ADDIS ABABA UNIVERSITY

COLLEGE OF TECHNOLOGY & BUILT ENVIRONMENT

SCHOOL OF BUILT ENVIRONMENT

THE POTENTIAL OF RESIDENTIAL ROOFTOP RAINWATER HARVESTING AS A SUPPLEMENTARY URBAN WATER SUPPLY OPTION IN ADDIS ABABA: THE CASE OF BOLE SUB-CITY WEREDA 6

BY

WEINSHET BERTA DEDEBO

ADDIS ABABA, ETHIOPIA

JUNE, 2026

THE POTENTIAL OF RESIDENTIAL ROOFTOP RAINWATER HARVESTING AS A SUPPLEMENTARY URBAN WATER SUPPLY OPTION IN ADDIS ABABA: THE CASE OF BOLE SUB-CITY WEREDA 6

By

WEINSHET BERTA DEDEBO

A THESIS SUBMITTED FOR GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILMENT OF MASTER OF SCIENCE DEGREE IN URBAN DESIGN AND DEVELOPMENT

ADVISOR

TIBEBU ASSEFA (PH.D.)

ADDIS ABABA, ETHIOPIA

JUNE, 2026

ADDIS ABABA UNIVERSITY

School of Built Environment

This is to certify that the thesis is prepared by Weinshet Berta Dedebo entiteled: "The Potential of Residential Rooftop Rainwater Harvesting as A Supplementary Urban Water Supply Option in Addis Ababa: The Case of Bole Sub-City Wereda 6" and submitted in partial fulfilment of the requirement for the degree of Masters of Science in urban design and development.

Approved by examining board, chairman and graduate committee

Dr. Tibebu Assefa		Jun 19/2026
Advisor	**Signature**	**Date**
Alazar Assefa.		June. 19/2026
External Examiner	**Signature**	**Date**
Hayal Desta		June 19/2026
Internal Examiner	**Signature**	**Date**
Astaw Mohammed (PhD)		Jun/19/26
Chairman	**Signature**	**Date**
Solomon Benti (PhD) Department Head		June 19/2026
Department Head	**Signature**	**Date**

SBE
School of Built Environment
Department of Urban & Regional Planning
College of Technology & Built Environment
Addis Ababa University

DECLARATION

I declare that this thesis is my original work. It follows the rules, ethics, and research guidelines. I also declare that I have properly cited and referenced any data, results or findings obtained from other works. This thesis has not been submitted to any other institution for degree or academic qualification in whole or in part.

Name: Weinshet Berta Dedebo

Signature: _______________

This is to confirm that the thesis work is complete and the candidate is ready for examination.

Advisor: Tibebu Assefa (Ph.D)

June, 2026

ACKNOWLEDGEMENT

Above all, I thank God for allowing me to finish this thesis work. This thesis would not be possible without his help. Then I would like to express my sincere gratitude to Dr. Tibebu Assefa for his guidance and helpful comments throughout the progress of this research. I would also like to extend my appreciation to the respondents who participated in this study during the data collection process. And lastly, I would like to express my big thanks to my family specially my mother for her unconditional encouragement and moral support throughout my academic journey. Thank you everyone.

ABSTRACT

Addis Ababa faces water shortages and intermittent supply due to increasing pressure on the municipal water supply system from rapid population growth and urbanization. At the same time, the city receives substantial rainfall, yet much of it is lost as runoff. This study assessed the potential of RRWH in Bole Sub-city, Wereda 6, by determining rooftop harvesting potential, assessing awareness, perception, and acceptability of RRWH, estimating its contribution to household water demand, and examining seasonal variability. Spatial, quantitative, and descriptive research methods were employed. Rooftop catchment area and mean annual rainfall were estimated using QGIS Spatial analysis. RRWH potential, its contribution to household water demand, and seasonal variation were determined through quantitative analysis. Descriptive analysis was applied to household survey data to assess awareness, perceptions, and acceptance of RRWH. The results show that the study area has a rooftop catchment area of 362332.41 m^2 and a mean annual rainfall of 1120.04 mm, yielding an estimated annual harvestable potential of 324661.5 m^3. This could meet 54.9% of annual household water demand. However, the harvesting potential is highly seasonal, with most rainfall occurring between June and September. Survey findings indicate high level of awareness regarding water scarcity and the use of rainwater for non-potable purposes. 93.3% of respondents use rainwater for washing/cleaning in the rainy season. However, 80.3% of the respondents had never heard of a formal RRWH system before the survey. The study concludes that rooftop rainwater harvesting RRWH can serve as a supplementary urban water supply option and contribute to improving household water security in the study area.

Keywords: **Rooftop rainwater harvesting, household water demand, non-potable uses, Addis Ababa.**

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AAWSA	Addis Ababa Water and Sewerage Authority
CSV	Comma delimited
Cwb	Subtropical Highland Climate
EMI	Ethiopian Meteorological Institute
EPSG	European Petroleum Survey Group
IDW	Inverse Distance Weighting
IUWM	Integrated Urban Water Management
QGIS	Quantum Geographic Information System
RWH	Rainwater Harvesting
RRWH	Rooftop Rainwater Harvesting
UN-HABITAT	United Nations Human Settlements Program
UTM	Universal Transverse Mercator
V3	Version 3 (for open buildings Dataset V3)
WSUD	Water Sensitive Urban Design

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Urban water insecurity is becoming a growing global challenge, particularly in rapidly urbanizing cities, where rapid urbanization, population growth, and climate variability continue to place increasing pressure on municipal water supply systems (Arsiso et al., 2017). This challenge is increasingly seen in developing countries, including in Ethiopia, where rapid urban growth and infrastructure limitations have contributed to recurring water shortage and intermittent municipal water supply (Abraha et al., 2022; Bekana et al., 2025). Municipal water supply, designed for gradual population growth, can't support rapid population growth and increasing household water demand (Biswas, 1991). These lead to a supply that does not satisfy demand, and intermittent water service delivery becomes the characteristic of municipal water systems (Nijhof et al., 2010; Bekana et al., 2025).

These inadequacies of municipal water infrastructure have led to the need for other forms of water supply sources (Biswas, 1991; Bekana et al., 2025). In response, water management approaches have shifted toward rooftop rainwater harvesting and other water-sensitive supply options to enhance water availability (Belmeziti et al., 2013; Abraha et al., 2022). These systems do not replace the municipal systems; rather supplement them.

Therefore, rooftop rainwater harvesting (RWH) gained attention. It is a practical supplementary water supply option. Studies in Ethiopia indicate that water availability can be improved using rooftop rainwater harvesting (Adugna et al., 2018; Tolosa et al., 2020). However, the quantitative capacity of rooftop rainwater harvesting in Addis Ababa is not identified. And studies in Ethiopia have mainly focused on identifying the rooftop harvesting capacity of institutional and condominium buildings. Investigations at the level of residential buildings remain limited. As a result, the potential contribution of rooftop rainwater harvesting to household water security is not determined.

The feasibility of RRWH system is determined by the harvesting potential of an area and household awareness, perception, and willingness to adopt the system. Therefore, understanding both harvesting potential and the social acceptability of rooftop rainwater harvesting is critical.

This study, therefore, aims to evaluate the capacity of rooftop rainwater harvesting, the social acceptability of rooftop rainwater harvesting, assess its ability to supplement household water demand, and examine seasonal variability in rooftop rainwater harvesting potential in Addis Ababa, Bole sub-city, Wereda 6.

1.2 Statement of the Problem

Addis Ababa is experiencing increasing water scarcity driven by rapid urbanization, population growth and the limited expansion of municipal water supply infrastructure. As a result, the municipal water supply system is unable to meet the water demand of the city. This forces Addis Ababa Water and Sewerage Authority (AAWSA) to implement water rationing. Therefore, many households experience interrupted water supply. At the same time, increasing dependence of the Addis Ababa Water and Sewerage Authority on groundwater has become another major concern regarding long-term urban water security in Addis Ababa.

Despite receiving substantial rainfall and having extensive rooftop areas, the implementation of rooftop rainwater harvesting in Addis Ababa remain limited. Therefore, most of the rainwater continues to be lost as surface runoff, contributing to urban flooding and increasing pressure on drainage infrastructure.

Although RRWH has been recognized as a potential supplementary water source, existing studies in Addis Ababa have primarily focused on institutional and condominium buildings and have assessed the technical harvesting potential. However, attention to residential households and the social acceptability of RRWH remain limited. As a result, there is limited localized evidence regarding harvestable potential, households' awareness, perceptions, and acceptance of rooftop rainwater harvesting, and its contribution to the household water demand.

Therefore, this study was conducted to fill these gaps by assessing the rooftop rainwater harvesting potential in residential households, evaluating awareness, perception, and acceptance of rooftop rainwater harvesting among households, and determining the contribution of RRWH to household water demand in Bole Wereda 6, Addis Ababa.

1.3 Objectives of the study

1.3.1 General Objective

To estimate the rooftop rainwater harvesting potential of residential households in Addis Ababa, Bole sub-city, Wereda 6, as a supplementary household-level water supply.

1.3.2 Specific Objectives

1. To estimate the rooftop rainwater harvesting potential of residential households.
2. To assess household awareness, perception, and acceptance of rooftop rainwater harvesting in the study area.
3. To estimate the contribution of rooftop rainwater harvesting in satisfying households' water demand.
4. To examine seasonal variability in rooftop rainwater harvesting potential.

1.4 Research questions

1.4.1 General question

What is the rooftop rainwater harvesting potential of residential households in Addis Ababa, Bole sub-city, Wereda 6, as a supplementary household water supply source?

1.4.2 Specific questions

1. What volume of the rainwater can potentially be harvested from residential rooftops in Bole Sub-city, Wereda 6?
2. What are the existing households' awareness, perceptions, and acceptance regarding rooftop rainwater harvesting as a supplementary water source?
3. To what extent can rooftop rainwater harvesting contribute to supplementing the household water demand in the study area?
4. How does seasonal rainfall variability influence rooftop rainwater harvesting potential and its contribution to household water supply?

1.5 Scope of the Study

The study is undertaken in Addis Ababa city, specifically in Bole Sub-city, Wereda 6. This area was selected due to its high concentration of residential developments and the frequent issues with intermittent water supply.

The research focused on water harvested from the roofs of residential buildings. It does not cover ground-catchment and roofs of buildings used for other functions. The study focuses on estimating harvesting potential using local rainfall data, roof coverage, and runoff coefficient. And identifying how much of the household water demand will be satisfied by this harvesting potential. Additionally, the study also focuses on identifying the awareness level, perception, and acceptance of the household about rooftop rain water harvesting in bole wereda 6.

1.6 Significance of the Study

Various stakeholders involved in the water management of Addis Ababa will be benefit from this research. First, for residents, it offers an additional water resource that can improve water availability and reduce dependence on the municipal water supply. Second, for the Addis Ababa Water and Sewerage Authority (AAWSA), it provides evidence on the technical potential of rooftop rainwater harvesting, the extent to which rooftop rainwater harvesting can supplement household water demand, and the potential of rooftop rainwater harvesting to reduce pressure on the city's municipal water supply. Third, urban planners and policymakers will also benefit from this study as it highlights the potential of rooftop rainwater harvesting from residential rooftops, and the levels of awareness, perceptions, and acceptance of rooftop rainwater harvesting (RRWH) among residents. This can guide urban planners and policymakers to the development of better strategies, incentive mechanisms, and building regulations to promote sustainable water management and water-sensitive urban development. Finally, this study contributes to the academic knowledge by addressing the limited localized evidence regarding rooftop rainwater harvesting potential in the residential area of Addis Ababa. Specifically, it provides empirical evidence on harvestable rooftop rainwater potential, household awareness, perceptions, and acceptance, and the demand-satisfaction capacity of rooftop rainwater harvesting for Bole sub city, Wereda 6. These findings can provide a framework for future studies and similar investigations in other residential areas.

Furthermore, the study contributes to broad efforts toward improving urban water security, promoting sustainable water use, and enhancing urban resilience. Therefore, the findings have planning, policy, and academic value.

1.7 Research limitations

The study estimates the theoretical harvestable potential by adopts a single representative runoff coefficient based on the most common roofing materials in the area. And it does not evaluate the actual physical storage availability within residential properties.

1.8 Organization of the Study

This research is organized in five chapters, which structured as follows:
Chapter One has the Background of the study, Statement of the problem, Objectives, Research questions, Scope of the study, Significance of the study and Research limitation.

Chapter Two contains Theoretical review, Contextual review, Household awareness level, perception, and acceptance of rooftop rainwater harvesting, Research gap and Conceptual framework of the study.

Chapter Three has Study area description, Research design, Data types and sources, Sampling design, Data Analysis Methods, and Ethical considerations.

Chapter Four presents Estimation of Rooftop Rainwater Harvesting Potential, Household awareness, perception and acceptance, Contribution of rooftop rainwater harvesting to total water demand, and Discussions.

Chapter Five has Conclusions and Recommendations

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews literature related to concepts and principles of rooftop rainwater harvesting, historical development, and estimation methods for harvestable rainwater potential. Applications of Geographic Information Systems (QGIS) in RRWH assessment, examines empirical studies conducted internationally and in Ethiopia, factors influencing household awareness, perception, and acceptance of rainwater harvesting systems are also reviewed. The chapter also identify existing knowledge gap to establish conceptual foundation for this research.

2.1 Theoretical Review

2.1.1 Rainwater Harvesting and Rooftop Rainwater Harvesting

Rainwater harvesting defined as collection of rainwater from impervious surface and store it in storage tank. There are various surfaces which use as catchment surfaces for rainwater harvesting that include rooftops, paved areas, and natural land surfaces. Rainwater is captured from these catchments before it is lost as surface runoff and stored in water storage tanks or allowed to infiltrate into the soil in order to use for domestic, agricultural, environmental, or groundwater recharge purposes (Tolossa et al., 2020; Che-Ani et al., 2009). Rainwater harvesting get recognized as a supplementary water supply option in water-scarce and rapidly urbanizing regions, as alternative that can improve local water availability while reducing pressure on municipal supply systems (Al-Houri et al., 2014).

There are different forms of rainwater harvesting, out of which rooftop rainwater harvesting (RRWH) is suitable systems in urban areas. Rooftop RWH involves the collection of rainfall from building roofs and conveying the water through gutters and downpipes to store it in tanks (Hari et al., 2018). Typically, the collected runoff made passes through first-flush and filtration mechanisms to remove debris and initial contaminants before entering storage facilities (Aryal et al., 2022; Katambara, 2013). The collected water could use for different household activities.

Therefore, rooftop rainwater harvesting can be seen as building-scale micro-catchments. In this system, the roof acts as the catchment surface. Rainfall represents the input, and stored water is the output of the system. The system performance of RRWH depends on several factors, including rainfall, roof material, runoff coefficients, and storage capacity (Hari et al., 2018; Katambara, 2013).

Within urban water systems, rooftop rainwater harvesting is commonly viewed as household-level intervention that supplements municipal water supply infrastructure rather than substituting it (Adugna et al., 2018; Staddon et al., 2018; Bañas et al., 2023). By capturing rainfall directly at the point of use, rooftop systems can reduce dependence on piped networks, improves household water reliability during supply interruptions, and contributes to diversified urban water supply strategies.

Overall, rooftop rainwater harvesting converts urban rainfall into a localized water resource. The setup of building-scale structural components of RRWH, including the catchment area, guttering channels, first-filter system, and storage configuration are shown in the Figure 2.1.

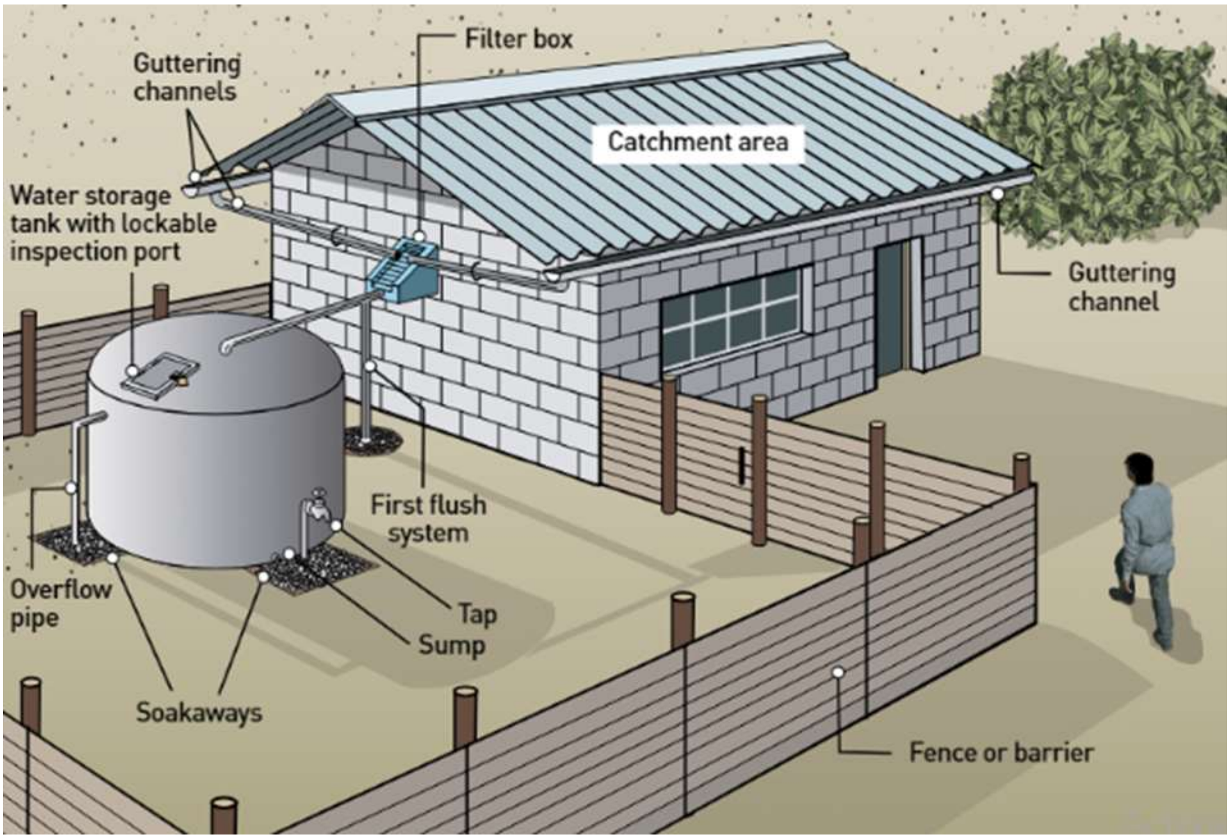

Figure 2.1: Rooftop rainwater harvesting
(Source: World Health Organization, 2020)

2.1.2 Historical Development of Rainwater Harvesting

Rainwater harvesting represents one of the earliest water management systems. By collecting and storing water. Archaeological and historical evidence indicates that numerous civilizations developed systems to capture rainfall from rooftops, courtyards, and natural surface catchments in order to supplement water under variable climatic conditions (UN-Habitat, 2005).

