Ethiopian Institute of Architecture, Building Construction and City Development

Urban Water Metabolism for Promoting Water-Sensitive Urban Planning Interventions in Adama City, Ethiopia

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Addis Ababa, Ethiopia

Addis Ababa University

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Declaration

I, the undersigned, declare that this is my original work, has never been presented at this or any other university, and that all the resources and materials used for the dissertation have been duly acknowledged.

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This is to certify that the dissertation prepared by **Abraha Tesfay Abraha**, entitled "**Urban Water Metabolism for Promoting Water-Sensitive Urban Planning Interventions in Adama City, Ethiopia**," is presented in fulfillment of the requirements for the Degree of Doctor of Philosophy in Urban and Regional Planning and meets the accepted standards concerning originality and quality

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Abstract

Urban metabolism quantifies resource flow within urban boundaries focusing on urban water, energy, nutrients and wastes. However, in developing nations, little research has been done to provide a quantitative picture of how water is consumed and transformed in urban landscape, as well as the water sensitive planning interventions needed to improve urban water security. This research was aimed to analyze the urban water metabolism of Adama city, Ethiopia as a foundation for evidence-based decision-making for water sensitive urban planning and enhance urban water security. The study employed a mixed-methods approach combining Material Flow Analysis (MFA) and urban water mass balance to track and trace water inflows, outflows and losses. Geospatial tools were used to map water supply source locations, distribution networks, consumption patterns and water stress. Water security was quantified using the Integrated Urban Water Security Index (IUWSI). The study applied the Random Forest algorithm in R version 4.0.5. This algorithm was used to identify factors influencing residential water consumption. Key informant interviews and surveys were conducted to collect data on consumption and conservation behaviors across households, commercial, institutional and industrial water users. The data collection was conducted by combining both the bottom-up and top-down data collection systems. Findings indicated that Adama city is located in a water-stressed geographical location that receives less than 1700 m^3 of water per person annually. The city's daily per capita water consumption is 69 liters falling short of Ethiopia's standard of 80 liters. The water distribution network covers only 45% of the area outlined in the master plan. The result also indicated a 38% gap between water demand and supply. Furthermore, nearly 30% of households receive water just at most three days a week. The centralized water supply accounts for 61% of the total consumption with 90% sourced from the distant Awash River indicating the city's dependency on remote sources. Water conservation practices in Adama are limited. This reflects a linear take-make-use-dispose model that overlooks internal alternative water harvestings. The urban water security index of 1.95 revealed that Adama lacks water sensitive planning and strategies to ensure the urban water security. The study also revealed that key factors influencing water consumption are family size, housing quality, income levels, the number of rooms, parcel legal status, supply reliability, climate and topography. In conclusion, Adama is experiencing significant urban water insecurity due to both economic and physical water scarcity along with limited water-sensitive interventions. Adama city is heavily dependent on a centralized water source which lacks internalization and diversification practices coupled with underdeveloped conservation practices. Another conclusion that can be drawn is that as long as the city's business as usual water consumption practice doesn't change, the water supply problem will worsen over time. Hence, to strengthen urban water security, Adama city should implement water-sensitive urban planning interventions and strategies that encompass community engagement, the adoption of water-saving technologies, water-sensitive urban land use planning and the establishment of a robust water sensitive legal framework to promote urban water security.

Keywords: Metabolism, water mass balance, water stress, water security, water sensitive, Adama, Ethiopia

