercial building planning and retrofitting.

The existing commercial buildings in the Merkato should be encouraged to improve rooftop collection systems, storage capacity, and conveyance systems to capture available rainwater more effectively and utilize it. And incorporating rooftop rainwater harvesting system in the planning stage for the buildings that will be built in the future.

3. Strengthen policy support and institutional encouragement.

Addis Ababa city administration and the Addis Ababa Water and Sewerage Authority (AAWSA) should promote rooftop rainwater harvesting as a supplementary urban water management strategy. They should encourage and reward buildings that incorporate rainwater harvesting system.

4. Prioritize buildings with promising harvesting potential.

Buildings with relatively large roof areas with significant non-potable demand should be prioritized for rooftop rainwater harvesting implementation. Because they can cover substantial amount of water demand and greater practical benefits can be obtained from them.

5. Water conservation and efficient water use practices should be promoted alongside rooftop rainwater harvesting to enhance the overall contribution of harvested rainwater to building water demand.

Recommendations for future research

Future studies should be done on the following areas

- ✓ Examining the economic feasibility of rooftop rainwater harvesting systems, including installation costs, storage requirements, and payback periods.
- ✓ Investigating the optimal sizing and design of rainwater storage systems in relation to seasonal rainfall variation in order to maximize rainwater utilization during rainy months and ensure adequate supply during dry periods.
- ✓ Investigating rainwater quality and treatment requirements to determine suitability for potable use and different categories of non-potable use.
- ✓ Evaluating the influence of roof maintenance condition and operational management practices on the actual performance of rooftop rainwater harvesting systems.

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ANNEXES

ANNEX-1 Publishable Manuscript

Rooftop Rainwater Harvesting Potential for Commercial Buildings in Merkato, Addis Ababa, Ethiopia

Rahel Wondmu Asefa

Abstract

Rapid urbanization and increasing commercial activity in Addis Ababa have put high pressure on the already struggling urban water supply system of AAWSA. This challenge is particularly evident in the Merkato, where commercial buildings experience frequent water shortages and supply interruptions. In this context, RRWH presents a promising supplementary water source. Therefore, this study assessed the potential of RRWH for commercial buildings in Merkato, Addis Ababa. Both qualitative and quantitative research approaches are employed. And a census survey was conducted on 34 commercial buildings. The findings showed that municipal water remains the dominant source of supply, with 27 buildings relying mainly on AAWSA, 6 using both AAWSA and borehole water, and 1 relying entirely on borehole water. However, the AAWSA water supply is unreliable as 88.2% of the surveyed buildings reported water shortage. The dominate water use is for the non-potable purposes.79% of buildings using water mainly for activities such as toilet cleaning and floor cleaning. All surveyed buildings are physically suitable for RRWH with gutters and roof materials favorable for runoff collection. The estimated annual RRWH potential ranged from 192.64 m³/year to 3693.43 m³/year with a contribution to existing municipal water consumption varying from 6.07% to 169.20%. The analysis of monthly variation revealed that RRWH potential is highly seasonal, with the highest yields occurring during July and August, while minimal contributions are observed in December and January. The study concludes that RRWH has significant potential to reduce dependence on AAWSA and improve water security in commercial buildings in Merkato. Promoting its use, particularly for non-potable applications, can therefore contribute meaningfully to strengthening the urban water supply system.

Keywords: Rooftop rainwater harvesting, Commercial buildings, Non-potable water use, Urban water supply, Merkato

1. Introduction

Water is essential for human survival, socioeconomic development, and environmental well-being (Meskele et al., 2024). However, rapid population growth, urbanization, industrialization, and changing lifestyles have intensified pressure on freshwater resources worldwide, resulting in a global water crisis (UN-HABITAT, 2005). According to Alves et al. (2025) it is estimated that 44 countries will face extremely high or high levels of water stress by 2040. Addis Ababa currently gets its water from two sources namely surface water source and ground water source. And there are three surface water sources Gefersa, Lagadadi, and Dire dams which are located outside of the city and groundwater sources are Akaki well fields and small boreholes dispersed in different parts of the city (The Resilience Shift et al., n.d.). The supply system of Addis Ababa is struggling and with the concentration of dense businesses in the area, Merkato faces even greater challenges. Merkato is a very large and vibrant marketplace located in the Addis Ababa Addis. It is the main market place of the city. And Commercial buildings represent a major source of urban water demand due the large number of people it hosts. Water use in commercial buildings accounts for up to 20% of total water withdrawal in urban areas with significant portions dedicated to non-potable purposes such as toilet flushing and cleaning, parking lot washing, floor cleaning, landscaping, and so on (Ferreira et al., 2023; Karim et al., 2021). Water demand in the commercial buildings is predominantly non-potable. And these uses do not require water to meet the water quality as drinking water (Karim et al., 2021).Rainwater harvesting is a decentralized approach that contributes to sustainable water management. Rainwater harvesting involves collection and storage of rainwater from different surfaces such as rooftop. It is collected at the point where it falls rather than allowing it to be surface runoff. Rainwater harvesting also helps reduce the pressure on potable water system. Because it substitutes the treated water used in non-potable purposes such as toilet cleaning and flushing, irrigation and washing (Andualem et al., 2019).