Evidence from ancient Roman settlements demonstrates the integration of rooftop rainwater collection into building design. Roman villas and urban houses commonly have roof catchment systems that directed rainfall into underground cisterns, which served as primary domestic water sources (Ertop et al., 2023; UN-Habitat, 2005). Similar practices were observed in dry areas in which rainfall was scarce. For example, in the Negev Desert of present-day Israel, runoff from natural and constructed catchments was harvested and accumulated in water storage tanks in order to support household consumption (UN-Habitat, 2005).

Long-standing traditions of household rainwater harvesting have also been documented in parts of Asia. In Thailand, for instance, rooftop rainwater harvesting household rainwater collection systems have been used for nearly two thousand years, demonstrating the long-term practicality of rainwater harvesting (Ertop et al., 2023). Likewise, in parts of North Africa, underground water storage with a capacity from 200-2,000 m^3 were built to store harvested rainwater, some of which remain functional today (UN-Habitat, 2005).

Historical evidence within Ethiopia also indicates early forms of rainwater harvesting. During the Axumite Kingdom, surface ponds and storage structures were constructed to collect seasonal rainfall for domestic and agricultural use (Alem, 1999). Archaeological remains found in Axum, Gondar, and Lalibela provide evidence of rainwater harvesting practices.

Overall, these historical examples prove that rainwater harvesting is not a modern innovation. It is long-established practice used across diverse climatic and cultural contexts. Modern rooftop rainwater harvesting systems represent an evolution of these traditional techniques within urban environments, where building roofs serve as catchment surfaces for rainwater harvesting.

2.1.3 Rainfall–Runoff Relationship

The performance of rooftop rainwater harvesting system is commonly assessed using rainfall–runoff relationships. Rainfall is the primary input in rooftop rainwater harvesting systems. The magnitude and temporal distribution of rainfall strongly influence harvesting potential and system reliability. For this reason, accurate estimation typically requires long-term rainfall records, preferably covering at least ten years, obtained from meteorological stations located near the study area (UN-Habitat, 2005).

The second critical determinant of harvesting potential is the catchment surface. In rooftop systems, the roof functions as an impervious collection area that converts rainfall into runoff. However, not all rainfall reaching the roof can be collected. Losses occur due to surface wetting, evaporation, leakage, spillage, and the diversion of the first flush of rainfall. To account for these losses, a runoff coefficient is applied. The runoff coefficient represents the proportion of rainfall that becomes runoff and varies according to roof material, slope, and surface condition (Hari et al., 2018; UN-Habitat, 2005). The variance of these coefficients based on different catchment and roofing material is presented in the following table:

Table 2.1: Runoff Coefficients for various Catchment Surfaces

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

(Source: Anchan & Prasad, 2021)

Accordingly, the potential harvestable volume from a rooftop can be estimated using the Gould and Nissen (1999) formulation:

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

Where; V is harvestable water volume in meter cubic

R is rainfall depth in meter

A is rooftop catchment area in square meter

C is runoff coefficient

Comparing the estimated harvestable volume with household water demand enables us to evaluate the theoretical contribution of rooftop rainwater harvesting to domestic water supply.

2.1.4 Household Water Demand

In urban environments, domestic water use constitutes a major component of municipal water consumption (Howard et al., 2020). This makes household demand a critical factor in determining the balance between water supply and demand within urban water systems. Therefore, understanding household water demand is essential for evaluating the capacity of existing water supply systems and identifying potential supplementary water sources.

Water demand can be estimated per capital demand:

Water Demand = Per Capita Demand × Population × No. of Day (Hari.et al., 2020)

There are factors that influence the volume of water consumed by households. This includes household size, income level, lifestyle, climatic conditions, and access to water supply infrastructure (Howard et al., 2020). These factors also determine a household's water shortage coping mechanisms.

These mechanisms include storing water during periods of water supply, purchasing water from private vendors, using alternative sources such as groundwater, or collecting rainwater through small-scale rainwater harvesting systems (Staddon et al., 2018; Tolossa et al., 2020).

In many developing urban areas, actual household water consumption is often controlled by the limited availability and reliability of municipal water supply systems rather than by household preferences alone. And under such conditions, due to limitations in water access, the amount of water households actually use may fall below their desired level of consumption.

Therefore, household water demand is often estimated using per capita water consumption standards. The minimum quantity of water required maintaining basic health and hygiene generally ranges between 50 and 100 litters per person per day (Howard et al., 2020).

In Addis Ababa, despite on-going infrastructure investments, the municipal water supply system has struggled to meet growing household demand, resulting in supply shortages and unequal distribution of water services across the city (Assefa et al., 2018; Bekana et al., 2025). And the actual water consumption is below the demand (The Resilience Shift et al., n.d.).

Table 2.2: Water Access, Adequacy and Level of Health Concern

Access level and total volumes of water used in the home	Accessibility of water supply	Adequacy for health needs	Level of health concern
Inadequate access (quantity collected can be below 5.3 L/person/day)	More than 1000 m in distance or 30 minutes total collection time	Drinking – cannot be assured Cooking – cannot be assured Hygiene – cannot be assured at the home, compromising food hygiene, handwashing and face washing; other hygiene activities have to be undertaken away from the home	Very high
Basic access (average quantity unlikely to exceed 20 L/person/day)	100–1000 m in distance or 5–30 minutes total collection time	Drinking – should be assured Cooking – should be assured Hygiene – food hygiene, handwashing and face washing may be assured; bathing and laundry cannot be assured at the home but may be carried out at water source	High
Intermediate access (average quantity about 50 L/person/day)	Water delivered through one tap on-plot, or within 100 m or 5 minutes total collection time	Drinking – assured Cooking – assured Hygiene – all food hygiene, handwashing and face washing assured under non-outbreak conditions; enhanced hygiene during infectious disease outbreaks not assured; bathing and laundry at the home should also be assured	Medium
Optimal access (average quantity more than 100 L/person/day[e])	Water supplied through multiple taps and continuously available	Drinking – all needs met Cooking – all needs should be met Hygiene – all food hygiene, handwashing and face washing needs should be met, including for bathing and laundry at the home, and household cleaning	Low

(Source: Howard et al., 2020)

2.1.5 Rooftop Rainwater Harvesting within Urban Water Systems

Centralized water supply systems often struggle to meet increasing water demand, particularly in rapidly expanding cities. Therefore, rooftop rainwater harvesting water management approaches such as rooftop rainwater harvesting have gained attention as a solution within urban water systems.

Rooftop rainwater harvesting systems collect rainfall from building roofs and store it for later use at the household level. In urban environments, rooftops are widely distributed catchment surfaces capable of capturing significant quantities of rainwater that would otherwise be lost as runoff (UN-HABITAT, 2005).

Rainwater collected from rooftops can be used for various domestic purposes, particularly including cleaning, washing, sanitation, and gardening (Bañas et al., 2023). Replacing municipal water with harvested rainwater for these activities can reduce household demand on centralize water supply and improve water availability in urban area.

Urbanization increases in impervious surfaces, like residential rooftops, roads, buildings and pavements. Therefore, it alters natural hydrological process by reduce the water infiltrate in the ground and that cause surface runoff. Therefore, as rainfall in urban areas is often rapidly conveyed into drainage systems, it places additional pressure on urban drainage systems. Capturing rainwater at the building level reduces the amount of runoff and helps lessen the pressure on urban drainage systems (UN-HABITAT, 2005; Shaari et al., 2009).

Rooftop rainwater harvesting also contributes to improving water access and reliability at the household level. It enables households to collect and store water during rainfall events. This rooftop rainwater harvesting approach allows households to manage part of their water supply independently (UN-HABITAT, 2005; Batchelor, 2011).

Furthermore, the adoption of rooftop rainwater harvesting can support broader urban water sustainability goals. As cities continue to expand and water demand increases, integrating rooftop rainwater harvesting water supply options such as rooftop rainwater harvesting into urban water management strategies becomes increasingly important (UN-HABITAT, 2005).

However, the effectiveness of rooftop rainwater harvesting in urban areas depends on several factors, including rainfall patterns, roof catchment area, storage capacity, household water demand levels, and awareness and acceptance level of the system in the community. Evaluating these factors is therefore necessary to determine the potential contribution of rooftop rainwater harvesting to supplement municipal water supply system.

2.1.6 Factors Affecting Rooftop Rainwater Harvesting Potential

The concept of rooftop rainwater harvesting is simple. But its performance varies due to difference in rainfall, rooftop characteristics, household demand and system design (Hari et al., 2018; Bañas et al., 2023). A more combined understanding is therefore essential for accurately assessing rooftop rainwater harvesting potential of an area.

2.1.6.1 Rainfall

The main factor which affects potential of rooftop rainwater harvesting potential is rainfall. Both availability and distribution of rainfall have effect. The availability of rainfall affects the quantity of harvested water where as its distribution affects the reliability of the system.

Therefore, areas with higher annual rainfall have greater harvesting potential, but the dependence on annual rainfall masks seasonal variability. Specially, in areas which have definite wet and dry season. This shows that rainwater harvesting systems may experience extended periods of limited supply despite high annual rainfall (Lange et al., 2012; Tolossa et al., 2020). Additional to availability and distribution of rainfall long term change in of precipitation may change the effectiveness of harvesting system over time, especially in regions with rapid urbanization like Addis Ababa (Feyissa et al., 2018). This emphasizes the use of long-term rainfall data to estimation of harvesting potential.

2.1.6.2 Catchment Characteristic

The other critical factor to determine rooftop rainwater harvesting potential is the characteristic of the roof. The widespread of roof surfaces in urban areas is an important resource for rooftop rainwater harvesting (Hari et al., 2018; Lupia et al., 2017).

In urban areas particularly cities where formal and informal settlements exist alongside the distribution of rooftop area is uneven. This is due to variations of building type, construction quality, and roof materials. And can lead to significant differences in harvesting potential. The other important characteristics of roof which affect harvesting potential is roof material. Smooth impervious surfaces like metal sheets produce higher runoff than rough or porous materials (Katambara, 2013).

2.1.6.3 System Design

System design also affects the efficiency of rooftop rainwater harvesting. It determine water loss at difference system components. Water is lost at the roof surface due to surface wetting and evaporation. At components like first flush water is realised to improve the quality. And the effect of these losses is represented as runoff coefficient when estimating harvesting potential. Runoff coefficient varies depending on rainfall intensity, and material, slope and condition of roof (Bañas et al., 2023). However, many empirical studies use constant runoff coefficient which can lead to overestimation of harvesting potential.

2.1.6.4 Storage tanks

Storage limitation also affects performance of rooftop rainwater harvesting system. Even there is sufficient rainfall the capacity of the storage determines the ability of the system to meet household demand (Bañas et al., 2023; Amos et al., 2016).

The storage tank typically represents the largest capital investment in a rainwater harvesting system (UN-HABITAT, 2005). Storage tanks may be positioned above ground, partly underground, or fully underground depending on space availability and household preference (Khoury-Nolde, n.d.). Common residential tank materials include reinforced concrete, masonry (brick or stone), Ferro cement, and pre-fabricated polyethylene or PVC (UN-HABITAT, 2005). In developing countries, low-cost options such as underground brick dome cisterns and wire-mesh concrete tanks have been successfully deployed in large-scale programs, including the construction of one million rainwater tanks in north-eastern Brazil (UN-HABITAT, 2005). For households with limited space, underground tanks are an efficient solution as they can be installed beneath compound surfaces without disrupting daily activities (UN-HABITAT, 2005).

2.1.6.5 Type of building, land use pattern and urban density

The type of building, land use pattern and urban density determine the availability of roof for catchment and the possibility of installation. That makes it another characteristic to affect the capacity of rooftop rainwater harvesting in urban area. Densely populated urban area offers considerable potential for rainwater harvesting (Belmeziti et al., 2013). But populated areas may face problems related to space restriction for storage tank, accessibility for maintenance and roof ownership and usage right especially in informal settlements.

Household water demand Household water demand is another essential factor which determines the practical contribution of rooftop rainwater harvesting. Since household demand depend on consumption pattern and household size additional to collected volume of rainwater. The efficiency of rooftop rainwater harvesting system depends on the relationship between harvested rainwater and demand (Howard et al., 2020). Studies in Ethiopia show the proportion of demand that can be meeting by the harvesting water is fluctuated significantly (Meskele et al., 2024). This is due to interaction of rainfall availability, rooftop area and storage capacity.

All the factors rainfall, roof characteristics, system design, storage capacity, urban characteristics, and household water demand do not function independently. There interactions determine the efficiency of rooftop rain water harvesting system. Large roof area may produce high runoff during heavy rain but without sufficient storage the water be lost, on the other hand if there is sufficient storage and rainfall is variable the system will not be efficient. This show that understanding the combine effect of this factor is essential for accurately assessing harvesting potential.

Addis Ababa is characterized by seasonal rainfall patterns, rapid urban expansion, and increasing water demand. All of which influence the feasibility of rooftop rainwater harvesting. Therefore, consideration of the interaction between these factors is essential. Rooftop size, building quality, and access to storage infrastructure may result in considerable differences in theoretical harvesting potential and actual harvesting potential of households. Consequently, accurate estimation of rooftop rainwater harvesting potential in Addis Ababa requires a combine analysis of climatic, rooftop areas, and assessment of household water demand.

2.1.7 RRWH within Sustainable Urban Water Management Frameworks

2.1.7.1 Water Sensitive Urban Design (WSUD)

Water Sensitive Urban Design (WSUD) is an urban design method that integrates urban water management and urban design. It aims to minimize the hydrological impacts of urban development by promoting the capture, storage, reuse, and management of water resources within the urban environment (Armitage et al., 2014). It aims to improve water security, reduce urban flooding, enhance environmental quality, and increase the sustainability of urban development.

Rooftop rainwater harvesting is one of the WSUD strategies because it captures rainfall directly at the source. By storing rooftop runoff for later household use, rainwater harvesting contributes to water conservation and reduces storm water runoff volumes. In rapidly urbanizing cities such as Addis Ababa, impervious surfaces increases and water shortages occur simultaneously, increase the importance of WSUD. This provides a useful framework to evaluate alternative water sources including rooftop rainwater harvesting as both a water supply and storm water management intervention.

The present study aligns with WSUD principles because it assesses the potential of residential rooftops to supplement household water supply while also reducing pressure on urban drainage infrastructure.

2.1.7.2 Integrated Urban Water Management (IUWM)

Integrated Urban Water Management (IUWM) is an approach that promotes coordinated management of all components of the urban water cycle. It manages water supply, wastewater, storm water, groundwater resources, and alternative water source co-ordinately. Unlike traditional approaches that manage these components separately, IUWM recognizes the interconnections between different water resources and seeks to maximize their combined benefits (Bahri et al., 2012).

Under the IUWM framework, alternative water sources such as rooftop rainwater harvesting are considered important elements of diversified urban water supply systems. Rainwater harvesting can reduce dependence on centralize municipal systems by providing supplementary water at the household level. This becomes particularly important in cities experiencing rapid population growth and increasing water demand.

Addis Ababa faces significant challenges related to water shortages and intermittent water distribution (The Resilience Shift et al., n.d.; Bekana et al., 2025). Within this context, rooftop rainwater harvesting represents decentralized water management strategy that complements existing infrastructure. Therefore, the present study contributes to the IUWM perspective by examining the extent to which rooftop rainwater harvesting can supplement household water demand.

2.1.7.3 Urban Resilience Theory

Urban resilience refers to the ability of cities and urban systems to withstand, adapt to, and recover from environmental, social, and infrastructural stresses and shocks. Reliable access to water is essential for public health, economic activities, and overall urban functioning. Therefore, water security is a part of urban resilience (The Resilience Shift et al., n.d.; Takin et al., 2023)

Urban water systems are facing pressure from climate variability, rapid urbanization, and increasing water demand. Therefore, dependence on a single centralized water supply system can increase vulnerability. Rooftop rainwater harvesting enhances resilience by diversifying water sources and providing households with an alternative supply during periods of water shortage or service interruption.

From an urban resilience perspective, rooftop rainwater harvesting can increase resilience by enabling households to store water during periods of rainfall and use it during supply interruptions. Consequently, the assessment of rooftop rainwater harvesting potential contributes to understanding how local scale interventions can strengthen the resilience of Addis Ababa's water system.

2.1.7.4 Sustainable Infrastructure Planning

Sustainable infrastructure planning emphasizes the development of infrastructure systems that meet present needs without compromising the ability of future generations to meet their needs. Sustainable infrastructure refers to any infrastructure including water infrastructure that planned, constructed, managed in a way that promotes environmental, social and economic sustainability throughout its lifecycle (Kustova et al., 2024)

Traditional urban water infrastructure often requires large scale investments in dams, treatment facilities, pipelines, and distribution networks. As urban populations continue to grow, these centralize systems face increasing financial and operational challenges. Sustainable infrastructure planning therefore encourages complementary decentralized solutions that improve efficiency and reduce environmental impacts.

Rooftop rainwater harvesting represents a form of decentralized water infrastructure because water is collected, stored, and utilized near to the point of consumption. Such systems can reduce demand on centralized infrastructure, lower storm water runoff, and improve household water security. Therefore, the present study evaluates rooftop rainwater harvesting as a sustainable infrastructure option that can contribute to long term urban water management in Addis Ababa.

2.2 Contextual review

Rapid population growth cause urban water scarcity. The need for alternative sources leads to the expansion of researches on rooftop rainwater harvesting (RWH). Different studies, conducted in different regions of the world estimate the harvesting potential of rooftop harvesting system for their region. And check to what extent that rooftop water harvesting supplement water supply. These researches estimate the capacity of the system by integrating factors which affect capacity of harvesting like rainfall data, rooftop catchment, runoff coefficient, and water demand. These sections review the findings from global studies, African urban contexts, and Ethiopia.

2.2.1 Global Studies

Global research shows that rooftop rainwater harvesting can provide significant volumes of water for urban use. But the results vary depending on climatic and physical conditions. Where there is adequate rainfall and large roof catchments, studies reports high harvesting potential. Researchers often use rainfall–runoff relationships and spatial GIS analysis techniques in order to determine rain water harvesting. For example, rooftop rainwater harvesting assessment in urban Jordan estimated annual harvestable volumes exceeding one million cubic meters in selected district (Al-Houri et al., 2014). These show the capacity of such systems in proving a reliable supplementary water source in water-scarce environments. Another, research conducted in Nepal show that a rooftop area of 372 m^2 receiving high annual rainfall could meet the full drinking water demand of an institutional facility (Aryal et al., 2020)

Geospatial techniques have further improved the accuracy of such estimations. Using QGIS-based analysis increase around the world, study in India using this analysis confirmed that large urban areas can generate substantial volumes of harvestable rainwater, in some cases above local domestic water demand (Hari et al., 2018). Similar findings have been reported in institutional and multi-story building contexts, where rooftop harvesting systems contribute significantly to water savings (Anchan & Prasad, 2021). At the urban scale, rainwater harvesting can reduce dependence on treated municipal water by providing an alternative rooftop rainwater harvesting supply (Belmeziti et al., 2013).