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Lists of Abbreviations

AHP	Analytic Hierarchy Process
CBD	Central business district
CN	Curve number
CR	Consistency ratio
DNN	Deep Neural Network
EFA	Ecological Footprint Analysis
EPA	Environmental Protection Agency
EFR	Environmental flow requirements
FAO	The Food and Agriculture Organization
GIS	Geographic information system
GOF	Goodness-of-Fit Functions
GPS	Global Positioning System
IOA	Input-Output Analysis
IUCN	The International Union for Conservation of Nature
IUWSI	Integrated Urban Water Security Index
LCA	Life Cycle Assessment
LID	Low-Impact Development
LIUDD	Low Impact Urban Design and Development
MFA	Material flow analysis
ML	Machine Learning
MUDC	Ministry of Urban Development and Construction
PMT	Participatory mapping techniques
RFR	Random Forest regression
SCS-CN	Soil Conservation Service Curve Number
SDGs	Sustainable Development Goals
SPSS	Statistical Package for the Social Sciences (SPSS)
SUD	Sustainable Urban Drainage Systems
TFWW	Total freshwater withdrawn
TRWR	Total renewable freshwater resources

UMEF4Water	Urban Metabolism Evaluation Framework for water
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
USDA	U. S. Department of Agriculture
USDA-SCS	Soil Conservation Service Classification Method
WPM	The Water Point Mapping
WSP	Water Sensitive Planning
WSUD	Water-sensitive urban design
WTA	Withdrawal-to-availability ratio

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Water serves as the “lifeblood” for sustaining all forms of existence. It is present in all facets of nature and makes up a sizable amount of the Earth's surface as well as the human body. Water has always been a harmonious force in the growth of civilizations and it forms the foundation of all human societies (Sargen, 2019; Water Science School, 2019). Since ancient times, water has played a crucial role in the growth and survival of human societies. The deep connection between people and water is demonstrated by ancient communities along the Nile, Tigris-Euphrates, and Yellow Rivers, as well as by the magnificent Roman aqueducts(Deming, 2020 ; Adamo et al., 2020). In contemporary times, it is still typical to see large cities flourishing next to rivers or other water bodies (Kurochkina, 2020). Water is ultimately the driving force behind all natural and manmade occurrences, the glue that holds all life together, and the foundation upon which human civilizations are constructed (Yannopoulos et al., 2015 ; Ganguly and Cahill, 2020).

Water holds its various natural qualities and benefits to give the planet a wealth of incomparable advantages. It is essential for promoting social stability and economic transformation (Kılı,2020). Its physical presence is essential for improving urban aesthetics and acting as a centre point for place-making in urban beautification through urban design projects (Vernon and Tiwari, 2009). Indeed, water is essential for life, but it also represents a key human rights (Spijkers, 2020) and is a strategically important natural resource that supports community well-beings (UNICEF, 2021). Water is considered a holy and divine natural resource in many religious institutions (IUCN, 2021). Water features or the blue infrastructures offer a refreshing contrast to concrete-heavy landscapes (New urbanism and water features, 2019).Water is crucial to all sustainable development goals (SDGs) and is integral to every aspect of development (UN-Water,2021). Achieving these goals depends on ensuring secured clean and adequate water supply system (UNICEF, 2021; UNESCO and UNESCO i-WSSM., 2019).

Surprisingly, humankind's use and treatment of this valuable resource is riddled with paradoxes. Despite water being essential for life and civilization, it has often been managed with a laissez-faire attitude leading to widespread water stress(UNICEF, 2021). Negligent management is driven by the misconception that water is an infinite (UN-Water, 2021). Additional factors that foster water stress include increased impervious surfaces that results in surface runoff and reduced groundwater recharge from urbanization(Zhang et al., 2018), lack of water centric spatial plan (McClain, 2013) and reliance on a single water source, lack of diversified alternatives and linear waste disposal systems(Renouf et al., 2017).

Since the previous century, global water use has surged sixfold, growing more than twice as fast as the population (UNESCO, 2019; Piesse, 2020). This rapid increase has caused widespread water stress where demand exceeds supply (UN-Water, 2019). Water stress occurs when annual per capita freshwater falls below 1,700 cubic meters (Zablon, 2021). Currently, 25% of the global population lives in regions experiencing water stress and 67% experience severe water scarcity for at least one month each year (UNICEF, 2020). If water management practices remain unchanged, stress is likely to escalate. By 2050, total water use is expected to increase by 55%, with manufacturing and residential demands rising by 400% and 130%, respectively and lead to a 40% water supply gap (Heidari et al., 2021).