Rooftop rainwater harvesting has been widely recognized as a practical and sustainable alternative water supply option in urban areas. Yet, there is no research in this context. Therefore, the main problem addressed in this study is the lack of assessment of rooftop rainwater harvesting potential for commercial buildings in Merkato, Addis Ababa.

2. Literature Review

Sustainable water management is a key component of sustainable development. It is defined as the use of water resources in a way that meets current ecological, social, and economic needs without compromising the ability of future generations to meet the same needs. It requires integrated and collaborative management approaches that go beyond administrative boundaries to enhance resilience and reduce risks in water systems. Water plays a crucial role in sustainable development. Because water is linked to energy, food production, health, peace, and poverty reduction. Therefore, access to safe and reliable water is a fundamental requirement for socioeconomic development. (Russo et al., 2014; United Nations Secretariat, 2023).

Commercial buildings represent considerable portion of urban water consumption. As shown in literature the typical water demand of commercial buildings is non- potable use. And the amount of water demanded in commercial building is higher (Ferreira et al., 2023) Studies conducted on commercial and retail buildings have shown that the non-potable consumption figure reaching about 70 to 90 percent of the total consumption of the building. And the main non-potable water use included general cleaning, toilet cleaning and flushing, and carpark washing (Ferreira et al., 2023; Fulazzaky et al., 2021). Study conducted on commercial building case study it is found out that the main water consuming activities was toilet flushing and pavement washing.(Alves et al., 2025). Rainwater harvesting is an effective and beneficiary water management practice. Because it collects and stores rainwater from catchment areas such as rooftops for later use. And it can either put to use directly or through groundwater recharge (UN-HABITAT, 2005). It is particularly very valuable in places where water resources are inadequate. Because it provides an alternative and reliable source of water that can help reduce pressure on existing supplies (Khoury-Nolde, n.d; UN-HABITAT, 2005). Rooftop harvested water is relatively clean and it can be suitable for many uses with little or no treatment. It is suitable for drinking after proper treatment. (Khoury-Nolde, n.d.).Therefore this regular and recurring pattern in the usage of water in commercial buildings gives an opportunity for rooftop rainwater harvesting. Because a large portion of their water demand does not require potable water quality (Ferreira et al., 2023).

The rainwater harvesting association established a guideline to encourage rainwater harvesting in Addis Ababa in 1999. The practicability of the guideline is questionable because it is applied only at an insignificant level. And it is only practiced by few and in household level with its traditional features. And this few uses only use in for non-potable purposes. This limited practice is the scenario despite all water-demanding activities (Adugna et al., 2018).

Commercial building is often characterized by large roof areas, concentrated water demand, and significant non-potable water uses. And these features make them a suitable candidate for rainwater harvesting. Its high potential in commercial buildings is evident. Studies show that the feasibility of a rooftop rainwater harvesting system depends on various factors. Among those factors are rainfall quantity and pattern, daily consumption, available roof area, storage capacity, number of Users, affordability and the existence of alternative water sources (Fulazzaky et al., 2021; Khoury-Nolde, n.d.).

But most existing studies in Ethiopia have focused on residential buildings, public institutions, or educational facilities. No attention has been given to commercial area like Merkato. This study addresses that gap by assessing rooftop rainwater harvesting potential as an alternative source of water in Mercato, Addis Ababa.

3. Materials and Methods

3.1 Study Area

The study area Merkato is a large marketplace in the capital city and it is the main market of the city which makes it host different types of trade and vibrant commercial activities. And within this area there are a number of commercial building and this study is conducted on them. Geographically, Addis Ababa is located between 8°50' N to 9°5' N and 38°38' E to 38°54'E. The average annual rainfall is 1184mm.Summers are much rainier which is June up to September. The average maximum and minimum temperatures range between 10.2 °C and 22.9 °C (Feyissa et al., 2018).