Though these studies show the substantial technical potential of rooftop rainwater harvesting, their findings are based on large rooftop areas.

2.2.2 African Urban Contexts

Rooftop rainwater harvesting is gaining attention in Africa. This is due to pressure on the municipal system.

Studies across African demonstrate that rooftop rainwater harvesting can provide meaningful supplementary water. But the system performance is highly dependent on local conditions. For instance, an assessment conducted in Tanzania showed that rainwater harvesting systems can reliably meet low daily water demands when appropriate storage is provided, however the performance declines significantly under higher demand levels due to seasonal variability (Katambara, 2013). Similarly, research in Namibia estimated that households could harvest tens to over one hundred cubic meters of rainwater per rainy season (Nashima, 2013).

Studies in East and West Africa strengthen the importance of rainfall variability in determining harvesting potential. For example, rainfall-driven assessments in Uganda along the slopes of Mount Elgon demonstrate that the contribution of rooftop rainwater harvesting is strongly influenced by precipitation patterns and catchment characteristics (Bernard & Joyfred, 2020; Durodola et al., 2020). More recent research also highlights the integration of rooftop harvesting with groundwater recharge and climate adoptation measures (Amihere-Ackah et al., 2025).

Similar to global studies, studies in African also focus on institutional, or campus.

2.2.3 Ethiopia and Addis Ababa

There is rapid population growth in urban areas of Ethiopia, and there is also an infrastructural limitation. This makes water supply a challenging task for municipal water supplies. As studies repeatedly show, this challenge is also affecting Addis Ababa. The water demand of Addis Ababa is increasing more rapidly than the supply, this result constant shortage and intermittent water distribution (Arsiso et al.,2017; Alemu & Dioha, 2020; Unto, 2024)

These conditions call for an alternative water source to supplement the municipal supply and improve water availability. Research proves that Ethiopia has potential for rainwater harvesting. For example, study conducted in Dilla town shows that rooftop rainwater harvesting can provide water and supplement municipal supply during supply disturbance (Kanno et al., 2021).

Another recent study conducted in Hosaena city shows that a large portion of water demand can be satisfied with rooftop rainwater harvesting when the roof area and storage capacity are adequately considered (Meskele et al., 2024). A review on rainwater harvesting in Ethiopia emphasize significance of rainwater harvesting as a means to improve water availability in semi-arid and water stress regions (Tolossa et al.,2020).

Research in Addis Ababa has shown that traditional residential compounds typically offer sufficient space for larger storage tanks, whereas condominium blocks may require shared systems or more compact configurations (Yilma et al., 2026). Despite this potential, a survey of Addis Ababa households found that 72.7% do not use modern rainwater harvesting systems, and key components such as permanently installed storage tanks, downpipes, and filters are largely absent, with most residents relying on improvised containers instead (Yilma et al., 2026). Studies on rooftop RWH in Ethiopian cities have recommended that future research focus on developing affordable storage tanks using alternative materials such as polyvinyl or stone and brick masonry, and that cost-benefit analyses be conducted to support household-level adoption (Meskele et al., 2024).

Similarly, research which assesses the potential for rooftop rainwater harvesting of large public institutions in Addis Ababa have shown that the wide rooftop area can capture a significant volume of rainwater (Adugna et al.,2018). Furthermore, Addis Ababa receives suitable amount of rainfall for rooftop rainwater harvesting. However, there is spatial variation in rainfall distribution across the city are presented in the figure below:

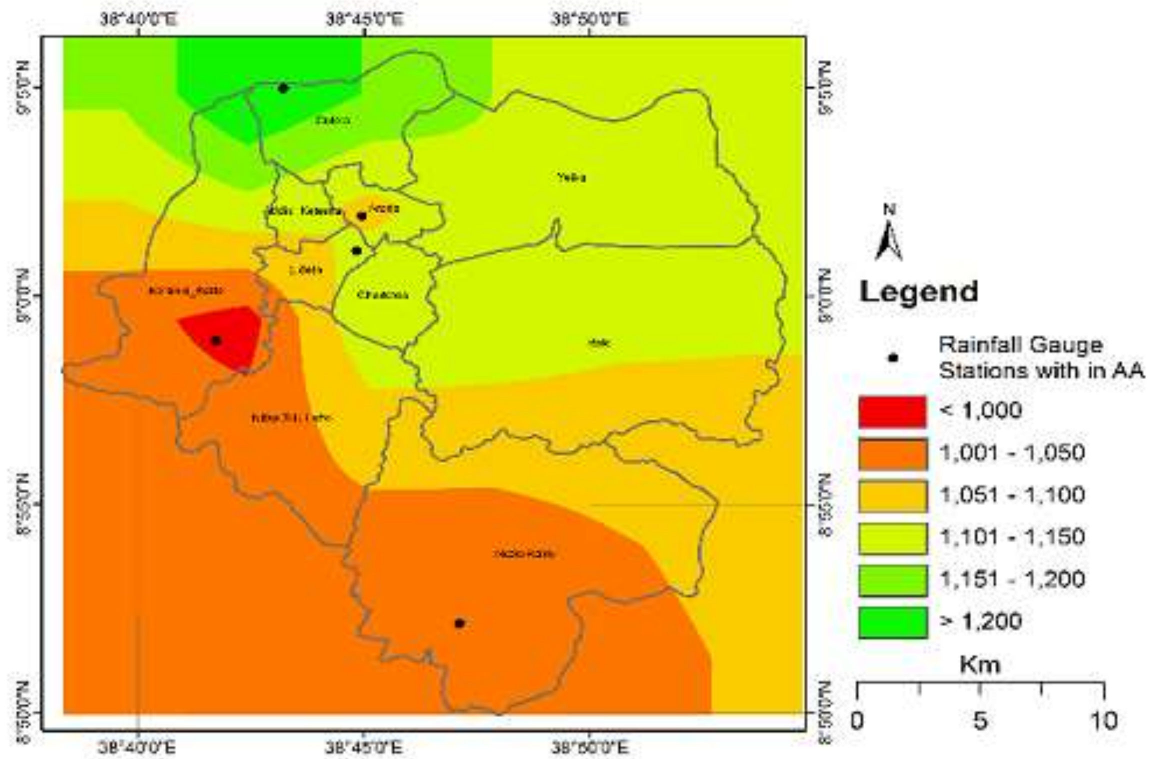

Figure 2.2: Rainfall distribution in Addis Ababa

(Source: Ewunetu, 2019)

Overall, empirical studies from the global to Ethiopian context confirm the potential of rooftop rainwater harvesting.

2.3 Household Awareness level, Perception, and Acceptance of RRWH

The effectiveness of rooftop rainwater harvesting systems is strongly influenced by social and behavioural factors. That includes household awareness, and perceptions regarding water quality and reliability. Additionally socio-economic and institutional conditions also play roles in determining whether households adopt rainwater harvesting technologies (Staddon et al., 2018; Tolossa et al., 2020).

Most households in developing countries experience limited and unreliable access to municipal water supply. Therefore, to reduce the dependency on the municipal supply and to improve water security rooftop rainwater harvesting has been promoted (Abraha et al., 2022; Bekana et al., 2025) And studies show that, the adoption rate to be low when households lack awareness of the technology, perceive harvested rainwater as unsafe or face financial and institutional barriers even where potential exists (Nijhof et al., 2010; Umukiza et al., 2023).

Understanding these factors is therefore essential for evaluating the feasibility of rooftop rainwater harvesting.

2.3.1 Awareness Level

Studies show that awareness level deeply affects the implementation of rooftop rain water harvesting system. If the system applied without the user having proper awareness its sustainability is low. Therefore, creating awareness should be the first stage in implementation process. Awareness shows the households familiarity with the concept, benefits and the operation of rooftop rainwater harvesting system.

Some studies show the adoption of rooftop rainwater harvesting system is hindered by awareness limitation. For example, research undertaken in Uganda many households were aware of water scarcity challenges but lacked adequate information about the potential and benefits of rooftop rainwater harvesting (Staddon et al., 2018). The study show that awareness on installation procedures, storage requirements, and potential uses of harvested rainwater strongly influenced households' willingness to adopt the system.

A study in Ghana on rainwater harvesting practices indicates that awareness levels often vary widely among households. With knowledge is higher in communities where rainwater harvesting has been actively promoted through government programs or community initiatives (Owusu & Asante, 2020). Households with information about the benefit of rooftop rainwater harvesting are more likely consider adopting rooftop rainwater harvesting system.

The awareness of rainwater harvesting is increasing in the Ethiopian. It is the water scarcity challenges that became more obvious in both rural and urban areas lead to such increasing awareness on rainwater harvesting. Review the on practice of rainwater harvesting in Ethiopia show that households can be encourage to adopt rooftop rainwater harvesting by improve information distribution (Tolossa et al., 2020).

The awareness level on rooftop rainwater harvesting is uneven across different urban communities despite growing recognition of its potential benefits.

Overall, findings suggest promoting rooftop rainwater harvesting using educational campaigns, demonstration projects, and community training and providing technical support will increase is adoptation.

2.3.2 Perception of Water Quality and Reliability

Adoptation of rooftop rainwater harvesting is determined by household perception of the quality of water and reliability of the system. Concerns about water safety and system performance may discourage households from adopting rooftop rainwater harvesting system even they are aware of the system. Perception of water quality is often one of the most significant barriers. And studies which examine the performance of rooftop rainwater harvesting systems indicate the quality of collected rainwater could be affect by roof material types, atmospheric pollutants, and the effectiveness of filtration systems (Aryal et al., 2022). Households often recognize that when rooftop rainwater harvesting system design properly it can produce water that is suitable for non-potable domestic uses. However, they still perceive rainwater to be unsafe for certain application.

The other concern identifies by research on urban rainwater harvesting system is related to potential contamination during collection and storage processes. For example, investigations show inadequate maintenance of storage tank or filtration system may lead to water quality deterioration over time (Carpio-Vallejo et al., 2024). Those have implication into the quality of stored rainwater and its effect on health. Such concerns can influence household perceptions regarding the reliability and safety of harvested rainwater.

Another important consideration affecting household attitudes toward rooftop rainwater harvesting is reliability. Households perceive rainwater harvesting as an unreliable water source during dry periods because rainfall is very little. Studies on rainwater harvesting systems of different climatic regions shows the consistency of water supply from rooftop rainwater harvesting is limited by rainfall variability and limited storage capacity (Bañas et al., 2023). Therefore, households view rainwater harvesting as a supplementary source which support the municipal supply.

Despite these concerns, research indicates that perceptions can change. When households gain direct experience with rainwater harvesting systems or receive information about appropriate system design and maintenance practices their perception often change. Therefore, by increasing community-based initiatives that showcase successful rainwater harvesting systems we can improve household confidence in the quality and reliability of harvested rainwater.

2.3.3 Factors affecting Adoption of Rooftop Rainwater Harvesting

As compared to awareness gap and perception of quality and reliability, the initial cost associated with installing storage tanks, gutters, and filtration systems are more barriers to adopt rooftop rainwater harvesting. Studies indicate that financial constraints can significantly affect the decision of low-income households and limit their ability to invest on adoption of rooftop rainwater harvesting system (Staddon et al., 2018). This indicates that even when households recognize the potential benefits of rainwater harvesting, the initial cost of system installation may discourage adoption.

Research on rainwater harvesting also highlights the importance of supportive policies, regulatory frameworks, and institutional arrangements to promote rooftop rainwater harvesting as water supply solutions (Nijhof et al., 2010). Institutional and policy frameworks have role in facilitating or constraining the implementation of rooftop rainwater harvesting system.

Institutional support can facilitate the distribution of technical knowledge, improve access to financing mechanisms, and promote the integration of rainwater harvesting into urban water supply (Umukiza et al., 2023). Studies conducted in African emphasize that successful implementation of rainwater harvesting systems requires coordinated efforts. It should involve government agencies, local communities, and non-governmental organizations.

Overall, existing studies indicate that the adoption of rooftop rainwater harvesting systems is influenced by a complex interaction. This means the adoption of rooftop rainwater is the result of interaction between awareness, perception, socio-economic capacity, and harvesting potential. Evaluating these factors is therefore essential. Understanding the extent to which rooftop rainwater harvesting can be accepted and utilized as a supplementary household water supply option in urban areas such as Addis Ababa is essential.

2.4 Research Gaps

Even if the research on rooftop rainwater harvesting is getting increased, there are still critical knowledge gaps in the assessment and its application in rapidly urbanizing cities such as Addis Ababa.

First, there are numerous global and regional studies which demonstrate the capacity of rooftop rainwater harvesting. This shows how to determine the harvesting capacity of an area. But empirical assessments in Ethiopian urban contexts remain limited. Researches in Ethiopia primarily focus on rural rainwater harvesting practices or large institutional buildings (Adugna et al., 2018; Tolossa et al., 2020). Relatively little attention is given to residential-scale. This limits the applicability of current findings to household-level. Where building characteristics, water demand patterns, and infrastructure constraints differ significantly from institutional or rural settings.

Second, studies often only focused on estimating the rainwater harvesting potential. Relatively few evaluate its contribution to household demand. A study without systematically comparing consumption requirement to harvesting potential is limiting. And its practical relevance is low. As emphasized in water demand studies, the effectiveness of any supplementary water source must be evaluated within a supply–demand framework (Howard et al., 2020). In Ethiopian household water access is often intermittent and insufficient (Arsiso et al., 2017; Alemu & Dioha, 2020). This make understanding the extent to which rooftop rainwater harvesting can balance demand is essential, but remains inadequately explored.

Third, there is a lack of localized empirical evidence on household awareness, perception, and acceptance in Addis Ababa. Global and regional studies indicate that adoption of rainwater harvesting system is strongly influenced by awareness, perceived water quality, cost, and institutional support (Staddon et al., 2018; Suni et al., 2025). However, these factors are context-specific and vary significantly across regions. The absence of such evidence for Addis Ababa limits understanding of households are willingness and financial capacity to adopt rooftop rainwater harvesting systems.

Finally, existing studies often examine technical potential and social acceptance independently. But the adoption of the system requires the integration of these dimensions. This is demonstrated in both empirical and behavioural research. The success of rooftop rainwater harvesting systems depends on the interaction between physical feasibility and user acceptance. Technical potential alone does not guarantee adoption, while social acceptance

2.5 Conceptual Framework of the Study

This study assumes that both technical and socio behavioural factors affect the capacity and success of rooftop rainwater harvesting. The technical factors are rainfall, roof area and runoff coefficient which determined the quantity of harvestable water. The social behavioural factors include awareness, perception, and acceptance.

The systematic interaction, input pathways, and outputs linking these two factors are visually structured in the following figure.

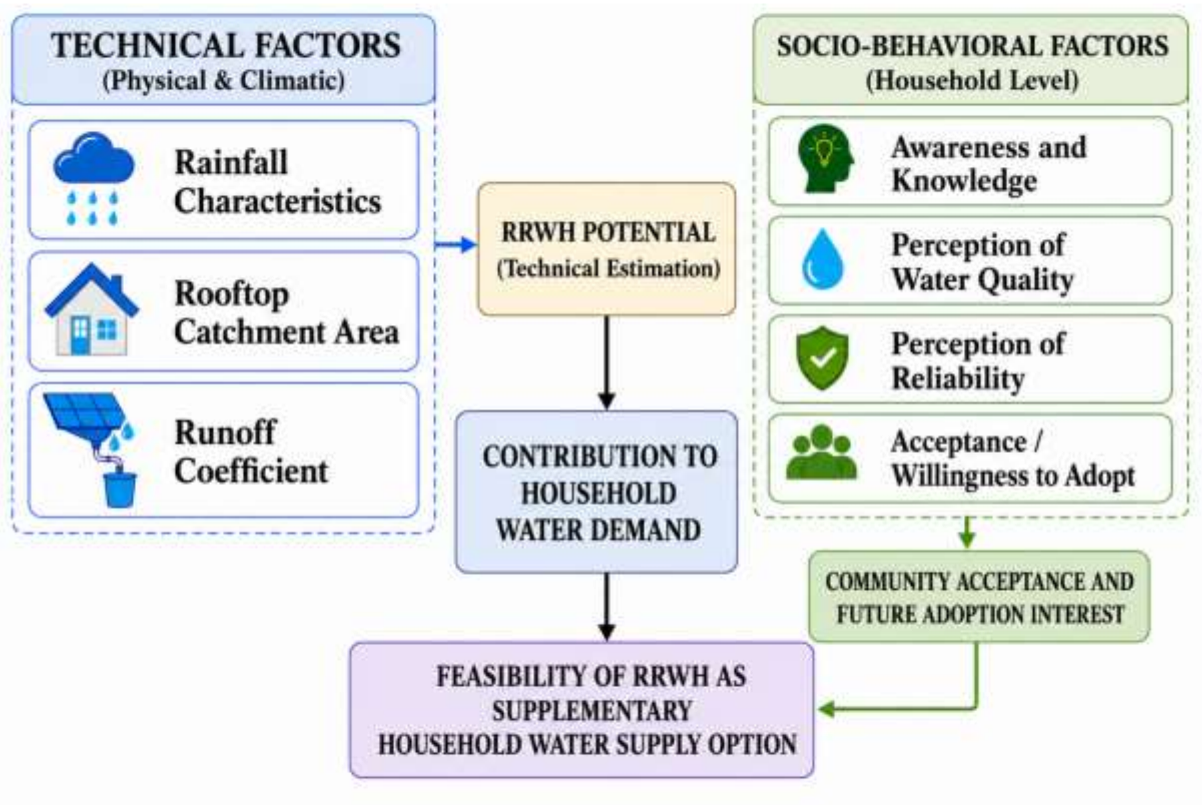

Figure 2.3: Conceptual framework of the study

CHAPTER THREE

MATERRIALS AND METHODS

In this chapter, the research materials and methodology elements are presented. The chapter has sections that describing the study area, research design, data sources, sampling procedures, data collection methods, and analytical techniques used in the study.

3.1 Study Area Description

Addis Ababa, the capital city of Ethiopia, is located between $8^0$50’-$9^0$05’ N (Feyissa et al., 2018; Addis Ababa City Administration and Resilient Cities Network, 2020). And the elevation decreasing from the northern highlands toward the southern parts of the city ranges from about 3,040 meters to 2,050 meters above sea level.

Climatically, Addis Ababa is characterized by a subtropical highland climate (Cwb) according to the Köppen–Geiger classification system. The city’s main rainy season occurs from June to September. The remaining months are relatively dry periods. This means the city experiences a distinct seasonal rainfall pattern.

Addis Ababa is one of the fastest growing cities in Africa, and a significant portion of the country’s urban population is currently accommodated in the city. The city has an estimated population of 5.9 million and is growing at an annual rate of 3.8%. This projection indicates continued rapid population growth in the coming decades (World Population Review, 2025).