Developing countries has no exception to these global water stress trends. Developing countries are experiencing increasing gaps between freshwater availability and demand (UNICEF, 2021). Africa, with 60% of its land classified as arid or semi-arid is under water stress(Gan et al., 2016). Particularly, Sub-Saharan Africa suffers from severe water scarcity driven by rapid population growth, climate change and erratic rainfall (Leal Filho et al., 2022). Ethiopia, known as Africa's "Water Tower," is struggling with increasing water demand and supply gap driven by rapid population growth, urbanization, climate change, erratic rainfall, and watershed degradation (Zablon et al., 2021). Ethiopian urban centers, especially those with rapid population growth and urbanization are facing a significant water stress challenges(Ministry of Water and Irrigation, 2020). Adama city exemplifies this issue as a water-stressed area with prolonged water insecurity. The city experiences declining well capacity, frequent supply breakdowns, water rationing, customer dissatisfaction, urban flooding, supply-demand gaps and significant water loss in its water supply distribution network.

Meanwhile, urban centers are often assumed not to be self-sufficient in water supply, ignoring their potential for generating alternative water sources within their boundaries. This issue arises from a lack of understanding and methods to assess how urban settlements use and manage water for various needs with in their urban boundary (Brown et al., 2009 ; Serrao-Neumann et al., 2017). An approach that addresses the appealing questions is urban metabolism. Urban metabolism serves as a metaphorical framework that conceptualizes resource flows within urban systems drawing parallels to natural ecosystem (Pincetl et al., 2012 ; Wolman, 1965). Urban metabolism includes key flows of water, materials, energy, and food and study their nexuses. This research focuses on urban water metabolism which examines how urban water is consumed and is transformed from source to water end use to support various urban development activities within the city boundary.

With increasing water stress, the urban water metabolism framework is gaining attention for enhancing water-sensitive planning (Renouf et al., 2018). There are examples of case study that employed water metabolism at urban center level. Sven Eberlei (2018) studied Brussels, Belgium, analyzing the city's metabolic flows of energy and water. The study identified resource inefficiencies and proposed a circular economy model. Fu et al., (2023) examined urban metabolic flows in China's megacities to analyze material stock accumulation. Christopher Kennedy et al., (2007) examined the urban metabolism of various urban centers, including Melbourne, Australia, and highlighted its role as a key input for achieving sustainability. Barles, (2009) analyzed Paris's urban metabolism using material flow analysis, revealing significant socioecological changes impacting the city's sustainability.

Water-sensitive planning integrates water management with land use decisions to create sustainable urban landscapes that enhance water resource management and urban water security (Renouf et al., 2017). A water-sensitive city vision goes beyond traditional water management by promoting diverse local water sources such as surface water, groundwater and recycled wastewater and emphasizes urban areas as water catchments (Brown et al., 2009). However, as Currie et al., (2015) and Currie and Musango (2016) highlighted that research on water metabolism in developing countries, particularly in Africa, is scant and there is still limited understanding how water stress and urban water insecurity is growing over time. Atkins and Flügel (2021) also reported that urban metabolism studies are rare

and still the interface between water management and urban planning is not studied adequately. Consequently, today there are practical reasons for studying urban water metabolism of developing countries and the same is true for Adama city.

In Ethiopia and particularly in Adama city, research on integrating urban metabolism with water-sensitive planning remains scarce, creating a critical gap in addressing the challenges of rapid urbanization and water management. Existing studies are fragmented and lack comprehensive data on water inflows and outflows hindering the city's ability to make informed water-sensitive intervention decisions. Historically, Adama city's water supply has evolved significantly since its establishment under the municipality in the 1930s, initially relying on two deep wells. Over time, groundwater has become less viable due to declining well capacity, rising fluoride levels and increasing urban water demand. Of the nine existing boreholes, only six remain operational, producing a combined 3,024 m^3/day with intermittent flow (Adama City Water supply and Sanitation office, 2021).