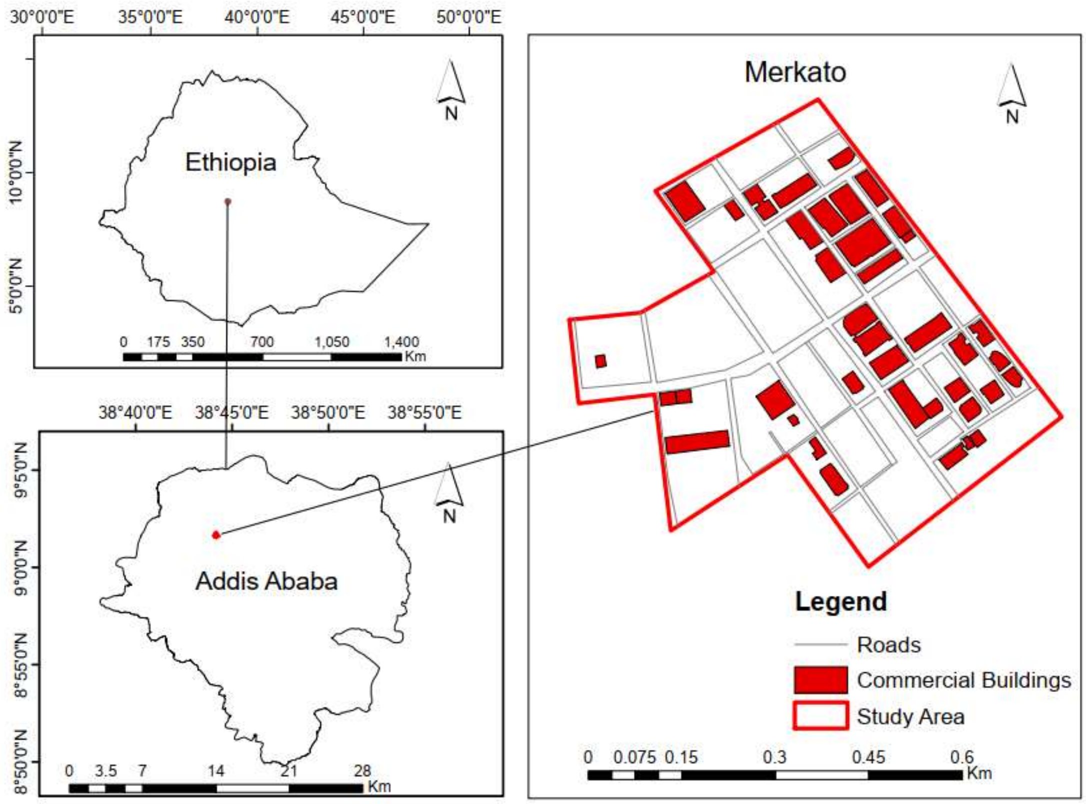

Fig 1 Location Map

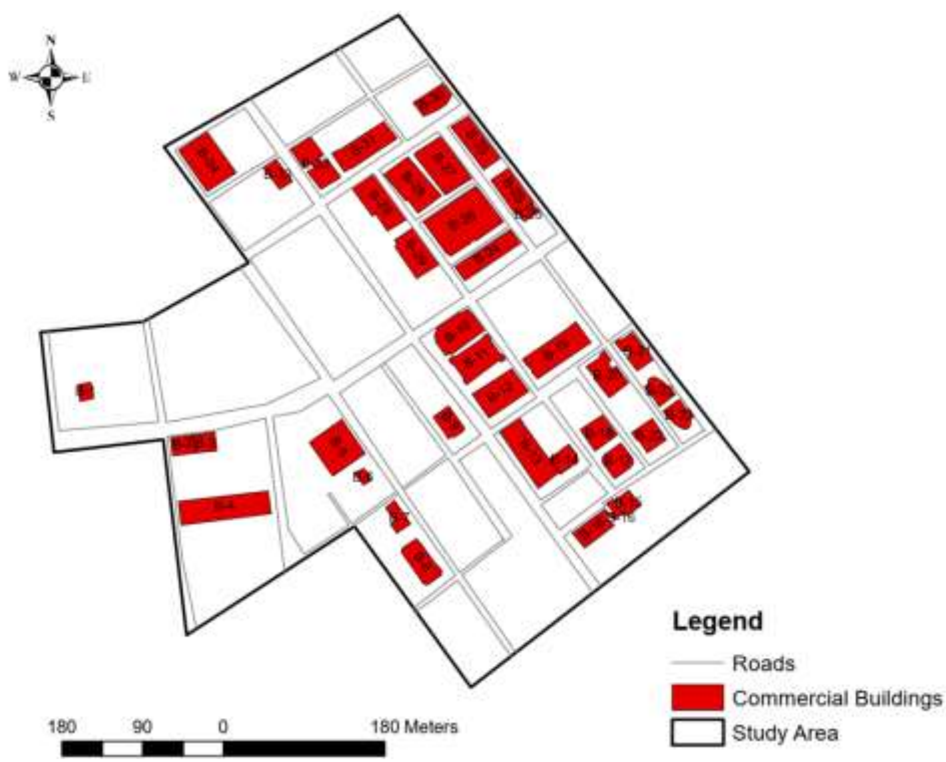

Fig 2 Study Area

3.2 Research Design and Sampling

The research design used for this study is mixed research approach. The research method used is a combination of descriptive and analytical approaches. A census approach was adopted. All 34 identified commercial buildings (G+4 and above) within the study area were included.

3.3 Data Collection

Both primary and secondary data were used in this study. Primary data were collected through face-to-face questionnaire survey with building administrators and building survey. Secondary data included three years monthly municipal water consumption records obtained from the Addis Ababa Water and Sewerage Authority (AAWSA) and daily rainfall data obtained from the Ethiopian Meteorology Institute (EMI).

3.4 Estimation of Rooftop Rainwater Harvesting Potential

Monthly and Annually rooftop rainwater harvesting potential was estimated using:

$$V = (A \times R \times C) / 1000$$

Where V = the harvested rainwater volume in m^3

A= roof catchment area in m^2

R = rainfall depth in mm/y or rainfall depth in mm/month

C = runoff coefficient

1000 is a conversion rate to m^3

For runoff coefficient, 0.85 was adopted because the dominant roof materials consisted of corrugated iron sheets, polycarbonate skylight panels, and waterproofed concrete slabs. And all of which generally exhibit relatively high runoff efficiency (Khoury-Nolde, n.d.; Thebuwena et al., 2024).

4. Results

4.1 Building Characteristics

The surveyed buildings ranged from G+4 to G+10. Rooftop areas varied substantially, from 185 m^2 to 3,547 m^2. This variation indicates strong variability in harvesting potential.