Administratively, Addis Ababa is divided into 11 sub-cities and 121 woredas. The present study focuses on Bole Wereda 6, which is located within Bole Sub-city. The area has mostly residential land use, and municipal water supply interruption is common which highlights the need for alternative and supplementary water sources. This makes it suitable for assessing household-level rooftop rainwater harvesting potential in urban settings. This is why it is chosen as a study area.

The administrative boundary of the selected wereda is mapped in Figure 3.1.

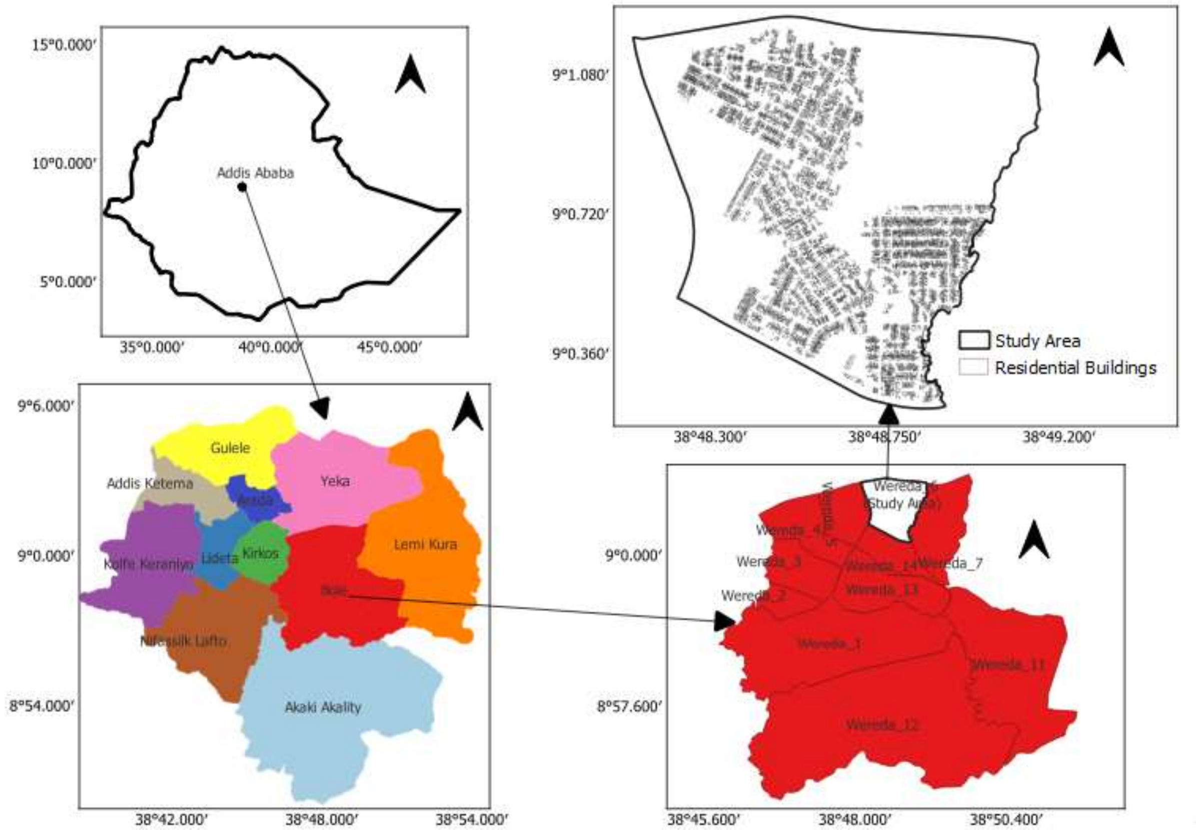

Figure 3.1: Location map of Bole Wereda 6

3.2 Research Design

The research design integrates quantitative, spatial analysis and descriptive methods because the study evaluates both the technical potential and social acceptance of rooftop rainwater harvesting. The quantitative method was used to assess the harvesting potential. QGIS spatial analysis was used to determine the rooftop area and rainfall of the study area. Then, the rooftop area, rainfall data, and runoff coefficient were used for the quantitative estimation of the harvesting potential. The descriptive method was used to determine the social acceptability of rooftop rainwater harvesting in the study area, with assessment to awareness, perception, and acceptance conducted using a household questionnaire survey. The combination of these methods enables the evaluation of rooftop rainwater harvesting as a supplementary household water supply option.

3.3 Data types and sources

Both primary and secondary data were collected. The primary data were collected from a household survey on household size, water use behaviour, rooftop characteristics, and awareness, perceptions, and acceptance of rooftop rainwater harvesting in the study area. Secondary data included building roof area data derived from the Open Buildings dataset, daily rainfall records obtained from the Ethiopian Meteorological Institute, and parcel boundary data obtained from the wereda administration.

3.4 Sampling Design

Prior to sampling, residential rooftops were categorized into three distinct scale based on catchment sizes. The catchment size was selected as the classification variable because it directly determines the potential volume of rainwater that can be harvested. Using the attribute-based clustering plugin in QGIS 3.28.3, a K-means clustering algorithm was applied to the total parcels of 2316.To determine the optimal number of classes Elbow Method was used, resulting in the identification of three distinct clusters.

Cluster 1 (Large Catchment) has roofs with areas ranging from 221.7 to 606.5m^2. Cluster 2 (Medium Catchment) has roofs with areas ranging from 131.3 to 221.1 m^2. Cluster 3 (Small Catchment) has roofs with areas ranging from 33.7 to 131.2 m^2.

The spatial distribution of roof categories across the wereda’s residential layout is presented in Figure 3.2.

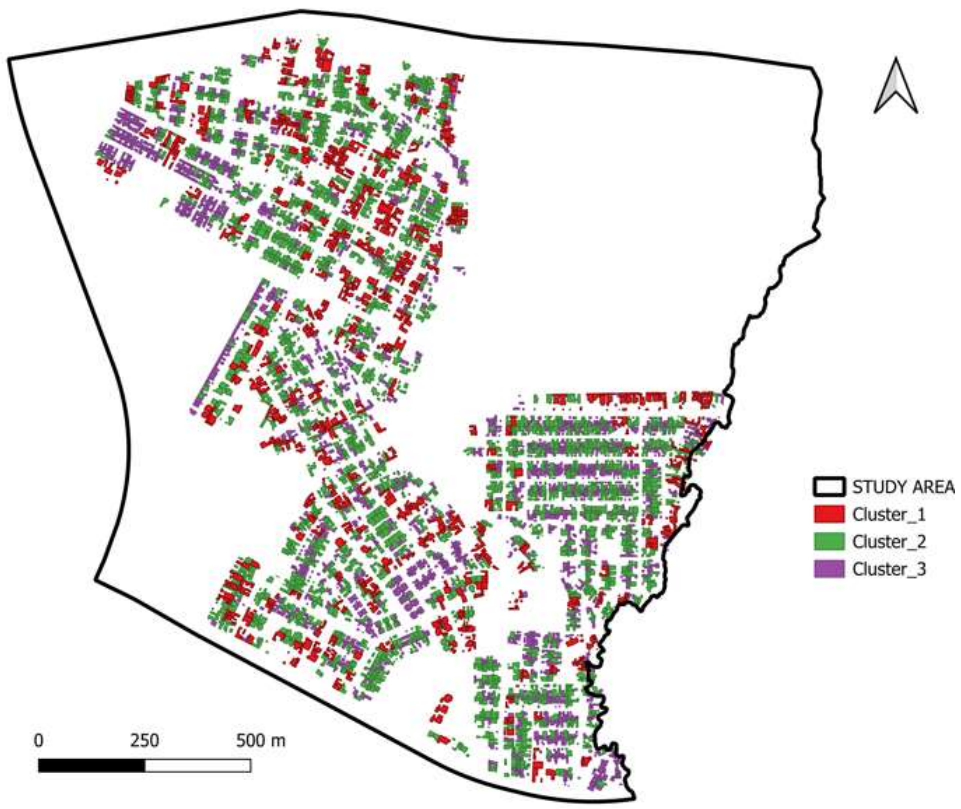

Figure 3.2: Roof Area Cluster Map

After clustering, a stratified sampling approach was employed. This is to ensure that households from all rooftop categories are sufficiently represented. The total sample size was determined using Cochran's (1977) formula with 95% confidence interval.

For an infinite population:

$n_o = (z^2 \times p \times q)/e^2$

Where:

Z = 1.96 (for a 95% confidence level)

p = 0.5(maximum variability, standard for assessment studies)

q =1-p = 0.5

e = 0.05 (precision level or margin of error)

$n_o = (1.96)^2 \times 0.5 \times 0.5/(0.05)^2 = 384.16$

Since the number of Parcels N = 2316, the Finite Population Corrections ware applied:

For finite population:

n = no / 1 + ((no-1)/ N)

n = no /1 + no – 1/N

n=384.16/1+ ((384.16-1)/ 2316) = 329.6

Total Sample Size (n) = 330 households

Then the total sample was proportionally distributed across the three clusters. Table 3.1 documented the definitive sample size allocation across these clusters. Within each cluster, systematic random sampling was applied to select households. A sampling interval was identified by dividing the number of households in each cluster by the allocated sample size for that cluster.

Table 3.1: Sample Distribution

Catchments	**Area Range (m^2)**	**Total Households**	**Proportion**	**Sample Size**
Clusters 1	221.7- 606.5	341	14.8%	49
Clusters 2	131.3 - 221.1	1054	45.5%	150
Clusters 3	33.7 - 131.2	921	39.7%	131

The selected sample residenntial households among the total households are highlighted in Figure 3.3

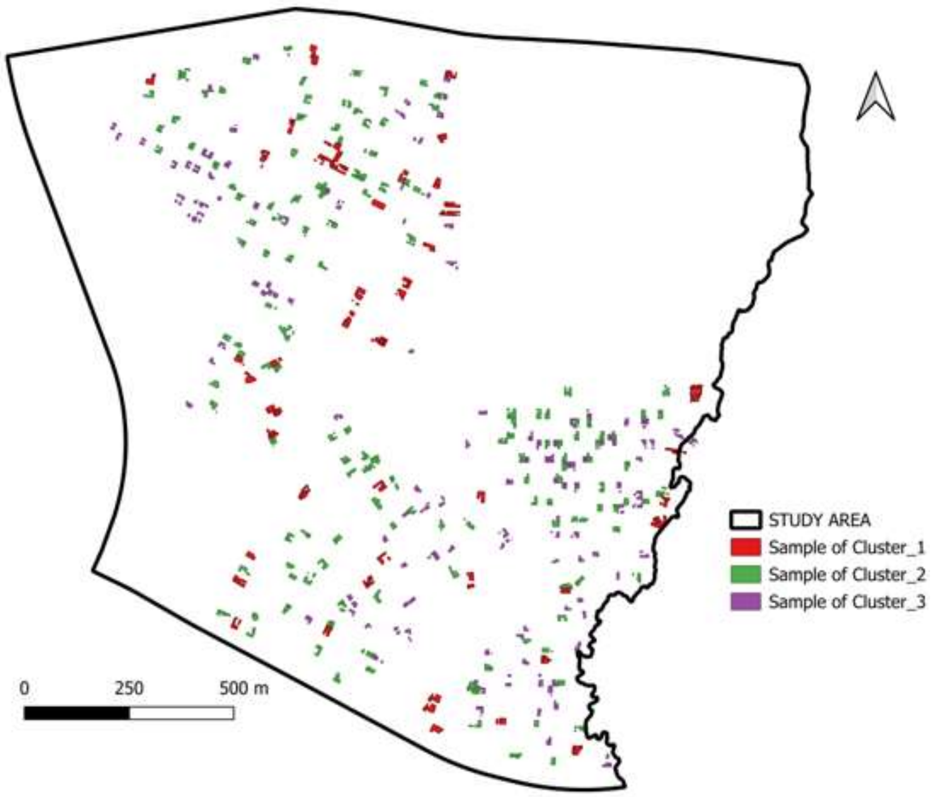

Figure 3.3: Samples Distribution Map

3.5 Data Analysis Methods

3.5.1 Estimation of Rooftop Rainwater Harvesting Potential

The rainfall-runoff equation was used to determine the potential volume of water from rooftop rainwater harvesting.

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

Where;

V = the annual volume of harvested rainwater

R = annual rainfall

A = rooftop area, and

C = the runoff coefficient.

3.5.1.1 Rainfall Data Processing

Mean annual rainfall values were calculated using daily rainfall data obtained from the Ethiopian Meteorological Institute. Missing values in the daily rainfall datasets were estimated, before calculating the mean annual rainfall, using the simple arithmetic mean method.

$$Px = 1/m\ [P1 + P2 + \ldots + Pm]$$

Where;

P_x = the estimated value of the missing data.

P = the value of the same parameter at the nearest weather station, and

m = the number of nearest stations.

Then, using the QGIS spatial analysis tool, the Inverse Distance Weighting (IDW) interpolation method, the mean annual rainfall of the study area is interpolated. The inverse distance weighting (IDW) interpolation method was selected because rain gauge stations closer to the study area are exert greater weight on local rainfall conditions than more distant stations. Zonal statistics were subsequently applied to extract the exact mean annual rainfall value within the study area boundary.

3.5.1.2 Catchment Area Extraction

The rooftop catchment area was quantified using data from Google Open Buildings Dataset Version 3(V3). Which was accessed through Google Cloud Storage (gs://open-building_data/v3/). This dataset utilizes high-resolution satellite images in computing the geometries of buildings. The buildings polygon data were converted into a shape file format. Then projected to the Adindan / UTM Zone 37N coordinate system (EPSG:20137). The Parcel boundary data obtained from the wereda were also prepared in the same projection.

Geometry validation and errors were executed in QGIS. Rooftop areas were calculated using the QGIS Field Calculator. Finally, buildings layer was spatially overlaid with parcels boundary layer to isolate and aggregate the total residential rooftop area within each parcel boundary.

3.5.1.3 Runoff coefficient

A runoff coefficient(C) of 0.8 was selected for this study. This is based on the survey data, which shows the primary roofing material to be corrugated iron sheet. According to UN-HABITAT (2005) standards, corrugated metal roofs typically have runoff coefficients between 0.7 and 0.9.

3.5.2 Assess Household Awareness, Perception, and Acceptance

Primary socio-behavioural data were gathered using structured questionnaire deployed on the Epicollect 5 mobile data collection platform. Field surveys targeted households within the study area to capture data on household size, municipal water supply conditions, and awareness, perceptions, and acceptance of rooftop rainwater harvesting systems.

3.5.3 Estimating Contribution to Household Water Demand

To measure the potential demand gap met by RRWH, household water demand was evaluated using two distinct baseline methods:

3.5.3.1 Empirical Billing Method

Actual water consumption records were acquired in Excel format from Addis Ababa Water and Sewerage Authority (AAWSA). This data was converted to a CSV format and put into QGIS to create a shapefile. Non-residential and external meters were filtered out, leaving only domestic water meters located within the study area. Monthly consumption was aggregated to determine the total annual consumption (m^3/year) for each water meters. Then the total water consumed by households in the area was determined by adding the annual consumption of each water meter.

3.5.3.2 Theoretical per Capita Demand Method

Population-driven was calculated by multiplying the estimated total population of the study area by a standard per capital daily water allocation. The total population was estimated based on the total number of residential parcels multiplied by the average household size derived from the Epicollect5 survey sample:

Total population = Total Residential Parcels × Average Household Size

Theoretical Water Demand (m^3/year) = Total population × Standard per Capital Demand (LPCD) ×365/1000 (Howard et al., 2020)

The contribution of RRWH was then evaluated by calculating the Demand Satisfaction Ratio:

Contribution to Consumption (%) = (Harvestable volume/ Consumption) ×100

Contribution to Demand (%) = (Harvestable volume/ Water Demand) ×100

3.5.4 Estimating Seasonal Variability

To assess how the harvestable potential fluctuates against demand throughout the year, monthly rainfall values derived from the IDW interpolation were used to calculate monthly harvesting potential. These monthly harvesting potentials then compared against corresponding monthly water demand to identify periods with excess harvestable potential and periods with insufficient harvestable potential.

3.6 Ethical Considerations

Respondents in the household survey were voluntary and informed about the purpose of the study. All data were treated confidentially and used solely for academic purposes.

CHAPTER FOUR
RESULTS AND DISCUSSION

This chapter has four main sections: the first section quantifies the potential of rainwater harvesting. The second section describes the awareness level, perception and acceptance of rooftop rainwater harvesting. The third section compares harvesting potential with water demand. The last section discusses results by comparing with other studies.

4.1 Estimation of Rooftop Rainwater Harvesting Potential

4.1.1 Rooftop Area of Residential Buildings

Spatial analysis of the building rooftop area revealed that the total built area within the study boundary covers 561050.21 m^2. As detailed in Table 4.1 residential buildings dominate this area, account for 362332.5 m^2 or 64.58% of the entire built area. The distribution of these residential catchments and various non-residential buildings is illustrated in Figure 4.1.

Table 4.1: Building Type and Catchment Area of Wereda 6

Feature	**Area (m^2)**	**Coverage Percent (%)**
Total built area in wereda 6	561050.21	100
Residential rooftop catchment	362332.41	64.58
Others (non- residential)	198717.8	35.42

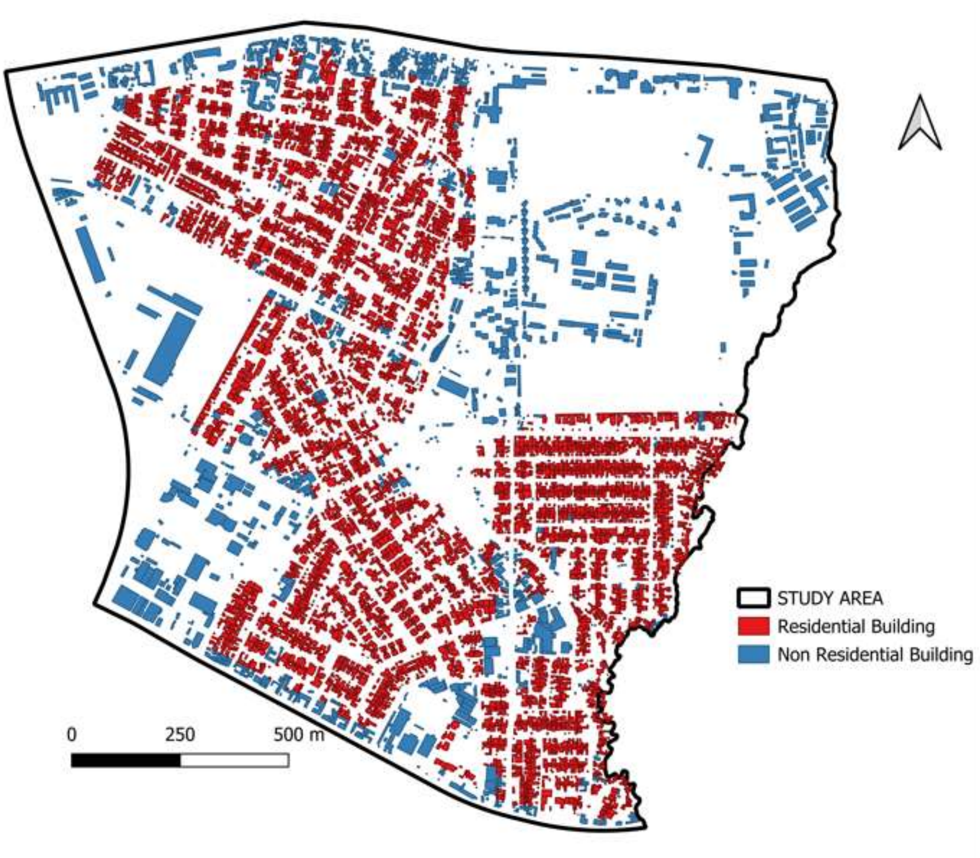

Figure 4.1: Bole Sub-City Wereda 6 Buildings

Table 4.2 shows the distribution of the total residential rooftop area in each category.