Adama city relies heavily on the Awash River, which supplies 43,300 m^3 of water daily, though only 41,228 m^3 reaches to distribution centers due to 9–10% transmission losses caused by power interruptions and maintenance issues. Water is delivered via six pumps and stored in six reservoirs with capacities ranging from 25 m^3 to 6,000 m^3 (Adama City Water supply and Sanitation office, 2021). Despite tripling water production and doubling consumption over the past three decades, the Adama's rapid spatial growth from 13,211 hectares in 1991 to 313,211 hectares in 2020 has outpaced its water supply infrastructure. Adama city's population has grown significantly over the last few decades, with numbers rising from 77,237 in 1984 to 220,212 in 2007, and an estimated 431,442 in 2020 (Adama Stuctural Plan Report,2020). The distribution network covers just 45% of the city's master plan, and a significant 20% of water is lost to faulty meters, leaks, and illegal connections. In 2023, Adama city faced a significant water supply-demand gap, with a daily demand of 66,013 m^3 and a shortfall of 24,785 m^3, leaving 38% of the demand unmet. According to DH-Consult (2018) in addition to seasonal variability a collapse of the Awash River supply would severely exacerbate Adama city's water insecurity, as the city lacks a reliable alternative water supply sources.

Hence, the research gap lies in the limited local knowledge on rising water insecurity, the absence of spatial water stress classification maps for urban areas and the lack of studies that integrate urban water metabolism with water-sensitive urban planning in Adama city. Therefore, the study's primary objective was to identify Adama's position on Ethiopia's water stress classification map and analyze its urban water metabolism. A mixed-methods approach was employed, utilizing Material Flow Analysis (MFA) and urban water mass balance to track urban water flows. Geospatial tools mapped water sources, distribution networks and consumption patterns. Water security was quantified using the Integrated Urban Water Security Index (IUWSI) and a Random Forest model using R software version 4.0.5 identified factors influencing residential water consumption. The research integrates system theory, ecological theories and water-sensitive city concepts to evaluate urban water metabolism and urban water security performance from the eye of water sensitive urban planning intervention of Adama city.

1.2 Problem Statement

Despite its vital importance, water is often undervalued, seen as an unlimited resource, and thus managed wastefully with a laissez-faire protection practices (Grafton et al., 2020; UNICEF, 2020). Urban centers today face significant challenges in securing water, yet water-focused urban development plans remain limited. Spatial plans, legal frameworks, water-saving technologies and community attitudes are not yet aligned with efforts to tackle growing urban water insecurity (Renouf et al., 2017). The traditional "business-as-usual" approach to water management in urban centers often fails to develop self-reliant systems, underestimating the potential for internal alternative water sources and increasing dependence on distant water supplies (Hailu , 2017).

To enable evidence-based water-sensitive urban planning and management, it is essential to assess water stress levels, track and trace water usage from source to end user, evaluate water-saving behaviors, measure water security performance and identify the key drivers influencing water consumption (Aboelnga et al., 2020). However, in developing nations, there is a lack of quantitative research on the growing water insecurity and on how water is metabolize in urban landscapes (Musango et al., 2017). Research that explores the integration of urban water management and water-sensitive urban planning remains limited (Renouf et al., 2017). It is noted that the gaps stem from a lack of comprehensive understanding of how urban settlements utilize and transform urban water to fulfill their water demands. Meanwhile, in developing countries, research offering quantitative evidence on urban water consumption and transformation in urban areas remains scarce (Currie et al., 2015). The identified research gap can be framed in terms of context, adequacy and methodological limitations. From a contextual perspective, researchers recommend localized studies to provide context-specific data for improved decision-making in water-sensitive interventions. In terms of adequacy, while urban metabolism has been widely studied in developed countries, it remains underexplored in developing ones (Currie et al., 2015). From a methodological standpoint, the urban water metabolism framework, which is a vital tool for water-sensitive urban planning, requires refinement in its inputs (Renouf et al., 2017). The current frameworks rely heavily on top-down data, overlooking decentralized water supplies, which impedes a comprehensive assessment of urban water security performance (C Kennedy et al., 2010).