4.2 Existing Water Supply Conditions

The dominant water source in the study area is the municipal water by AAWSA. However, supply reliability was very poor. Out of the 34 surveyed buildings, 30 buildings which is 88.2% from the total reported frequent water shortages.

Table 1 Water Supply Reliability

Water supply condition	Frequency	Percentage (%)
Buildings with shortage	30	88.2
No shortage	4	11.8
Total	34	100

This finding highlights the severity of water shortage in the study area. And this result is consistent with previous observations regarding urban water stress in Addis Ababa (Adugna et al., 2018).

4.3 Water Consuming Activities

Water consumption was predominantly non-potable. Toilet cleaning and floor cleaning were the most frequent water-consuming activities. Commercial services such as cafes and restaurants, Hair salons, and public toilets further increased overall water consumption.

Table 2 Major water-consuming commercial services

Water-consuming commercial services	Frequency	Percentage (%)
Cafe and restaurant only	8	23.53
Cafe and restaurant + public toilets	3	8.82
Cafe and restaurant + hotel	1	2.94
Public toilet only	3	8.82
All services	14	41.18
None	1	2.94
Total	34	100

4.4 Rooftop Rainwater Harvesting Potential

All surveyed buildings have shown physical suitability because they have gutters to convey the rainwater and favorable roof surfaces for rainwater harvesting.

Estimated annual harvesting potential ranged from 195.71 m^3/year to 3752.38 m^3/year and the estimated monthly potential ranges from 0.97 m^3/month to 922.95 m^3/month. Buildings with larger rooftops demonstrated greater harvesting capacity. The extent of coverage varies among buildings and is influenced mainly by seasonal variation and the relationship between roof catchment area and water consumption rather than by roof area alone. The highest harvesting potential was observed during the July and August, due to increased rainfall availability and several surveyed buildings achieved substantially higher harvesting volumes and coverage percentages in rainy season. For instance, B-23 recorded the highest monthly harvesting potential, reaching approximately 454.71% in July and 488.89% in August. Similarly, B-11, B-19, and B-4 also demonstrated high monthly harvesting potential during peak rainfall periods. The minimum harvesting contribution was generally observed during December and January, where coverage percentages in several buildings dropped below 10%.

5. Discussion

This study assessed the potential of rooftop rainwater harvesting in the commercial buildings in the Merkato area of Addis Ababa, with specific emphasis on water supply conditions, water consumption, water use patterns, and harvesting potential. The findings show that the study area is characterized by commercial buildings with large variation in rooftop area, from 185 m^2 to 3547 m^2. And the dominant water supply in the area is the municipal water supply from AAWSA. This source of supply system is unreliable with the majority of the surveyed building (88.2 %) reported water shortage showing the unmet demand of the commercial buildings. So as a result, seven buildings explore another source of water which is borehole water use in order to meet their demands. And as a coping mechanism all buildings use storage tanks that ranges from 10,000 to 96,000 liters which demonstrate that storage has become an essential adaptation strategy rather than a supplementary convenience. And 20 % of the surveyed building use tanker delivered water additionally as a solution for the water shortage.

The dominant water use in the surveyed buildings is non-potable use. 79.4% of buildings using water mainly for activities such as toilet cleaning and floor cleaning. These activities occur daily across all buildings, indicating a regular and recurring water usage pattern that does not require potable-quality water. In addition to that a commercial service that consume water such as cafe and restaurants, hair salons, and public toilets were found to increase water consumption significantly. And buildings with multiple services and active commercial activities have higher water consumption. And comparison of estimated harvesting potential with existing municipal water consumption showed that rooftop rainwater harvesting can cover a small up to larger portion of monthly and annually water Consumption. The extent of coverage varies among buildings and is influenced mainly by seasonal variation and the relationship between roof catchment area and water consumption rather than by roof area alone.

Overall, the findings indicate that rooftop rainwater harvesting can serve as a supplementary or alternative source of water depending on the relationship between roof catchment area and water consumption. Therefore, it showed that it can be a promising supplement to the existing water supply of commercial buildings in the Merkato for non-potable purposes.

6. Conclusion

According to the result the research concluded that rooftop rainwater harvesting can make a meaningful contribution to building water supply. In some buildings, the estimated harvested rainwater could serve as supplementary source and in some building, it can serve as alternative source of water.

Generally, the study concludes that rooftop rainwater harvesting has significant potential to reduce dependence on the unreliable municipal water supply. And it can be used for non-potable uses, and can play an important role in improving water security in the commercial buildings of the Merkato.

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ANNEX-2 Questionnaire

College of Technology & Built Environment

School of Built Environment

Dear Participant,

My name is **Rahel Wondmu Asefa**. I am currently pursuing a **Master of Science Degree in Urban Design and Development** at the School of Built Environment (SBE), Addis Ababa University. And for my thesis, I am assessing the potential of rooftop rainwater harvesting to use as an alternative source of water supply in the commercial buildings in the Merkato, Addis Ababa. The study objective is

- ✓ Assessing the current water supply and source
- ✓ Determining the water consumption
- ✓ Assessing the usage patterns in these commercial buildings
- ✓ Assessing the potential of rooftop rainwater harvesting

Thank you very much for your time and cooperation.