Table 4.2: Catchment Categories

Catchment Category	Household Share (%)	Total Roof Area (m^2)
Medium-Scale	45.5	174,882.50
Small-scale	39.7	96,635.5
Large-scale	14.8	90,814.5

4.1.2 Rainfall data of the study area

Rainfall data used for the estimation were obtained from seven surrounding meteorological stations and it is shown in Table 4.3. The table presents the mean annual rainfall values recorded at the seven rain gauge stations used in this study. The rainfall values range from 994.13 mm/year at Medhanialem station to 1289.65 mm/year at Intoto station

Table 4.3: Annual Rainfall Value at the Rain Gauge Station

No	Rain Gauge Station Name	Longitude	Latitude	Mean Annual Rainfall (mm)
1	Abissiniya School	38.72333	9.04472	1182.45
2	Addis Ababa Bole	38.79871	8.981081	1073.05
3	Addis Ababa Observatory	38.7475	9.01891	1229.76
4	Intoto	38.725	9.08367	1289.65
5	Kotebe TTC	38.839	9.048	1086.82
6	Medhanialem	38.727	9.059	994.13
7	Yekatit	38.73056	9.0335	1273.40

(Source: Ethiopian Meteorological Institute, 2026)

Based on rainfall data presented in Table 4.3 the mean annual rainfall of the study area determined to be 1120.04 mm/year. The interpolation of rainfall from the seven rain gauge stations is presented in Figure 4.2, while Figure 4.3 shows the local rainfall distribution within the study area.

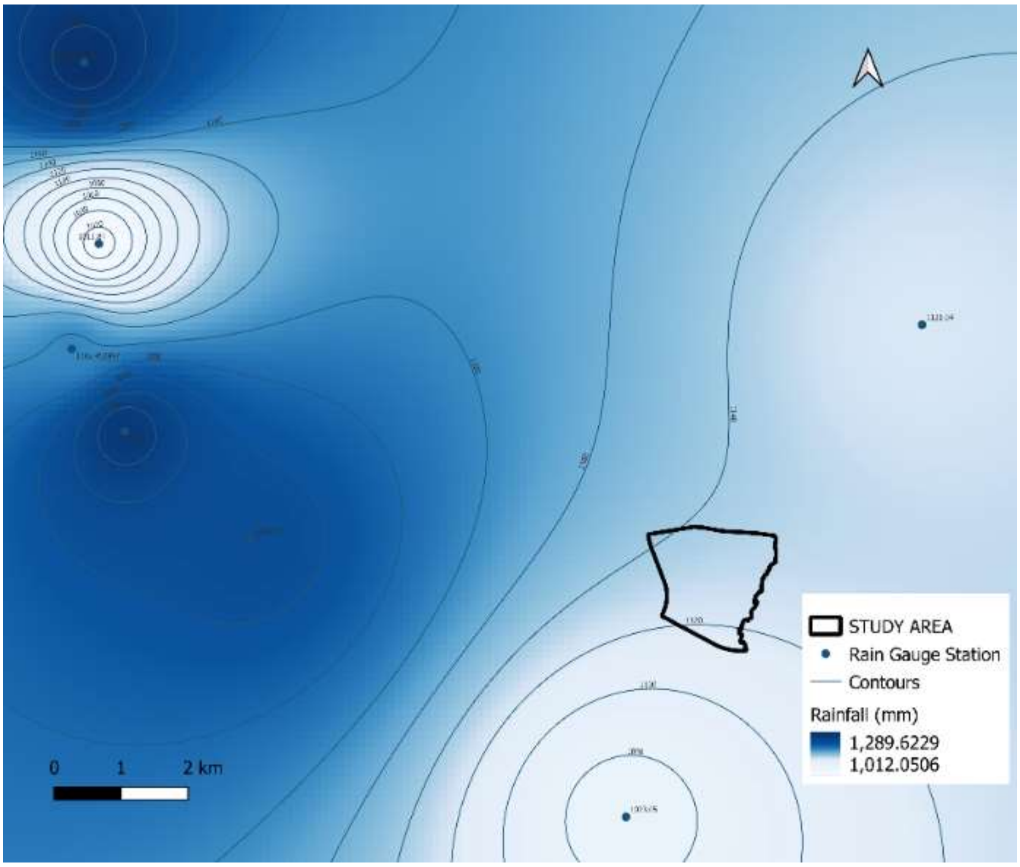

Figure 4.2: Rainfall IDW interpolation with the study area

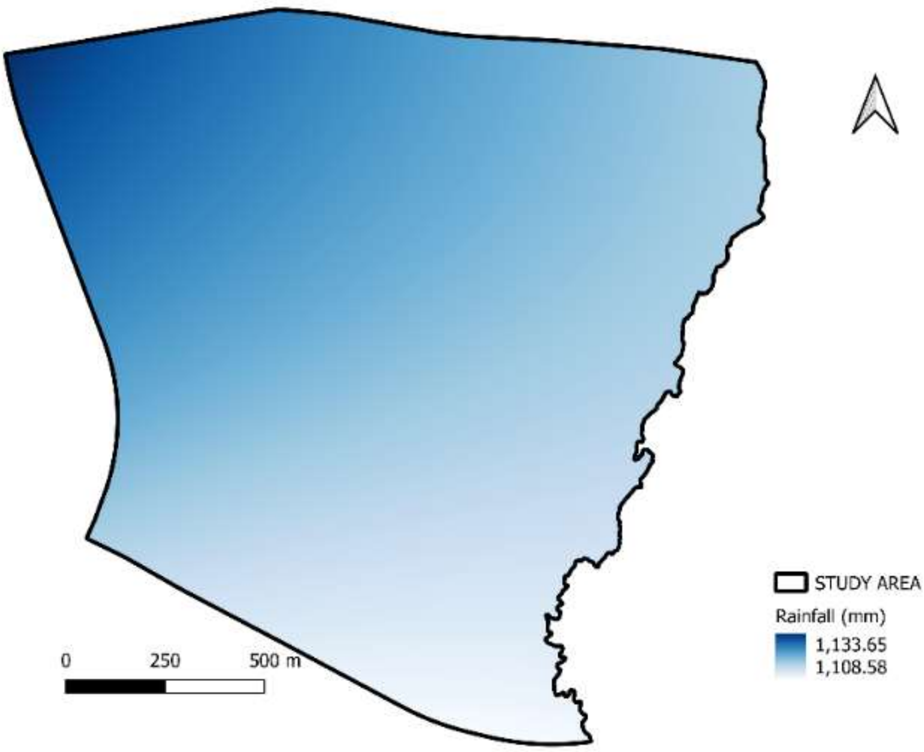

Figure 4.3: Rainfall of the study area

4.1.3 Estimated Harvestable Volume

Based on the local mean annual rainfall of 1120.04 mm/year (1.12 m/year), catchment area and designated runoff coefficient (C) of 0.8, the theoretical annual rooftop rainwater harvesting potential is determined. Table 4.4 illustrate the harvestable potential of each catchment categories.

Table 4.4: Annual Harvestable Volume per Catchment Category

Catchment Category	**Sum of Roof Area (m^2)**	**Harvestable Volume(m^3/year)**
Medium-scale	174882.5	156700.3
Small-scale	96635.5	86588.5
Large-scale	90814.5	81372.7
Total	362332.5	324661.5

Table 4.5 presents the estimated monthly rainfall depths and corresponding rooftop rainwater harvesting (RRWH) potential. The results illustrate the temporal distribution of harvestable rainwater throughout the year and provide insight into the influence of seasonal rainfall patterns on rainwater availability for potential utilization in the study area.

Table 4.5: Monthly rooftop rainwater harvesting potential

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	9.99	19.74	49.16	85.20	80.77	131.8	269.8	280.6	149.6	29.03	7.83	6.51
RRWH Potential (m3/m)	2896.08	5722.48	14248.61	24696.61	23411.16	38209.14	78216.74	81334.57	43354.37	8415.08	2268.59	1887.66

4.2 Household Awareness, Perception, and Acceptance

4.2.1 Analysis of Municipal Water Supply

The Epicollect5 field survey data reveal intermittent water supply from the municipal water supply system. An overwhelming 87.58% (289 households) reported that they only have a two day per week. Similarly, the rest 12.42% (41 households) reported an intermittent supply with little improvement to a three day per week. This means all the households face at least four days a week without municipal supply. This shows consistency with the city- level water shortage and rationing program by the Addis Ababa Water and Sewerage Authority. This highlights the importance of supplementary water sources like RRWH.

The weekly distribution frequencies of municipal water supply in the study area are illustrated in the chart below:

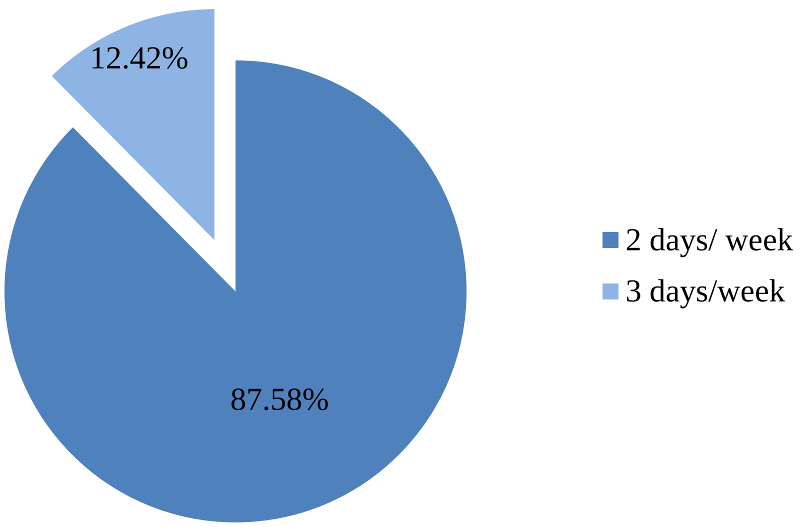

Figure 4.4: Municipal Water Supply Frequency

4.2.2 Awareness Levels

The survey results reveal that the respondent aware of the immediate use and benefits of rainwater, but there is a lack of understanding of storing rainwater to use during the dry season.

4.2.2.1 Immediate Utility vs. Seasonal Storage Awareness

Respondents show a high level of insight regarding the use of rainwater for non-potable tasks. For instance, 93.3% (308 respondents) recognize that rainwater could be used for washing and cleaning, and 86.6% (286 respondents) identified it for toilet flushing. This suggests that the community understands that rainwater could substitute municipal water for non-potable uses.

However, this awareness does not extend to storing rainwater to use it during the dry season. The survey asked before this survey, have you heard about a rooftop rainwater harvesting system, and 80.3% (265 respondents) replied ‘’No’’.

This inconsistency indicates that most households use rainwater from the roof during the rainy season as an active source. Rather than storing it for the dry season. The respondents do not yet understand the rooftop rainwater harvesting system. And that the system could bridge the water scarcity gap experienced during the dry season. Only 19.7% (65 respondents) show that they had prior awareness of rooftop rainwater harvesting. Figure 4.5 show the awareness level prior to the survey.

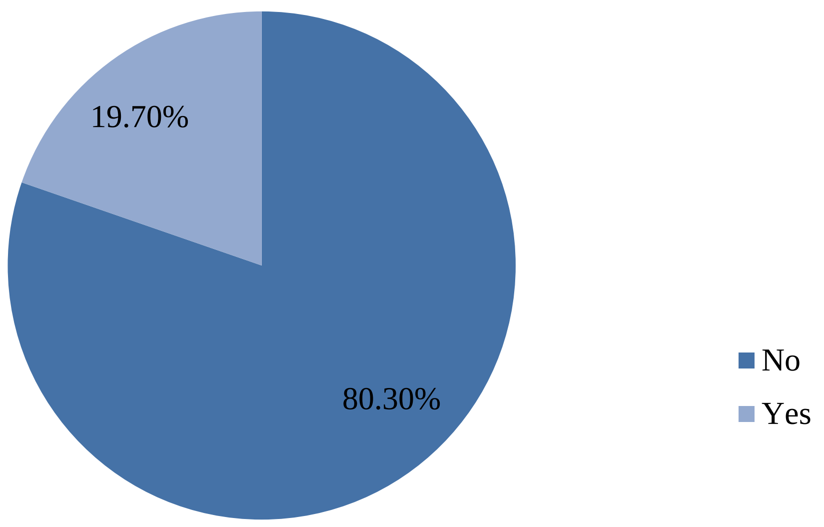

Figure 4.5: Prior Awareness of Rooftop Rainwater Harvesting

These findings further prove that awareness of RRWH among households is limited, with only a small fraction possessing adequate knowledge of the concept. The exact breakdown of familiarity level across the community is presented in Table 4.6.

Table 4.6: Familiarity Levels among Respondents

Prior Awareness	Awareness Level	Number of Respondents	Percentage (%)
No	Not familiar	265	80.31
Yes	Not familiar	1	0.3
	Heard of it	16	4.85
	Somewhat familiar	28	8.48
	Very familiar	20	6.06
	Total	330	100

4.2.3 Perception of Quality and Reliability

Households' perception of harvested water quality and how they perceive its reliability to provide water during municipal water is unavailable is a determining factor for the adaptation of rooftop rainwater harvesting.

4.2.3.1 Perception of Water Quality

The survey result shows a positive outlook on the quality of harvested water. 79.4% (262 respondents) considered the water as "Safe" with an additional 13.6% (45 respondents) viewing it as "Very safe". This suggests that the community consider rainwater as a safe source for non-potable uses. However, only 8 of the respondents were willing to use it for drinking after treatment, which shows that the positive perception of quality is strictly associated with non-potable use. The respondent's safety rating for using rooftop rainwater across various non-potable household applications are summarized in Figure 4.6.

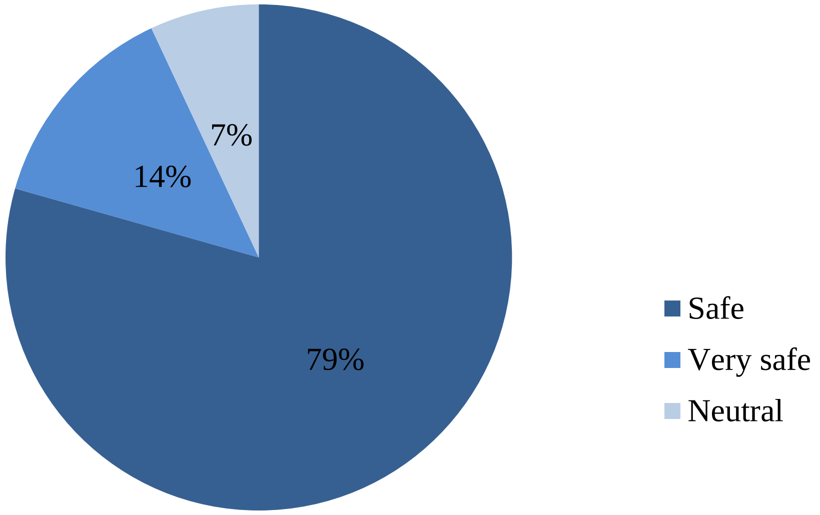

Figure 4.6: Perception of Water Quality

4.2.3.2 Perceived System Reliability

The reliability of rooftop rainwater is associated with supply reliability and economic reliability. The respondent's response shows how the community perceives these. 91.2% of householders believe that the system provides reliable water during water shortages. Combined, 90.3% of respondents "Agreed" or "Strongly Agreed" that RRWH can significantly reduce monthly water bills. And 87.6% of respondents agreed that the system reduces their total dependence on the Addis Ababa Water and Sewerage Authority (AAWSA).

Figure 4.7 summarize residents' expectations regarding the reliability of rooftop rainwater harvesting.

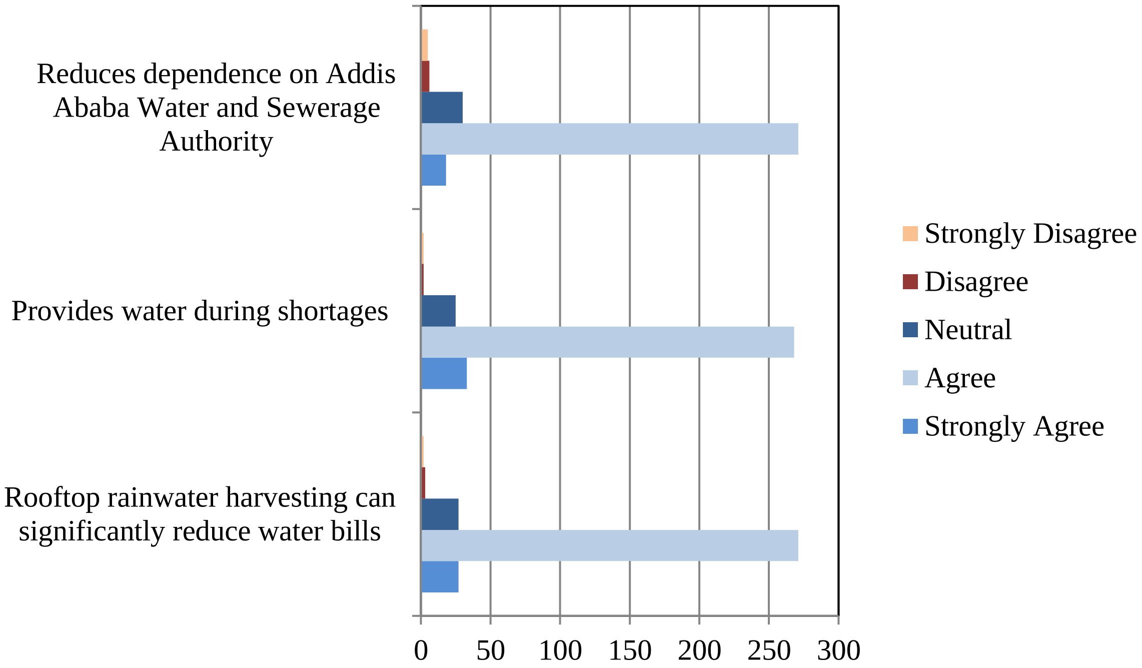

Figure 4.7: Perception of Rooftop Rainwater Harvesting Reliability

4.2.4 Community Acceptance and Future Adoption Interest

The harvesting potential and positive perceptions do not grant the adoption of rooftop rainwater harvesting. These transitions from positive perception to actual implementation within the households require commitment. That survey shows an interest gap when asked about recommending the practice to others, 64.8% (214 respondents) answered yes, but when asked if they would consider an installation in the future, 93.0% (307 respondents) indicated they would not. This reveals that social approval does not translate into personal adoption interest. Only 2.1% (7 respondents) expressed a definite interest in adopting. This means the community recognizes the theoretical value of RRWH, but they perceive the practical or financial burden of installation as too high for their own households.