Sincerely

Rahel Wondmu Asefa

Questionnaires

1. Building Name: - ____
2. Number of Stories: - ______________________
3. Primary source of water:

   ☐ Addis Ababa Water and Sewerage Authority ☐ Borehole ☐ Tanker

   ☐ Other: ____
4. Is there a water shortage in the building? ☐ Yes ☐ No
5. If your answer is yes, do you use alternative sources during shortages?

   ☐ Yes ☐ No If yes, specify ____________________________________
6. Do you have water storage tanks?

   ☐ Yes ☐ No

   If yes, how many? ________ Total capacity: _____________litres
7. Main uses of water in the building (check all that apply)

   ☐ Potable ☐ Non potable
8. Please indicate the frequency and usage of these activities

Activity	How many times per week?
Drinking	
Toilet flushing	
Floor cleaning	
Window cleaning	
Car washing	
other	

9. Please tick the services available in your building

Services the consume water	Tick if the service is present in the building	Frequency
Cafe and Restaurant	☐	
Hair Salon	☐	
Public Toilets	☐	
Others	☐	

10. Are there gutters or any rain collection systems?

☐ Yes ☐ No

11. What is the roofing material type?

☐ Corrugated iron ☐ Concrete slab ☐ Tiles ☐ Other: ____________________

12. Has rainwater harvesting been practiced before?

☐ Yes ☐ No

13. Please state suggestions you have regarding rainwater use in your commercial building.

____

____

____

____

____

ANNEX 3 - Surveyed building Annual Harvesting Potential in m^3

No.	Building Name	Building Code	Roof Area in m^2	Total Harvesting Potential in m^3
1	Zelela Commercial Building	B-1	280	296.21
2	Jabulani commercial Building	B-2	518	547.99
3	Soblani Business Center	B-3	490	518.37
4	Merkato Shema Tera Market Center	B-4	2605	2755.83
5	Mehal Mercato Real Estate Share Company	B-5	2036	2153.89
6	Chalot Market Center	B-6	185	195.71
7	Telelan Business Center	B-7	466	492.98
8	Afia Commercial Center	B-8	1160	1227.17
9	Addis fana Private limited company	B-9	670	708.79
10	Dire tera share company	B-10	1617	1710.63
11	Dire Building P.L.C	B-11	1615	1708.51
12	Africa commercial Center	B-12	1688	1785.74
13	Tewekel share company	B-13	2094	2215.25
14	Agenbi Building Construction P.L.C	B-14	584	617.81
15	ATAA Construction Share Company	B-15	399	422.10
16	Zeway Commercial Building	B-16	1101	1164.75
17	Rahey Be Sidamo Tera Lemat Nigid Share Company	B-17	813	860.07
18	Sidamo Building Share Company B3	B-18	860	909.80
19	Adamas zemenay share Company	B-19	1996	2111.57
20	Sidamo Building Share Company B1	B-20	1141	1207.07
21	Sidamo Building Share Company B2	B-21	825	872.77
22	Metesaseb Le Edeget General Trading	B-22	757	800.83
23	Cinema Ras Building Share Company	B-23	1215	1285.35
24	Mars Commercial Center	B-24	1410	1491.64
25	Addis Ababa Market Center	B-25	2711	2867.97
26	Military Tera Negadioch Share Company C	B-26	3547	3752.38
27	Military Tera Negadioch Share Company B	B-27	2052	2170.81
28	Military Tera Negadioch Share Company A	B-28	1884	1993.09
29	Mesert Hiwot Share Company A and B	B-29	3098	3277.38
30	Siket Commercial Center	B-30	818	865.36
31	Addis Adamas Commercial Center	B-31	1672	1768.81
32	Yedigit Meselale Commercial Building	B-32	1369	1448.27
33	Antsbaraki Share Company	B-33	524	554.34
34	Nigat Birhane share company	B-34	2138	2261.79

ANNEX 4 - Annual Coverage of Harvested Rainwater for the AAWSA Consumption for buildings entirely dependent on AAWSA Supply

No.	Building Name	Building Code	Average Annual Consumption from AAWSA	Total Harvesting Potential in m^3	Coverage of harvested rainwater in %
1	Zelela Commercial Building	B-1	4880.00	296.21	6.07
2	Jabulani commercial Building	B-2	1975.67	547.99	27.74
3	Soblani Business Center	B-3	3969.67	518.37	13.06
4	Merkato Shema Tera Market Center	B-4	4446.96	2755.83	61.97
5	Chalot Market Center	B-6	1636.56	195.71	11.96
6	Telelan Business Center	B-7	2468.00	492.98	19.97
7	Addis fana Private limited company	B-9	1931.45	708.79	36.70
8	Dire tera share company	B-10	3421.64	1710.63	49.99
9	Dire Building P.L.C	B-11	2297.66	1708.51	74.36
10	Africa commercial Center	B-12	4034.00	1785.74	44.27
11	Tewekel share company	B-13	5343.27	2215.25	41.46
12	Agenbi Building Construction P.L.C	B-14	1064.33	617.81	58.05
13	ATAA Construction Share Company	B-15	1061.28	422.10	39.77
14	Zeway Commercial Building	B-16	3238.27	1164.75	35.97
15	Rahey Be Sidamo Tera Lemat Nigid Share Company	B-17	2546.64	860.07	33.77
16	Sidamo Building Share Company B3	B-18	4166.28	909.80	21.84
17	Adamas zemenay share Company	B-19	2301.24	2111.57	91.76
18	Sidamo Building Share Company B1	B-20	2123.32	1207.07	56.85
19	Sidamo Building Share Company B2	B-21	3945.94	872.77	22.12
20	Metesaseb Le Edeget General Trading	B-22	1515.24	800.83	52.85
21	Cinema Ras Building Share Company	B-23	759.66	1285.35	169.20
22	Mesert Hiwot Share Company A and B	B-29	8352.00	3277.38	39.24
23	Siket Commercial Center	B-30	2269.32	865.36	38.13
24	Addis Adamas Commercial Center	B-31	5655.67	1768.81	31.28
25	Yedigit Meselale Commercial Building	B-32	4405.00	1448.27	32.88
26	Antsbaraki Share Company	B-33	2414.66	554.34	22.96
27	Nigat Birhane share company	B-34	6057.60	2261.79	37.34

ANNEX 5- Monthly Coverage of Harvested Rainwater for the AAWSA Consumption for buildings entirely dependent on AAWSA Supply

Building Code	**Description**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
B-1	Monthly Consumption in m^3	356.33	324.33	326.33	456.00	454.00	461.00	480.00	485.33	414.00	719.67	172.33	230.67
	Mean Rainfall in m^3	18.77	21.90	35.77	69.51	72.86	45.18	7.97	3.88	1.48	2.65	4.25	12.00
	Coverage in %	5.27	6.75	10.96	15.24	16.05	9.80	1.66	0.80	0.36	0.37	2.47	5.20
B-2	Monthly Consumption in m^3	131.00	166.00	194.67	164.67	196.67	185.33	178.33	197.67	130.67	213.67	95.33	121.67
	Mean Rainfall in m^3	34.73	40.51	66.17	128.59	134.79	83.58	14.74	7.18	2.73	4.90	7.86	22.21
	Coverage in %	26.51	24.40	33.99	78.09	68.54	45.10	8.27	3.63	2.09	2.29	8.24	18.25
B-3	Monthly Consumption in m^3	284.00	323.00	344.67	357.67	366.00	307.00	325.00	359.00	291.33	452.67	246.00	313.33
	Mean Rainfall in m^3	32.85	38.32	62.59	121.64	127.50	79.06	13.95	6.79	2.58	4.64	7.43	21.01
	Coverage in %	11.57	11.86	18.16	34.01	34.84	25.75	4.29	1.89	0.89	1.02	3.02	6.70
B-4	Monthly Consumption in m^3	395.00	367.00	384.33	426.67	404.00	387.67	415.00	399.00	294.33	356.67	257.00	360.33
	Mean Rainfall in m^3	174.64	203.72	332.77	646.69	677.84	420.33	74.15	36.09	13.73	24.66	39.52	111.68
	Coverage in %	44.21	55.51	86.58	151.57	167.78	108.43	17.87	9.05	4.67	6.91	15.38	30.99
B-6	Monthly Consumption in m^3	122.33	122.00	190.33	169.00	317.33	83.00	97.33	94.00	75.33	176.00	127.00	69.33
	Mean Rainfall in m^3	12.40	14.47	23.63	45.93	48.14	29.85	5.27	2.56	0.98	1.75	2.81	7.93
	Coverage in %	10.14	11.86	12.42	27.18	15.17	35.96	5.41	2.73	1.29	1.00	2.21	11.44
B-7	Monthly Consumption in m^3	137.29	169.91	177.97	191.52	199.58	226.91	402.54	258.05	218.64	234.74	88.56	162.29
	Mean Rainfall in m^3	31.24	36.44	59.53	115.68	121.26	75.19	13.26	6.46	2.46	4.41	7.07	19.98
	Coverage in %	22.76	21.45	33.45	60.40	60.76	33.14	3.30	2.50	1.12	1.88	7.98	12.31
B-9	Monthly Consumption in m^3	183.49	175.37	162.48	165.84	157.73	153.24	181.52	149.33	145.02	164.82	102.00	190.61