This finding suggests that the willingness to adopt is not hindered by a lack of interest but rather by specific barriers. The survey findings identified high installation cost and lack of technical knowledge as the major barriers limiting households' willingness to install a rooftop rainwater harvesting system. Water quality concerns and unsuitable roof conditions were less frequently identified by respondents. The community is willing to support the idea of rainwater harvesting, but the current economic and technical environment in the study area makes personal adoption seem unfeasible for the vast majority. The willingness to adopt formal rooftop rainwater harvesting system is shown in the chart below:

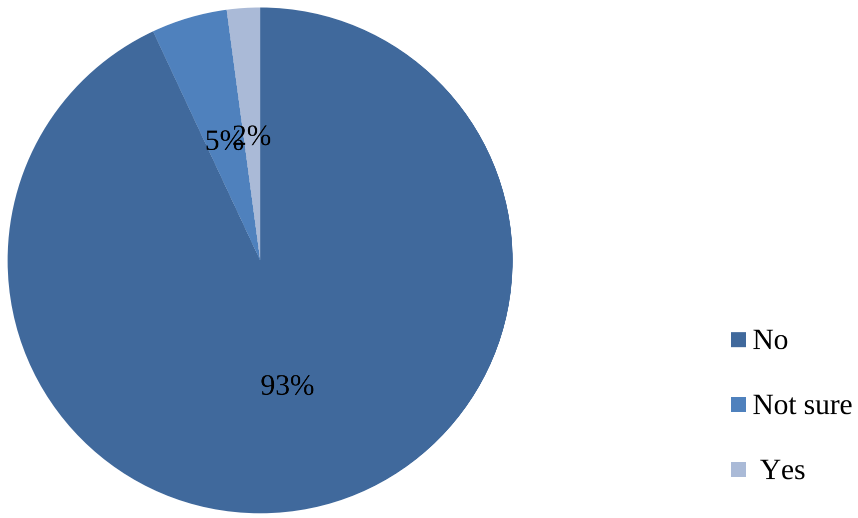

Figure 4.8: Willingness to Adopt Rooftop Rainwater Harvesting

The specific barriers identified by respondents during field data collection are ranked by frequency in Table 4.7.

Table 4.7: Barriers Limiting Households Adoption of RRWH System

Barriers to Adoption	**Responses**	**Percentage (%)**
High installation cost	265	80.30
Lack of technical "know-how"	217	65.76
Roof not suitable	5	1.52
Water quality concerns	12	3.64

4.3 Contribution of RRWH to Household Water Demand

This section compares rooftop rainwater harvesting potential with household water demand. The analysis is based on a comparison between the total annual volume of harvestable rainwater and the total annual household water consumption derived from billing records and later from demand driven by per capita demand.

4.3.1 Total Household Water Demand

Household water consumption in the study area was estimated using consumption records of Addis Ababa Water and Sewerage Authority (AAWSA).

According to AAWSA records, a total of 2,580 domestic water users were within the study area. However, the spatial analysis of the parcel boundary data identified 2,316 residential parcels within the study boundary. The difference between the number of water users and residential parcels is due to multiple water connections within a single parcel.

The total annual water consumption of the study area was calculated by aggregating the consumption of all residential water meters located within the study boundary. Based on this analysis, the total actual annual household water consumption of the study area was determined to be 515,691 m^3 per year.

The estimated household water demand was also estimated using population-based per capita demand standards. The household survey conducted on 330 sampled parcels recorded a total population of 2,276. Accordingly, the average parcel size was identified.

Average parcel size=2276/330

$$=6.89 \approx 7 \text{ persons/parcel}$$

Using the total number of residential parcels identified within the study area (2,316 parcels), the total study area population was estimated as:

Total population= Total number of residential parcels × Average parcel size

$$= 2316 \text{ parcel} \times 7 \text{ persons/parcel}$$

$$= 16212 \text{ persons}$$

Assuming a standard domestic water demand of 100 lpcd, the annual household water demand was estimated using the following relationship (Hari et al., 2020):

Water Demand = standard per capita demand × Total population × No of days

$$= 0.1 m^3/\text{person/day} \times 16212 \text{person} \times 365 \text{days/year}$$

$$= 591738 \text{ m3/ year}$$

The estimated theoretical household water demand is slightly higher than the actual annual household water consumption derived from AAWSA billing records. This difference suggests that actual water consumption in the study area is constrained by intermittent municipal supply and limited water availability rather than by household demand alone.

4.3.2 Annual Contribution of RRWH to Water Demand

Comparing the total harvestable volume against the water need of the community highlights the impact of this supplementary source. It can cover 62.9% of current actual consumption and meet 54.9% of the theoretical household water demand.

The summary of these annual supply demand cross-reference is presented as follows:

Table 4.8: Contribution of RRWH to Household Water Consumption

Indicators	Value	Unit
Total Household Water Consumption	515691	m³/year
Total Harvestable Rainwater	324661.5	m³/year
Contribution of Rooftop Rainwater Harvesting	62.9	%

Table 4.9: Contribution of RRWH to Household Water Demand

Indicators	Value	Unit
Total Household Water Demand	591738	m³/year
Total Harvestable Rainwater	324661.2	m³/year
Contribution of Rooftop Rainwater Harvesting	54.9	%

4.3.3 Monthly Contribution of RRWH to Water Demand

The capability of rooftop rainwater harvesting to supplement water need varies significantly throughout the year due to seasonal rainfall variation. During the dry periods like November and December harvesting potential drops significantly, meeting only 4.66% and 3.76% of household water demand.

The highest harvesting potential is recorded during peak rainy periods like July and August. The rooftop rainwater harvesting potential far exceeds household water demand, reaching 155.63% and 161.84% monthly water demand respectively.

This shows the importance of a storage tank for storing excess rainwater during the rainy periods to use it during dry periods. The complete seasonal breakdown comparing monthly harvesting potential to monthly consumption and demand value is presented below:

Table 4.10: Monthly Contribution of RRWH to Household Water Consumption

Month	**RRWH Potential (m^3/month)**	**Household Water Consumption (m^3/month)**	**Coverage in percentile**
Jan	2896.08	42167.00	6.87
Feb	5722.48	42693.00	13.40
Mar	14248.61	42091.00	33.85
Apr	24696.61	44771.00	55.16
May	23411.16	45684.00	51.25
Jun	38209.14	46568.00	82.05
Jul	78216.74	37968.00	206.01
Aug	81334.57	40296.00	201.84
Sep	43354.37	51494.00	84.19
Oct	8415.08	38873.00	21.65
Nov	2268.59	40084.00	5.66
Dec	1887.66	43002.00	4.39

Table 4.11: Monthly Contribution of RRWH to Household Water Demand

Month	RRWH Potential (m^3/month)	Estimated Household Water Demand (m^3/month)	Coverage in percentile
Jan	2896.08	50257.20	5.76
Feb	5722.48	45393.60	12.61
Mar	14248.61	50257.20	28.35
Apr	24696.61	48636.00	50.78
May	23411.16	50257.20	46.58
Jun	38209.14	48636.00	78.56
Jul	78216.74	50257.20	155.63
Aug	81334.57	50257.20	161.84
Sep	43354.37	48636.00	89.14
Oct	8415.08	50257.20	16.74
Nov	2268.59	48636.00	4.66
Dec	1887.66	50257.20	3.76

This seasonal relationship plotting monthly rainwater harvesting potential against estimated water demand is illustrated in Figure 4.10.

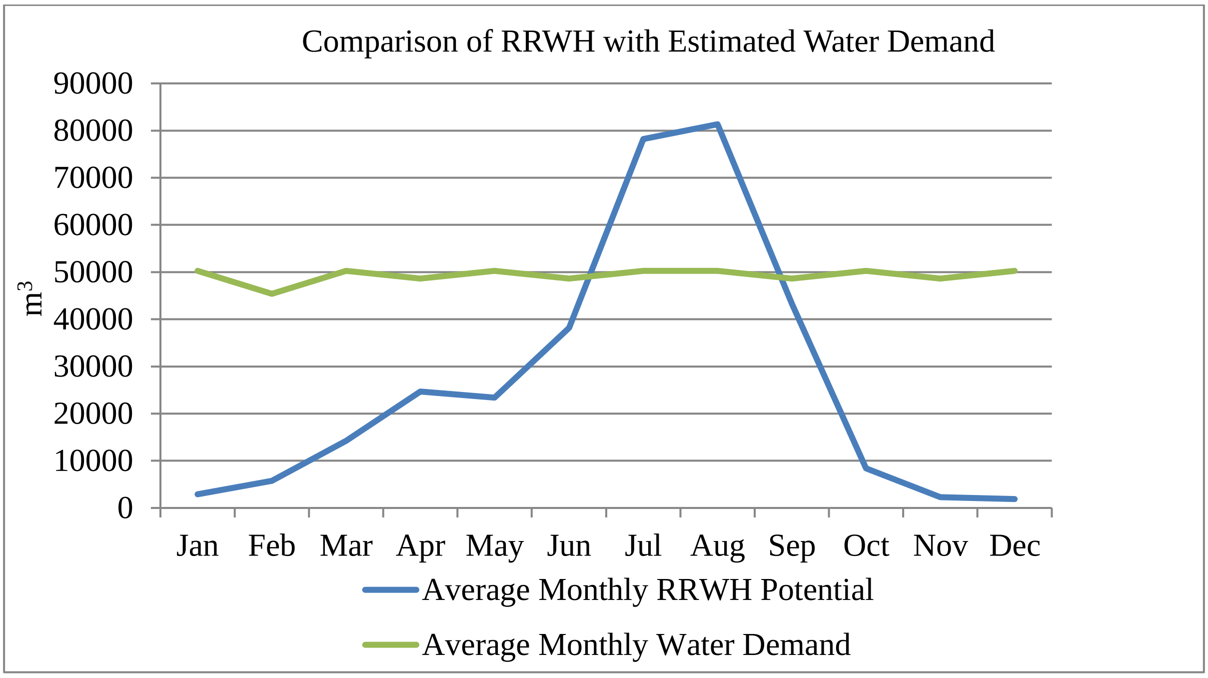

Figure 4.9: Comparison of RRWH with Water Demand

4.4 Discussion

4.4.1 Rooftop Catchment Area

The analysis identified a total residential rooftop catchment area of 362332.5 m^2, representing 64.58% of the total build-up area within the study area. This coverage indicates favourable conditions for rooftop rainwater harvesting. Since the rooftop area is one of the principal factors determining the quantity of harvestable rainwater, this substantial catchment suggests considerable potential for supplementary water supply at the household level.

This high concentration of residential rooftop emphasizes that residential buildings form the primary asset available for decentralized rainwater harvesting in study area. Consequently, implementation of rooftop rainwater harvesting system will achieve the highest volumetric yield by targeting residential surface rather than non-residential buildings in this area.

The finding is consistent with previous studies conducted in Ethiopia, which highlight the availability of rooftops as catchment surface (Adugna et al., 2018; Kanno et al., 2021). For instance, a city-wide study conducted on large public institutions in Addis Ababa estimated a total institutional rooftop area of 766713 m^2, demonstrating the existence of a significant rooftop area that can contribution to urban rainwater harvesting (Adugna et al. 2018). Although the rooftop area identified in the current study is expectedly smaller. This variation is scale dependent because thit study focused on only residential rooftops within a single wereda, whereas the previous study assessed large public institutions across the city.

The result suggests that the physical infrastructure required for rooftop rainwater harvesting already exists in the form of residential rooftops. And make the area suitable for decentralized water management.

4.4.2 Rainfall Suitability and Seasonal Implications

The mean annual rainfall of the study area was 1120.04 mm/year and it is slightly lower than the city's average annual rainfall of 1184 mm/year reported by Ewunetu et al. (2019). This difference is small and may be attributed to spatial variations in rainfall distribution across the city. The rainfall received in the study area indicates favourable climatic conditions for rooftop rainwater harvesting.

The annual rainfall of the study area falls within the range identified as suitable for rooftop rainwater harvesting by previous studies. For example a study conducted in Mbeya,Tanzania, reported that area receiving mean annual rainfall ranging from 986mm to 2200mm as suitable for harvesting rainwater from rooftops (Katambara et al., 2013). Similarly, a study conducted in Karnataka, India found that a mean annual rainfall of 1200mm/year to be favorable condition for rooftop rainwater harvesting. Therefore, the rainfall characteristics of the study area suggest favourable climatic conditions exist in the study area to harvest rainwater from rooftop.

The findings further indicate the presence of seasonal rainfall variability within the study area. Therefore, the suitability of rainfall for rooftop rainwater harvesting should not be evaluated solely on the basis of total annual rainfall. This is consistent with the finding reported by Adugna et al. (2018). Seasonal variation implies that water availability from harvested rainwater is not evenly distributed throughout the year. Consequently, the effectiveness of rooftop rainwater harvesting depends not only on rainfall quantity and catchment availability but also on adequate storage capacity, appropriate system design, and effective water management practices.

4.4.3 Awareness and Perception

The study found that 80.3% of respondents had never heard of a formal rooftop rainwater harvesting system before the survey. This is similar to finding reported by a study conducted in Darussalam, where only 37.5% of respondents indicated familiarity with rainwater harvesting systems (Suni et al., 2025). The awareness in this study appears lower, which can be attributed to differences in educational background. The study in Darussalam focused on young and educated respondents, whereas the current study did not differentiate respondents by age or education level.

Finding from the household survey indicate that respondents in the study area generally hold a positive perception of rooftop rainwater harvesting. This finding is similar to a study conducted in Darussalam, who reported that 83.78% of respondents agreed that rainwater harvesting could increase water availability for non-potable purposes. While 77.7% considered rainwater harvesting a sustainable water source (Suni et al., 2025). Similarly, a study conducted in twelve countries found that rainwater was generally perceived more positively than other alternative water sources (Stec et al., 2023).

4.4.4 Acceptance and Barriers

High installation cost was identified as the most important barrier to adoption, followed by lack of technical knowledge. This is similar to studies conducted previously, for example a study in Darussalam found that 49.32% of the respondent perceived rainwater harvesting system as expensive and 72.26% requested technical guidance (Suni et al., 2025). Another study conducted in twelve countries shows that 31% of respondents identify cost as a barrier for rooftop rainwater harvesting (Stec et al., 2023). These findings show that financial and technical barriers are common challenges across different countries and contexts. Therefore, awareness campaigns, financial support mechanisms and technical assistances should be integrated to promote adoption of rooftop rainwater harvesting in Addis Ababa.

4.4.5 Contribution to Water Demand

The potential of rooftop rainwater harvesting to satisfy water demand in the study area found to be significant but varies throughout the year due to seasonal rainfall variation. This is similar to other studies conducted in Addis Ababa including a study on large public institutions. This found that individual institutions' self-sufficiency ranged from 0.9% to 649% depending on season and institution size (Adugna et al., 2018).

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This study was conducted to assess the potential of rooftop rainwater harvesting (RRWH) as a supplementary water source in Bole Sub-city, Wereda 6. The study was undertaken in response to the increasing municipal water shortages in Addis Ababa and the need to explore supplementary water sources. The study achieved its objectives by estimating rooftop rainwater harvesting potential, assessing household awareness, perception and acceptance, examining seasonal variation of rooftop rainwater harvesting potential, and evaluating the contribution of harvested rainwater to household water demand.

The study confirms that rooftop rainwater harvesting has considerable potential to supplement household water supply and contribute to improving water security in the study area. The findings indicate that the physical conditions necessary for rainwater harvesting are available, while households generally show favourable attitudes toward the utilization of rainwater. However, the wider adoption of rooftop rainwater harvesting may be constrained by economic and technical challenges that require appropriate interventions.

Overall, the study concludes that integrating rooftop rainwater harvesting into urban water management strategies could help to diversify urban water source and improve household water security which reduce pressure on the municipal water supply. It also concludes that rooftop rainwater harvesting can contribute to urban runoff reduction, and support more sustainable and resilient urban water management in Addis Ababa.

5.2 Recommendations

The following recommendations are proposed to improve the implementation and use of rooftop rainwater harvesting systems in Addis Ababa.

- ✓ Policy makers and urban planners should integrate rooftop rainwater harvesting with building code, regulations, and urban development policies.
- ✓ Governmental institutions and water authorities should establish financial support mechanisms. Like subsidies, low interest loans, or tax incentives to assist households in installing rooftop rainwater harvesting.

- ✓ The Addis Ababa Water and Sewerage Authority (AAWSA) should consider rooftop rainwater harvesting as urban water management strategy aimed at reducing pressure on the municipal water supply system and improving urban water resilience.
- ✓ Local institutions and government agencies should implement awareness campaigns to show the benefits, installation, operation and maintenance requirements of rooftop rainwater harvesting.
- ✓ Residents should adopt rooftop rainwater harvesting system for non-potable uses such as washing, gardening and for toilette flushing.
- ✓ There should be awareness program within the community to share knowledge and promote rooftop rainwater harvesting system.

Recommendations for Future Research

- ✓ Future research should evaluate actual storage capacities and the impact of storage limitations on the practical performance of rooftop rainwater harvesting systems.
- ✓ Further research should investigate the water quality of harvested rainwater to determine its suitability for various domestic uses.
- ✓ Future research should evaluate seasonal storage performance and determine the storage capacity required to utilize excess rainwater during peak rainfall periods.
- ✓ Future research should conduct detailed cost–benefit analyses of rooftop rainwater harvesting systems to evaluate their economic viability for households with different income levels.

REFERENCES

Abraha, T., Tibebu, A., & Ephrem, G. (2022). Rapid urbanization and the growing water risk challenges in Ethiopia: The need for water sensitive thinking. Frontiers in Water, 4. https://doi.org/10.3389/frwa.2022.890229

Adeba, D., Kansal, M. L., & Sen, S. (2015). Assessment of water scarcity and its impacts on sustainable development in Awash Basin, Ethiopia. Sustainable Water Resources Management, 1(1), 71–87. https://doi.org/10.1007/s40899-015-0006-7

Adugna, D., Jensen, M., Lemma, B., & Gebrie, G. (2018). Assessing the potential for rooftop rainwater harvesting from large public institutions. International Journal of Environmental Research and Public Health, 15(2), 336. https://doi.org/10.3390/ijerph15020336

Alene, A., Yibeltal, M., Abera, A., Andualem, T. G., & Lee, S. S. (2022). Identifying rainwater harvesting sites using integrated GIS and a multi-criteria evaluation approach in semi-arid areas of Ethiopia. Applied Water Science, 12(10). https://doi.org/10.1007/s13201-022-01756-7

Al-Houri, Z. M., Abu-Hadba, O. K., & Hamdan, K. A. (2014). The potential of rooftop rainwater harvesting as a water resource in Jordan: Featuring two application case studies. Journal of Water Resource and Protection, 8(2), 147–153. https://doi.org/10.5281/zenodo.1096278

Alemu, Z. A., & Dioha, M. O. (2020). Modelling scenarios for sustainable water supply and demand in Addis Ababa city, Ethiopia. ENVIRONMENTAL SYSTEMS RESEARCH, 9(1). https://doi.org/10.1186/s40068-020-00168-3

Alem, G. & INTEGRATED DEVELOPMENT FOR WATER SUPPLY AND SANITATION. (1999). Rainwater harvesting in Ethiopia: an overview. In 25th WEDC Conference Addis Ababa, Ethiopia, 1999.