	Mean Rainfall in m^3	44.92	52.40	85.59	166.33	174.34	108.11	19.07	9.28	3.53	6.34	10.17	28.72
	Coverage in %	24.48	29.88	52.68	100.29	110.53	70.55	10.51	6.22	2.44	3.85	9.97	15.07
	Monthly Consumption in m^3	207.33	247.00	258.33	260.67	347.00	330.67	328.33	402.00	249.33	306.00	177.00	308.00
B-10	Mean Rainfall in m^3	108.40	126.46	206.56	401.42	420.75	260.91	46.03	22.40	8.52	15.31	24.53	69.32
	Coverage in %	52.29	51.20	79.96	154.00	121.26	78.90	14.02	5.57	3.42	5.00	13.86	22.51
	Monthly Consumption in m^3	218.33	208.67	193.33	197.33	187.67	182.33	216.00	177.67	177.67	191.00	121.33	226.33
B-11	Mean Rainfall in m^3	108.27	126.30	206.30	400.93	420.23	260.59	45.97	22.38	8.51	15.29	24.50	69.24
	Coverage in %	49.59	60.53	106.71	203.17	223.93	142.92	21.28	12.59	4.79	8.00	20.20	30.59
	Monthly Consumption in m^3	294.33	357.33	292.67	368.33	346.67	301.00	339.67	327.33	374.33	430.33	279.67	322.33
B-12	Mean Rainfall in m^3	113.16	132.01	215.63	419.05	439.23	272.37	48.05	23.39	8.90	15.98	25.61	72.37
	Coverage in %	38.45	36.94	73.68	113.77	126.70	90.49	14.15	7.14	2.38	3.71	9.16	22.45
	Monthly Consumption in m^3	430.06	467.69	409.54	513.42	517.70	518.99	560.87	524.54	437.33	419.80	237.68	305.65
B-13	Mean Rainfall in m^3	140.38	163.76	267.49	519.84	544.87	337.88	59.60	29.01	11.04	19.82	31.77	89.77
	Coverage in %	32.64	35.01	65.31	101.25	105.25	65.10	10.63	5.53	2.52	4.72	13.37	29.37
	Monthly Consumption in m^3	71.00	112.00	69.67	87.67	95.00	110.67	98.33	104.00	113.33	78.67	49.67	74.33
B-14	Mean Rainfall in m^3	39.15	45.67	74.60	144.98	151.96	94.23	16.62	8.09	3.08	5.53	8.86	25.04
	Coverage in %	55.14	40.78	107.08	165.37	159.96	85.15	16.90	7.78	2.72	7.03	17.84	33.68
	Monthly Consumption in m^3	76.33	97.67	117.00	98.33	97.67	110.00	117.00	88.33	86.33	69.00	42.67	61.00
B-15	Mean Rainfall in m^3	26.75	31.20	50.97	99.05	103.82	64.38	11.36	5.53	2.10	3.78	6.05	17.11
	Coverage in %	35.04	31.95	43.56	100.73	106.30	58.53	9.71	6.26	2.44	5.47	14.19	28.04
	Monthly Consumption in m^3	229.73	276.35	269.99	306.03	326.37	295.00	277.20	316.62	288.65	295.00	160.64	196.69
B-16	Mean Rainfall in m^3	73.81	86.10	140.64	273.32	286.49	177.65	31.34	15.25	5.80	10.42	16.70	47.20
	Coverage in %	32.13	31.16	52.09	89.31	87.78	60.22	11.31	4.82	2.01	3.53	10.40	24.00

B-17	Monthly Consumption in m^3	180.67	217.33	212.33	240.67	256.67	232.00	218.00	249.00	227.00	232.00	126.33	154.67
	Mean Rainfall in m^3	54.50	63.58	103.85	201.83	211.55	131.18	23.14	11.26	4.29	7.70	12.34	34.85
	Coverage in %	30.17	29.25	48.91	83.86	82.42	56.54	10.62	4.52	1.89	3.32	9.76	22.53
B-18	Monthly Consumption in m^3	335.33	364.67	319.33	400.33	403.67	404.67	437.33	409.00	341.00	327.33	185.33	238.33
	Mean Rainfall in m^3	57.65	67.26	109.86	213.50	223.78	138.77	24.48	11.92	4.53	8.14	13.05	36.87
	Coverage in %	17.19	18.44	34.40	53.33	55.44	34.29	5.60	2.91	1.33	2.49	7.04	15.47
B-19	Monthly Consumption in m^3	444.33	194.33	116.33	174.67	242.00	150.33	162.00	159.00	154.33	186.67	144.00	173.33
	Mean Rainfall in m^3	133.81	156.10	254.97	495.51	519.37	322.07	56.82	27.66	10.52	18.89	30.28	85.57
	Coverage in %	30.12	80.32	219.17	283.69	214.62	214.23	35.07	17.39	6.82	10.12	21.03	49.37
B-20	Monthly Consumption in m^3	137.00	185.67	188.00	226.00	245.67	182.33	187.00	168.67	183.67	152.33	113.33	153.67
	Mean Rainfall in m^3	76.49	89.23	145.75	283.25	296.90	184.11	32.48	15.81	6.01	10.80	17.31	48.92
	Coverage in %	55.83	48.06	77.53	125.33	120.85	100.97	17.37	9.37	3.27	7.09	15.28	31.83
B-21	Monthly Consumption in m^3	392.00	408.67	328.00	443.00	430.67	379.67	324.00	295.33	299.00	228.67	154.00	263.00
	Mean Rainfall in m^3	55.31	64.52	105.39	204.81	214.67	133.12	23.48	11.43	4.35	7.81	12.52	35.37
	Coverage in %	14.11	15.79	32.13	46.23	49.85	35.06	7.25	3.87	1.45	3.42	8.13	13.45
B-22	Monthly Consumption in m^3	110.00	135.67	201.00	119.67	164.33	132.33	134.67	105.67	99.33	123.67	96.67	92.33
	Mean Rainfall in m^3	50.75	59.20	96.70	187.93	196.98	122.15	21.55	10.49	3.99	7.17	11.49	32.45
	Coverage in %	46.14	43.64	48.11	157.04	119.86	92.30	16.00	9.93	4.02	5.79	11.88	35.15
B-23	Monthly Consumption in m^3	71.00	62.67	58.00	66.33	64.67	49.33	55.67	75.67	78.67	73.00	43.67	61.00
	Mean Rainfall in m^3	81.45	95.02	155.21	301.62	316.15	196.05	34.58	16.83	6.40	11.50	18.43	52.09
	Coverage in %	114.72	151.62	267.60	454.71	488.89	397.39	62.13	22.25	8.14	15.76	42.22	85.39
B-29	Monthly Consumption in m^3	606.00	786.00	604.00	686.00	733.00	820.00	809.00	901.00	809.00	588.00	455.00	555.00
	Mean Rainfall in m^3	207.69	242.28	395.74	769.08	806.12	499.88	88.18	42.92	16.33	29.33	47.00	132.81

	Coverage in %	34.27	30.82	65.52	112.11	109.98	60.96	10.90	4.76	2.02	4.99	10.33	23.93
	Monthly Consumption in m^3	207.00	212.33	231.67	162.00	183.33	191.00	253.67	224.67	163.67	193.00	92.00	155.00
B-30	Mean Rainfall in m^3	54.84	63.97	104.49	203.07	212.85	131.99	23.28	11.33	4.31	7.74	12.41	35.07
	Coverage in %	26.49	30.13	45.10	125.35	116.10	69.10	9.18	5.04	2.63	4.01	13.49	22.62
	Monthly Consumption in m^3	498.67	471.00	509.33	515.33	476.00	456.67	589.33	519.67	463.00	486.00	245.67	425.00
B-31	Mean Rainfall in m^3	112.09	130.76	213.58	415.08	435.07	269.79	47.59	23.17	8.81	15.83	25.37	71.68
	Coverage in %	22.48	27.76	41.93	80.55	91.40	59.08	8.08	4.46	1.90	3.26	10.33	16.87
	Monthly Consumption in m^3	351.33	352.33	388.33	413.33	374.00	332.67	396.67	428.33	364.33	442.67	223.33	337.67
B-32	Mean Rainfall in m^3	91.78	107.06	174.88	339.86	356.22	220.90	38.97	18.97	7.22	12.96	20.77	58.69
	Coverage in %	26.12	30.39	45.03	82.22	95.25	66.40	9.82	4.43	1.98	2.93	9.30	17.38
	Monthly Consumption in m^3	213.00	163.00	210.33	244.33	220.00	182.00	190.67	230.67	231.00	344.67	64.00	121.00
B-33	Mean Rainfall in m^3	35.13	40.98	66.94	130.08	136.35	84.55	14.92	7.26	2.76	4.96	7.95	22.46
	Coverage in %	16.49	25.14	31.82	53.24	61.98	46.46	7.82	3.15	1.20	1.44	12.42	18.57
	Monthly Consumption in m^3	354.00	525.33	481.33	600.00	455.67	342.67	691.00	507.67	498.67	657.33	334.67	609.33
B-34	Mean Rainfall in m^3	143.33	167.20	273.11	530.76	556.32	344.98	60.86	29.62	11.27	20.24	32.44	91.66
	Coverage in %	40.49	31.83	56.74	88.46	122.09	100.67	8.81	5.84	2.26	3.08	9.69	15.04

ANNEX 6 – Storage capacity of the surveyed building

No.	Building Name	Building Code	Storage Capacity in Liters
1	Zelela Commercial Building	B-1	29000
2	Jabulani commercial Building	B-2	10000
3	Soblani Business Center	B-3	30000
4	Merkato Shema Tera Market Center	B-4	52000
5	Mehal Mercato Real Estate Share Company	B-5	10000
6	Chalot Market Center	B-6	23000
7	Telelan Business Center	B-7	10000
8	Afia Commercial Center	B-8	36000
9	Addis fana Private limited company	B-9	20000
10	Dire tera share company	B-10	10000
11	Dire Building P.L.C	B-11	40000
12	Africa commercial Center	B-12	42000
13	Tewekel share company	B-13	40000
14	Agenbi Building Construction P.L.C	B-14	20000
15	ATAA Construction Share Company	B-15	15000
16	Zeway Commercial Building	B-16	25000
17	Rahey Be Sidamo Tera Lemat Nigid Share Company	B-17	50000
18	Sidamo Building Share Company B3	B-18	40000
19	Adamas zemenay share Company	B-19	60000
20	Sidamo Building Share Company B1	B-20	80000
21	Sidamo Building Share Company B2	B-21	85000
22	Metesaseb Le Edeget General Trading	B-22	30000
23	Cinema Ras Building Share Company	B-23	60000
24	Mars Commercial Center	B-24	60000
25	Addis Ababa Market Center	B-25	96000
26	Military Tera Negadioch Share Company C	B-26	55000
27	Military Tera Negadioch Share Company B	B-27	40000
28	Military Tera Negadioch Share Company A	B-28	35000
29	Mesert Hiwot Share Company A and B	B-29	60000
30	Siket Commercial Center	B-30	34000
31	Addis Adamas Commercial Center	B-31	80000
32	Yedigit Meselale Commercial Building	B-32	50000
33	Antsbaraki Share Company	B-33	25000
34	Nigat Birhane share company	B-34	40000