Amihere-Ackah, P., Monney, I., Okyere, D. C., Adjei, K. A., & Appiah-Adjei, E. K. (2025). Assessing the potential of managed aquifer recharge using rooftop rainwater harvesting with shallow wells in peri-urban communities in Kumasi, Ghana. Discover Water, 5(1). https://doi.org/10.1007/s43832-025-00245-7

Amos, C. C., Rahman, A., & Gathenya, J. M. (2016). Economic analysis and feasibility of rainwater harvesting systems in urban and peri-urban environments: A review of the global situation with a special focus on Australia and Kenya. Water, 8(4), 149. https://doi.org/10.3390/w8040149

Anchan, S. S., & Prasad, H. S. (2021). Feasibility of roof top rainwater harvesting potential - A case study of South Indian University. Cleaner Engineering and Technology, 4, 100206. https://doi.org/10.1016/j.clet.2021.100206

Armitage, N., Fisher-Jeffes, L., Carden, K., Winter, K., Naidoo, V., Spiegel, A., Mauck, B., & Coulson, D. (2014). Water Sensitive Urban Design (WSUD) for South Africa: Framework and guidelines. In Water Research Commission, Urban Water Management Research Unit, & Departments of Civil Engineering, Environmental & Geographical Science, Social Anthropology, and Political Studies, University of Cape Town, Water Research Commission (TT 588/14). https://wrcwebsite.azurewebsites.net/wp-content/uploads/mdocs/TT%20588-13.pdf

Arsiso, B. K., Tsidu, G. M., Stoffberg, G. H., & Tadesse, T. (2017). Climate change and population growth impacts on surface water supply and demand of Addis Ababa, Ethiopia. Climate Risk Management, 18, 21–33. https://doi.org/10.1016/j.crm.2017.08.004

Aryal, M., Joshi, P., & Thakuri, S. (2022). Performance of rooftop rainwater harvesting system as a source of drinking water. International Journal of Environment, 11(1), 62–80. https://doi.org/10.3126/ije.v11i1.45841

Assefa, Y. T., Babel, M. S., Sušnik, J., & Shinde, V. R. (2019). Development of a generic domestic water security index, and its application in Addis Ababa, Ethiopia. Water, 11(1), 37. https://doi.org/10.3390/w11010037

Bahri, A., Global Water Partnership, Technical Committee, Bahri, A., Kadi, M. A., & Vairavamoorthy, K. (2012). Integrated Urban Water Management. In Global Water Partnership.

Bañas, K., Robles, M. E., & Maniquiz-Redillas, M. (2023). Stormwater harvesting from roof catchments: A review of design, efficiency, and sustainability. Water, 15(9), 1774. https://doi.org/10.3390/w15091774

Batchelor, C., Fonseca, C., Smits, S., & IRC International Water and Sanitation Centre. (2011). Life-cycle costs of rainwater harvesting systems. In Occasional Paper 46. IRC International Water and Sanitation Centre. https://www.ircwash.org/sites/default/files/Batchelor-2011-Lifecycle.pdf

Bekana, T. H., Ebrea, M. G., Yessuf, N. H., Kindhun, A., Hunegnew, D. A., Desta, B. G., & Shiferaw, E. T. (2025). Urban water scarcity in Addis Ababa city: Hard versus soft path solutions: A systematic review. Discover Geoscience, 3(1). https://doi.org/10.1007/s44288

Belmeziti, A., Coutard, O., & De Gouvello, B. (2013). A new methodology for evaluating potential for potable water savings (PPWS) by using rainwater harvesting at the urban level: The case of the municipality of Colombes (Paris region). Water, 5(1), 312–326. https://doi.org/10.3390/w5010312

Bernard, B., & Joyfred, A. (2020). Contribution of rainfall on rooftop rainwater harvesting and saving on the slopes of Mt. Elgon, East Africa. The Scientific World JOURNAL, 2020, 1–11. https://doi.org/10.1155/2020/7196342

Biswas, A. K. (1991). Water for sustainable development in the 21st century: A global perspective. GeoJournal, 24(4), 341–345. https://doi.org/10.1007/BF00578255

Carpio-Vallejo, E., Düker, U., Waldowski, J., & Nogueira, R. (2024). Contribution of rooftop rainwater harvesting to climate adoptation in the city of Hannover: Water quality and health issues of rainwater storage in cisterns and ponds. International Journal of Hygiene and Environmental Health, 256, 114320. https://doi.org/10.1016/j.ijheh.2024.114320

Che-Ani, A. I., Shaari, N., A. Sairi, Zain, M. F. M., & Tahir, M. M. (2009). Rainwater harvesting as an alternative water supply in the future. European Journal of Scientific Research, 34(1), 132–140. http://www.eurojournals.com/ejsr.htm

Cochran, W. G. (1977). Sampling techniques (3rd ed.). John Wiley & Sons.

Durodola, O. S., Bwambale, J., & Nabunya, V. (2020). Using every drop: rainwater harvesting for food security in Mbale, Uganda. Water Practice & Technology, 15(2), 295–310. https://doi.org/10.2166/wpt.2020.019

Ertop, H., Kocięcka, J., Atilgan, A., Liberacki, D., Niemiec, M., & Rolbiecki, R. (2023). The importance of rainwater harvesting and its usage possibilities: Antalya example (Turkey). Water, 15(12), 2194. https://doi.org/10.3390/w15122194

Ewunetu, G.A. 2019. Evaluation of Addis Ababa water supply system using integrated approach. PhD dissertation submitted to Ethiopian Institute of Architecture, Building Construction and City Development, Addis Ababa University.

Feyissa, G., Zeleke, G., Bewket, W., & Gebremariam, E. (2018). Downscaling of future temperature and precipitation extremes in Addis Ababa under climate change. Climate, 6(3), 58. https://doi.org/10.3390/cli6030058

Gould, J., & Nissen-Petersen, E. (1999). Rainwater catchment systems for domestic supply: Design, construction and implementation. Intermediate Technology Publications.

Hari, D., Reddy, K. R., Vikas, K., Srinivas, N., & Vikas, G. (2018). Assessment of rainwater harvesting potential using GIS. IOP Conference Series: Materials Science and Engineering, 330, 012119. https://doi.org/10.1088/1757-899X/330/1/012119

Howard, G., Bartram, J., Williams, A. R., Overbo, A., Fuente, D., & Geere, J. (2020). Domestic water quantity, service level and health (2nd ed.). World Health Organization.

Kanno, G. G., Lagiso, Z. A., Abate, Z. G., Areba, A. S., Gondol, B. N., Temesgen, H., Van Wyk, R., & Aregu, M. B. (2021). Estimation of rainwater harvesting potential for emergency water demand in the era of COVID-19: The case of Dilla town, southern Ethiopia. Environmental Challenges, 3, 100077. https://doi.org/10.1016/j.envc.2021.100077

Katambara, Z. (2013). Quantifying rooftop rainwater harvest potential: Case of Mbeya University of Science and Technology in Mbeya, Tanzania. Engineering, 5(10), 816–818. https://doi.org/10.4236/eng.2013.510098

Khoury-Nolde, Norma. (n.d.). Rainwater Harvesting.4. Mathur, P.S., Prashad, Deependra, and Sharma, Dilip Kumar. (n.d.). Rainwater Harvesting and Utilisation.

Kustova, I., Hudenko, J., & Lace, N. (2024). A Systematic review of sustainability criteria in infrastructure development. In Paolo S. Calabrò (Ed.), Sustainability (Vol. 16, p. 4564). https://doi.org/10.3390/su16114564

Lange, J., Husary, S., Gunkel, A., Bastian, D., & Grodek, T. (2012). Potentials and limits of urban rainwater harvesting in the Middle East. Hydrology and Earth System Sciences, 16(3), 715–724. https://doi.org/10.5194/hess-16-715-2012

Lloyd, S. D., Wong, T. H. F., Chesterfield, C. J., Cooperative Research Centre for Catchment Hydrology, & Melbourne Water Corporation. (2002). Water Sensitive Urban Design - A Stormwater Management perspective.

Lupia, F., Baiocchi, V., Lelo, K., & Pulighe, G. (2017). Exploring rooftop rainwater harvesting potential for food production in urban areas. Agriculture, 7(6), 46. https://doi.org/10.3390/agriculture7060046

Meskele, D. Y., Shomre, M. W., & Soche, T. K. (2024). Evaluating rooftop rainwater harvesting potential to satisfy urban water demand in Hosaena City, South Central Ethiopia. Water Science & Technology Water Supply, 24(7), 2395–2408. https://doi.org/10.2166/ws.2024.147

Nashima, F. P. (2013). The potential of rainwater harvesting: A case of the city of Windhoek, Namibia. Journal of Water Resources and Ocean Science, 2(6), 170–177. https://doi.org/10.11648/j.wros.20130206.13

Nijhof, S. N. S., Jantowski, B. J. B., Meerman, R. M. R., & Schoemaker, A. S. A. (2010). Rainwater harvesting in challenging environments: Towards institutional frameworks for sustainable domestic water supply. Waterlines, 29(3), 209–219. https://doi.org/10.3362/1756-3488.2010.022

Owusu, S., & Asante, R. (2020). Rainwater harvesting and primary uses among rural communities in Ghana. Journal of Water, Sanitation and Hygiene for Development, 10(3), 502–511. https://doi.org/10.2166/washdev.2020.059

Staddon, C., Rogers, J., Warriner, C., Ward, S., & Powell, W. (2018). Why doesn't every family practice rainwater harvesting? Factors that affect the decision to adopt rainwater harvesting as a household water security strategy in central Uganda. Water International, 43(8), 1114–1135. https://doi.org/10.1080/02508060.2018.1535417

Suni, S., Firdaous, M. H., Zailani, F. F., Gödeke, S., Raffi, R. M., & Abas, P. E. (2025). Urban Water Management and Public Acceptance of Rainwater Harvesting Systems: Insights from Young and Educated Respondents in Muslim Communities. Sustainability, 17(7), 3046. https://doi.org/10.3390/su17073046

Takin, M., Cilliers, E. J., & Ghosh, S. (2023). Advancing flood resilience: the nexus between flood risk management, green infrastructure, and resilience. Frontiers in Sustainable Cities, 5. https://doi.org/10.3389/frsc.2023.1186885

The Resilience Shift, Arup, & Resilient Cities Network. (n.d). City Characterisation Report: Addis Ababa. The City Water Resilience Approach.

Tolossa, T. T., Abebe, F. B., & Girma, A. A. (2020). Review: Rainwater harvesting technology practices and implication of climate change characteristics in Eastern Ethiopia. Cogent Food & Agriculture, 6(1), 1724354. https://doi.org/10.1080/23311932.2020.1724354

Umukiza, E., Ntole, R., Chikavumbwa, S. R., Bwambale, E., Sibale, D., Jeremaih, Z., Apollonio, C., & Petroselli, A. (2023). Rainwater harvesting in arid and semi-arid lands of Africa: Challenges and opportunities. Acta Scientiarum Polonorum Formatio Circumiectus, 22(2), 41–52. https://doi.org/10.15576/asp.fc/2023.22.2.03

UN-Habitat. (2005). Blue drop series: Rainwater harvesting and utilization. United Nations Human Settlements Programme.

Unto, P. B. (2024). The effect of water loss on demand–supply departure of Addis Ababa, Ethiopia. Discover Water, 4(1). https://doi.org/10.1007/s43832-024-00152-3

World Health Organization. (2020). Technical fact sheet: Rainwater collection and storage. https://cdn.who.int/media/docs/default-source/wash-documents/sanitary-inspection-packages/2-tfs-rainwater-collection-storage-d.pdf?sfvrsn=8dfb1bf8_6

World Population Review. (2025). Addis Ababa population 2025. https://worldpopulationreview.com/world-cities/addis-ababa-population

Yilma, Semere, Adugna, Dagnachew, and Benti, Solomon. (n.d.). Assessment of the perception, attitude, and practice of the local community to supplement the urban water system through rooftop rainwater harvesting in Addis Ababa. Water Practice & Technology, 21(5), 1694-1711. https://doi.org/10.2166/wpt.2026.243

ANNEXES

A. PUBLISHABLE MANUSCRIPT

ESTIMATING THE POTENTIAL OF RESIDENTIAL ROOFTOP RAINWATER HARVESTING USING QGIS AND LOCAL RAINFALL DATA IN BOLE SUB-CITY, WEREDA 6, ADDIS ABABA, ETHIOPIA

Weinshet Berta

Abstract

The study assesses the theoretical rooftop rainwater harvesting potential, awareness level, perception, and acceptability of rooftop rainwater harvesting (RRWH), and, potential contribution of rooftop rainwater harvesting to household water demand in Bole Sub-city, Wereda 6. It proved supplementary option to addresses a severe water security crisis in the city, where demand is significantly higher than supply, leading to rationing.

Key findings include harvesting Potential, roof areas determined using QGIS and an average annual rainfall of 1120.04 mm/year estimated by interpolating annual rainfall of seven rainfall stations. The study estimated a total annual harvestable volume of 324661.5 m³. And also investigate the demand satisfaction. The analysis reveals that RRWH can meet 62.9% of the total annual household water consumption, and 54.9% of the total annual household water demand in the study area. The other investigation is about awareness, perception, and acceptability. There is a high awareness of water scarcity and the use of rainwater for non-potable uses in the rainy season (93.3% for washing/cleaning). But the majority 80.3% of respondents had never heard of a formal RRWH system before the survey. These indicate the awareness gap is not about use of rainwater rather it is about how to make it useful during the dry season.

Keywords: **Rooftop rainwater harvesting, catchment area, annual rainfall, demand**

1. Introduction

Municipal water supply of cities in developing countries are facing pressure due to rapid urbanization, population growth, and increasing climate change, including those in Ethiopia (Abraha et al., 2022; Bekana et al., 2025) This shortage force Addis Ababa Water and sewerage authority to ration water. On the other hand this shortage led to exploitation of groundwater reserves, which currently provide over 60% of the city's supply (Bekana et al., 2025)

These inadequacies of municipal water infrastructure have led to the need for other forms of water supply sources (Biswas, 1991; Bekana et al., 2025). In response, water management approaches have shifted toward rooftop rainwater harvesting and other water-sensitive supply options to enhance water availability (Belmeziti et al., 2013; Abraha et al., 2022). These systems do not replace the municipal systems, rather supplement them. Rooftop rainwater harvesting involves the collection and storage of rainfall from building rooftops for subsequent domestic use.

Despite an average annual rainfall of 1,184 mm, and expanded roof area the potential of Rooftop Rainwater Harvesting (RRWH) remains untouched. This is due to lack of localized, evidence. These evidences include estimation of harvesting potential, identifying the capacity of this harvesting potential to satisfy the demand. Without this data, urban planners cannot determine the physical capacity of the city to support itself through rainwater.

However, despite these advances, empirical research specifically addressing residential rooftop rainwater harvesting in Addis Ababa remains limited. Existing studies largely focus on institutional buildings, emergency supply scenarios, or generalized urban assessments, with limited attention to typical residential rooftop characteristics.

This study addresses these gaps by evaluating the volumetric potential, social feasibility, and demand-satisfaction capacity of RRWH in Bole Wereda 6.

2. Literature Review

Municipal water supply of cities in developing countries are facing pressure due to rapid urbanization, population growth, and increasing climate change, including those in Ethiopia (Abraha et al., 2022). In response, water management approaches have shifted toward rooftop rainwater harvesting and other water-sensitive supply options to enhance water availability (Belmeziti et al., 2013).

Rooftop rainwater harvesting (RRWH) has gained more attention due to its potential to supplement domestic water supply and to reduce stormwater runoff (Belmeziti et al., 2013). Rooftop rainwater harvesting refers to the collection and storage of rainwater from building rooftops for later domestic or non-potable use.

According to Gould and Nissen-Petersen (1999), the quantity of harvestable rooftop rainwater primarily depends on rainfall characteristics, rooftop catchment area, and runoff efficiency. And the advancement of Geographic Information System (QGIS) technologies has further improved the accuracy to determine rooftop area and spatial assessment of rainwater harvesting potential (Hari et al., 2018).

In Ethiopia, the growing limitations of centralized urban water infrastructure have increased interest in alternative household-level water supply strategies. Addis Ababa receives relatively high annual rainfall, averaging approximately 1184 mm/year, indicating substantial untapped rooftop rainwater harvesting potential (The Resilience Shift et al., n.d.). Nevertheless, the practical application and localized assessment of RRWH systems remain limited.

Previous studies conducted in Ethiopia have primarily focused on institutional or condominium-level rainwater harvesting systems. Adugna et al. (2018) assessed rooftop rainwater harvesting potential in selected public institutions in Addis Ababa and reported considerable opportunities for supplementary urban water supply. Similarly, Meskele et al. (2024) demonstrated that rooftop rainwater harvesting could substantially contribute to household water demand in urban Ethiopian settings.

Despite these efforts, limited studies have evaluated the harvesting potential of residential rooftops using spatially explicit QGIS-based approaches at neighborhood scale in Addis Ababa. In addition, existing studies have often focused on technical estimations without detailed spatial analysis of residential rooftop catchment distribution.

Therefore, this study aimed to estimate the potential volume of rainwater that can be harvested from residential rooftops in Bole Sub-city, Wereda 6 using QGIS-derived rooftop area data and local rainfall records. The study contributes to the growing body of knowledge on rooftop rainwater harvesting urban water supply systems and provides evidence to support sustainable urban water management strategies in Addis Ababa.

3. Materials and Methods

3.1 Study Area

The study was conducted in Bole Sub-city, Wereda 6, Addis Ababa, the capital city of Ethiopia, is located between 8°50′–9°05′ N latitude and 38°38′–38°54′ E longitude which is near the geographical canter of the country. Climatically, Addis Ababa is characterized by a subtropical highland climate (Cwb). The city experiences a distinct seasonal rainfall pattern. Bole Wereda 6 was selected due to its predominantly residential land use pattern, increasing urban development, and persistent intermittent municipal water supply.

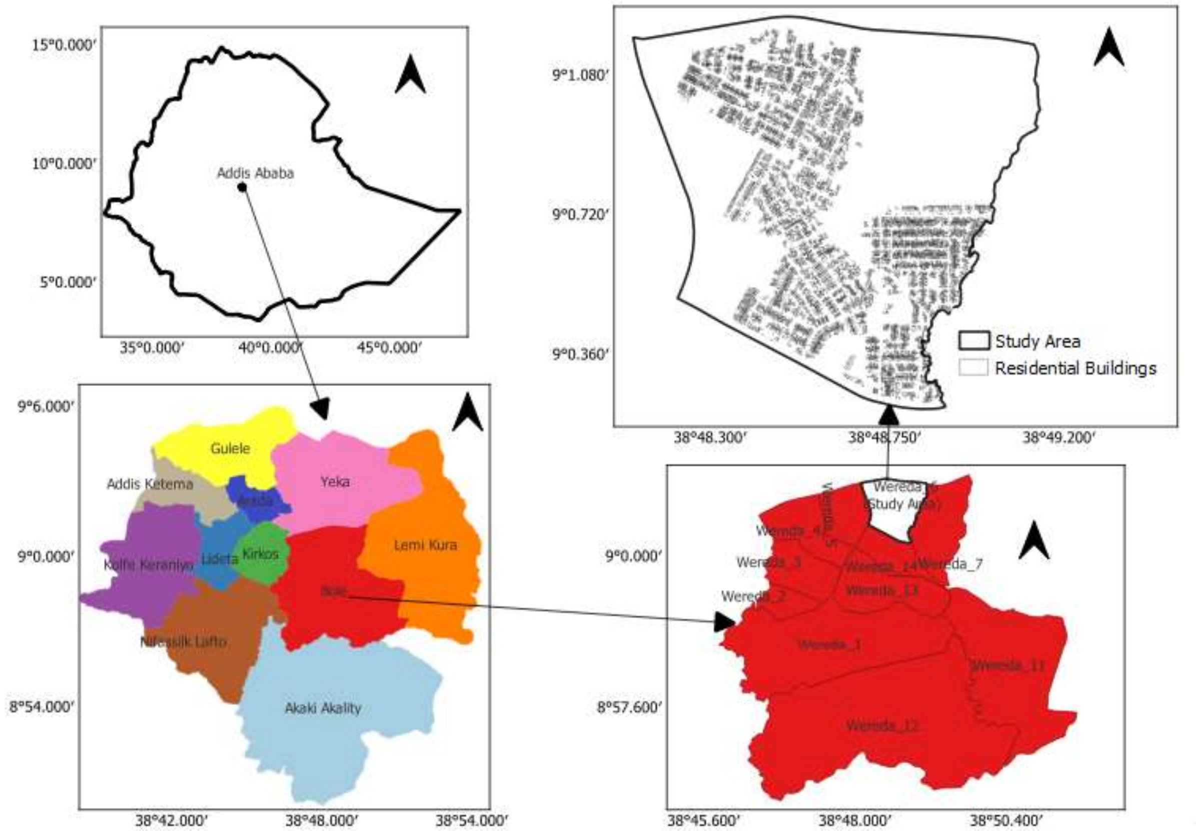

Figure 3. 1: Location map of Bole Wereda 6

3.2 Data Sources

The study used both primary and secondary data sources. Primary data were collected through a structured household survey. Which gather information on household size, water use behaviour, rooftop characteristics, and awareness, perceptions and acceptance of rooftop rainwater harvesting in the study area. Secondary data included building roof area data derived from the Open Buildings dataset, daily rainfall records obtained from the Ethiopian Meteorological Institute, and parcel boundary data obtained from the wereda administration.

3.3 Rooftop Area Extraction

The rooftop catchment area was quantify using data from Google Open Buildings Dataset This Open Buildings dataset was converted into shape file format. Then projected using the Adindan / UTM Zone 37N coordinate system (EPSG:20137). Then by using QGIS tools geometric errors in the data were corrected. Rooftop areas were calculated using the field calculator and buildings were spatially overlaid with parcel boundaries to determine the rooftop area within each parcel.

The analysis identified a total built-up rooftop area of 561,050.21 m² within the study area, of which residential rooftops accounted for 362,332.5 m² (64.58%).

3.4 Rainfall Analysis

Rainfall distribution within the study area is determined using the inverse distance weighted (IDW) method in QGIS. The rainfall is interpolated from the mean annual rainfall of seven rain gauge stations. The interpolated rainfall raster was clipped to the study area boundary. And zonal statistical analysis was performed to determine to determine the mean annual rainfall of the study area. And the study area mean annual rainfall is 1120.04 mm/year.

3.5 Estimation of Rooftop Rainwater Harvesting Potential

Rainfall-runoff equation was used to determine the potential volume of water from rooftop rainwater harvesting.

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

Where;

V= the annual volume of harvested rainwater,

R = annual rainfall,

A = rooftop area, and

C = the runoff coefficient.

Runoff coefficient(C) of 0.8 was used. This is based on the survey data which show the primary roofing material to be corrugated iron sheet. According to UN-HABITAT (2005) standards, corrugated metal sheets have runoff coefficient between 0.7 and 0.9.

4. Results

4.1 Rooftop Catchment Characteristics

The rooftop area of residential buildings is determined by conducting QGIS spatial analysis on the roof area. And the area is found to be significant for rooftop rainwater harvesting. The total built area of the study area is 561050.21 m2. And 362332.5 m2 or 64.58% of the built area is cover by residential buildings.

Table 4.1: Catchment Characteristics of Wereda 6

Feature	Area (m^2)	Percentage of total area
Total built area in wereda 6	561050.21	100%
Residential rooftop catchment	362332.41	64.58%
Others (non- residential)	198717.8	35.42%

4.2 Rainfall Characteristics

Rainfall distribution within the study area is determined using the inverse distance weighted (IDW) method in QGIS. The rainfall is interpolated from the mean annual rainfall of seven rain gauge stations. The interpolated rainfall raster was clipped to the study area boundary. And zonal statistical analysis was performed to determine to determine the mean annual rainfall of the study area. And the study area mean annual rainfall is 1120.04 mm/year. However, the rainfall significantly varies within a year the peak rainfall is in August and the lowest rain is in December.

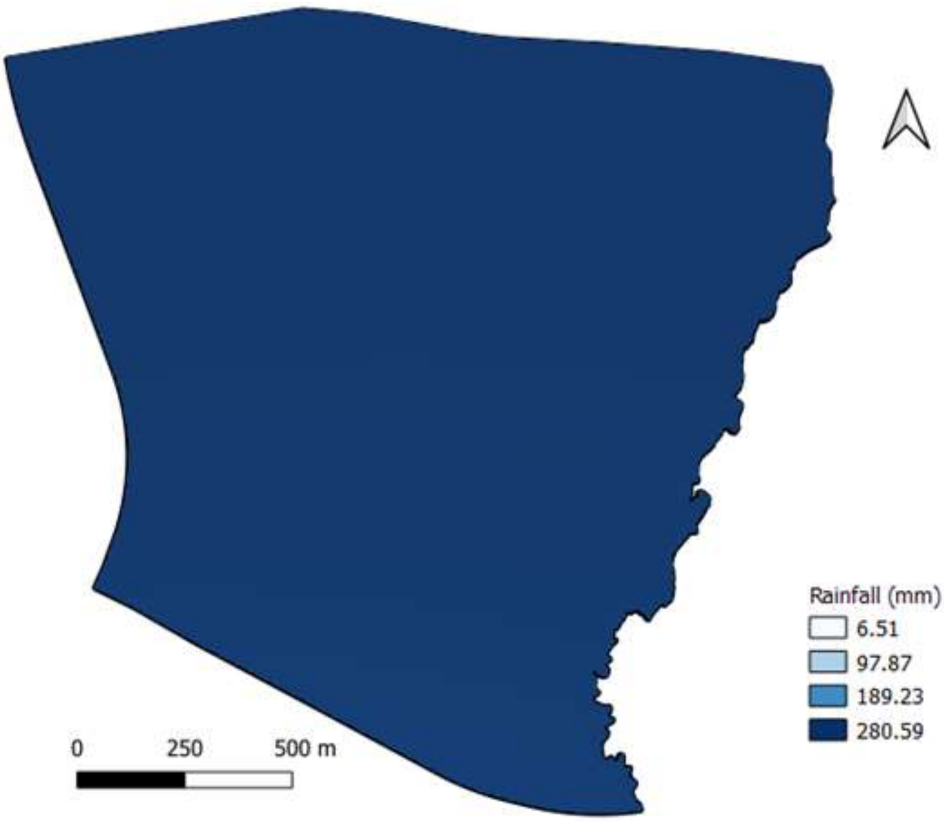

Figure 4.1: Peak Rainfall in August

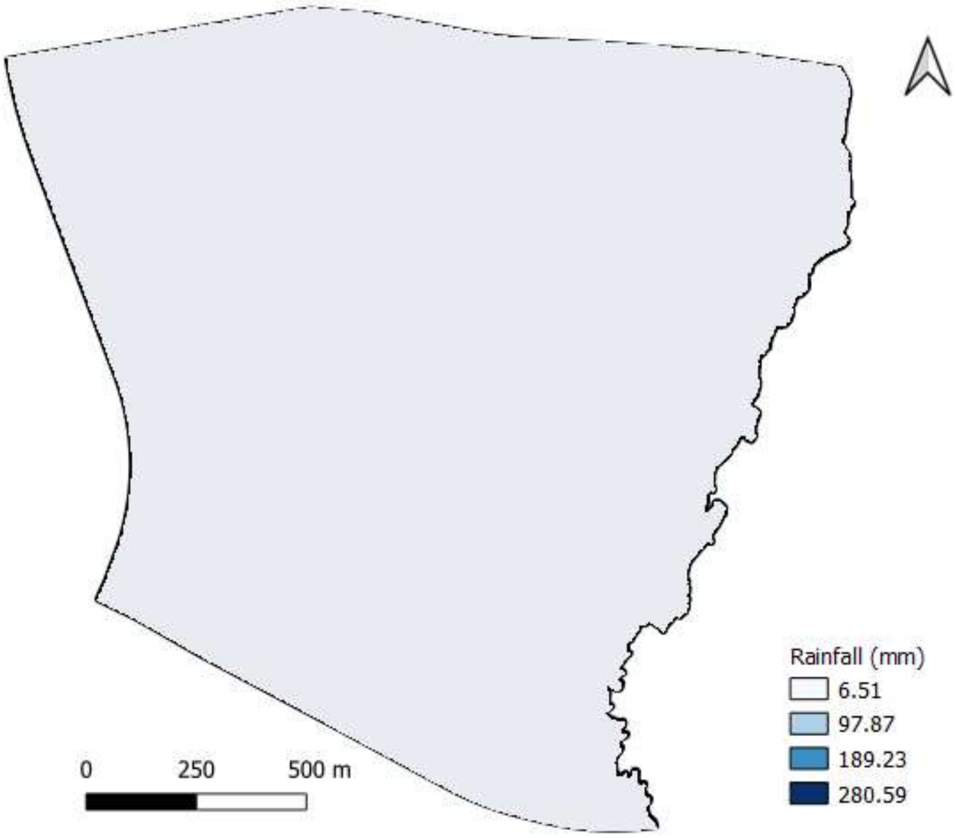

Figure 4.2: Lowest Rainfall in December

4.3 Estimated Harvestable Rainwater Volume

Based on the local mean annual rainfall of 1120.04 mm, and by applying a representative runoff coefficient (C) of 0.8, the theoretical annual rooftop rainwater harvesting is calculated. And found that 324661.5 m³/year volumes of water can be captured from residential rooftops within Bole Wereda 6.

Table 4. 2 Harvestable Volume per Catchments

Catchments	**Sum of Roof Area (m^2)**	**Harvestable Volume(m^3/year)**
Large-scale	90814.5	81372.7
Medium-scale	174882.5	156700.3
Small-scale	96635.5	86588.5
Total	362332.5	324661.2

5. Discussion

The findings demonstrate considerable technical potential for rooftop rainwater harvesting within the study area. The estimated annual harvestable volume of 324661.5 m^3/year indicates that residential rooftops in Bole Wereda 6 represent a significant but underutilized urban water resource.

The results are consistent with previous Ethiopian studies that identified rooftop rainwater harvesting as an important supplementary urban water supply strategy. Similarly, reported substantial harvesting potential from institutional rooftops in Addis Ababa. However, unlike previous studies that focused primarily on large institutional buildings, the present study specifically demonstrates the considerable contribution that these rooftops can make toward urban water supply systems (Adugna et al., 2018).

The relatively high harvesting potential observed in this study is associated with three major factors: high annual rainfall, extensive residential rooftop coverage, and the predominance of corrugated iron roofing materials with relatively high runoff efficiency. These conditions create favourable opportunities for integrating RRWH into household-level water management strategies.

Nevertheless, the estimated harvestable volume represents theoretical potential under ideal capture conditions. Actual harvested volumes may be lower due to first-flush diversion losses, evaporation, leakage, storage limitations, and seasonal rainfall variability.

6. Conclusion

This study estimated the technical potential of rooftop rainwater harvesting in Bole Sub-city, Wereda 6 using QGIS-derived rooftop area data and local rainfall information. The findings revealed that residential rooftops possess significant harvesting capacity.

The results suggest that RRWH can contribute substantially to supplementary urban water supply strategies in Addis Ababa. Integrating rooftop rainwater harvesting rainwater harvesting systems into urban planning and household water management could reduce pressure on centralized water infrastructure and improve urban water resilience.

Future studies should incorporate storage analysis, seasonal water balance modelling, and economic feasibility assessments to evaluate the practical implementation potential of RRWH systems under real-world conditions.

REFERENCES

Abraha, T., Tibebu, A., & Ephrem, G. (2022). Rapid urbanization and the growing water risk challenges in Ethiopia: The need for water sensitive thinking. Frontiers in Water, 4. https://doi.org/10.3389/frwa.2022.890229

Addis Ababa Resilience Project Office, & Tadesse, M. (2021). THE CITY WATER RESILIENCE APPROACH CITY CHARACTERISATION REPORT ADDIS ABABA. In Addis Ababa Resilience Project Office. https://www.arup.com/globalassets/downloads/insights/c/city-water-resilience-approach/characterisation-report/ccr-addis-abbab.pdf

Adugna, D., Jensen, M., Lemma, B., & Gebrie, G. (2018). Assessing the potential for rooftop rainwater harvesting from large public institutions. International Journal of Environmental Research and Public Health, 15(2), 336. https://doi.org/10.3390/ijerph15020336

Belmeziti, A., Coutard, O., & De Gouvello, B. (2013). A new methodology for evaluating potential for potable water savings (PPWS) by using rainwater harvesting at the urban level: The case of the municipality of Colombes (Paris region). Water, 5(1), 312–326. https://doi.org/10.3390/w5010312

Bekana, T. H., Ebrea, M. G., Yessuf, N. H., Kindhun, A., Hunegnew, D. A., Desta, B. G., & Shiferaw, E. T. (2025). Urban water scarcity in Addis Ababa city: Hard versus soft path solutions: A systematic review. Discover Geoscience, 3(1). https://doi.org/10.1007/s44288

Gould, J., & Nissen-Petersen, E. (1999). Rainwater catchment systems for domestic supply: Design, construction and implementation. Intermediate Technology Publications.

Hari, D., Reddy, K. R., Vikas, K., Srinivas, N., & Vikas, G. (2018). Assessment of rainwater harvesting potential using GIS. IOP Conference Series: Materials Science and Engineering, 330, 012119. https://doi.org/10.1088/1757-899X/330/1/012119

Meskele, D. Y., Shomre, M. W., & Soche, T. K. (2024). Evaluating rooftop rainwater harvesting potential to satisfy urban water demand in Hosaena City, South Central Ethiopia. Water Science & Technology Water Supply, 24(7), 2395–2408. https://doi.org/10.2166/ws.2024.147

B. INTERVIEW QUESTIONNAIRES

Weinshet Berta
Mobile; +251970217882
E-mail; weinshetberta@gmail.com
Advisor: Dr. Tibebu Aseffa
Mobile; +251911313666
E-mail; tibebu.assefa@eiabc.edu.et

Dear Sir/Madam

I am currently undertaking a Master of Science Degree in Urban Design and Development at College of Technology & Built Environment (CTBE), Addis Ababa University. In fulfilment of this study's, i am required to research a topic area and produce thesis. the topic I have chosen is assessing the potential of residential rooftop rainwater harvesting as a supplementary urban water supply option in Addis Ababa: the case of bole wereda 6, and I am investigating the following:

1. Household demographics,
2. Rooftop characteristics,
3. Water supply conditions,
4. Awareness level of households,
5. Perceptions of rooftop rainwater harvesting, and
6. Acceptance and Adoption of rooftop rainwater harvesting

I would be very grateful if you could complete the attached questionnaire, the information provided will be treated with strict confidence.

Yours faithfully, Weinshet Berta

Section 1: Household & Building Characteristics

1.1 Housing tenure status:

☐ Homeowner ☐ Rented ☐ Government/Kebele

1.2 Number of people living in the household: ______ persons

1.3 Primary material of your roof:

☐ Corrugated Iron Sheets ☐ Concrete slab ☐Other

Section 2: Current Water Supply & Reliability

2.1 Water Reliability: On average, how many days per a week do you get water from the municipal (AAWSA) line?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

Section 3: Awareness level

3.1 Awareness: Before this survey, have you heard about rooftop rainwater harvesting?

☐ Yes ☐ No

3.2 Familiarity: How familiar are you with how rooftop rainwater harvesting systems work?

☐ Very familiar

☐ Somewhat familiar

☐ Heard of it, but no details

☐ Not familiar

3.3 Recognized Uses: Which of the following uses of harvested rainwater are you aware of? (Select all that apply)

☐ Washing/cleaning

☐ Toilet flushing

☐ Gardening

☐ Drinking (after treatment)

Section 4: Perceived Safety and benefits

4.1 Perceived Safety: In your opinion, how safe is rainwater collected from rooftops for non-drinking household use?

☐ Very safe

☐ Safe

☐ Neutral

☐ Unsafe

☐ Very unsafe

4.2 Perceived benefits of rooftop rainwater harvesting: (Scale 1-5: 1=Strongly Disagree,2= Disagree,3=Neutral,4= Agree and 5=Strongly Agree):

4.2.1 Rooftop rainwater harvesting can significantly reduce water bills.

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

4.2.2 Provides water during shortages

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

4.2.3 Reduces dependence on Addis Ababa Water and Sewerage Authority.

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Section 5: Acceptance and Adoption Willingness

5.1 Adoption Interest: If you do not have a system, would you consider installing one in the future?

☐ Yes ☐ No ☐ Not sure

5.2 Barriers: What would be your biggest concern or barrier to adopt rooftop rainwater harvesting? (Select top 2)

☐ High installation cost

☐ Lack of technical "know-how"

☐ Water quality concerns

☐ Roof not suitable

5.3 Recommendation: Would you recommend rooftop rainwater harvesting to others in your community?

☐ Yes ☐ No ☐ Not sure

Thank You!