From this standpoint, Ethiopian urban centers, particularly Adama city exhibits these gaps. At the urban scale, key strategic questions remain largely unaddressed such as, in what spatial water stress level classification does Adama city fall within the context of Ethiopia's water stress map, how is water metabolized within the urban settlement? is the city self-reliant enough to ensure urban water security? Moreover, key factors such as housing quality, parcel ownership, proximity to the city center, reliability, topographic roughness index (TRI), topographic position index (TPI), temperature, and rainfall patterns have rarely been employed in modeling urban water consumption.

Adama city exemplifies the challenges faced by water-stressed Ethiopian urban centers. In the previous decades, despite tripling water production and doubling consumption, Adama's rapid expansion from 13,211 hectares in 1991 to 313,211 hectares in 2020 has outpaced its water infrastructure. The population grew from 77,237 in 1984 to an estimated 431,442 in 2020, yet the distribution network covers only 45% of the city with 20% of water lost due to leaks and faulty meters (Adama Stuctural Plan Report,2020). Frequent service disruptions and rationing lead to prolonged water shortages with residents receiving piped water only every few days. In a decentralized system, delays and long wait times aggravate stress, disrupt education and economic activities for women and children and worsen overall living conditions. Many peripheral residents depend on costly trucked water, straining their budgets and disrupting basic needs, businesses, schools, health, and industries.

Adama city's water supply depends heavily on a single source, the Awash River, which provides 90% of its centralized water, leaving the city highly vulnerable to crises if the supply fails (DH-Consult, 2018). According to the Adama Stuctural Plan Report (2020), the city's daily per capita water consumption is 69 liters falling short of Ethiopia's standard of 80 liters. Nearly 30% of Adama households receive water at most only three days a week, with many spending over 20% of their income on purchasing water. Aging infrastructure causes 20% revenue loss and 24.71% live in high flood hazard zones (Wodnimu and Erena, 2022). These challenges fuel rising water insecurity and municipal water supply service dissatisfaction (Aminu and Reddythota, 2024). Hence, these challenges emphasize the need to understand urban metabolism and its role in fostering water-sensitive urban planning interventions to enhance urban water security.

1.3. Objectives of the Study

1.3.1 General Objective

This research was aimed to explore Adama city's urban water metabolism and characterize water consumption and transformation in line with water-sensitive principles, so land use and water resource management planners can make informed decisions to improve urban water security.

1.3.2 Specific Objectives

1. To identify Adama city's water stress designation within Ethiopia's spatial water stress classification map.
2. To track and trace the city-wide water consumption from source to end-use
3. To quantify urban water security performance through the lens of water metabolism
4. To characterize water consumption by integrating spatial and non-spatial water consumption determinants.

1.4. Research Questions

1. In what spatial water stress level classification does Adama city fall within the context of Ethiopia's water stress map?
2. How is water metabolized by urban settlements from source to end-use?
3. How is the city performing to achieve urban water security?
4. How do spatial and non-spatial determinants influence urban water consumption?

1.5 Significance of the Study

This research makes a significant contribution to the scientific community, urban planners, policymakers, and local communities by advancing knowledge of urban water metabolism and promoting water-sensitive thinking.

1.5.1 Contribution to the Scientific Community

This study contributes to the scientific community by promoting the understanding of urban water metabolism. A key research gap identified in this study is the reliance of existing urban metabolism frameworks on top-down data collection which often overlooks decentralized water flows such as recycled water and rooftop harvesting. Addressing this

limitation, this research contributes by employing a mixed-methods approach that integrates top-down and bottom-up data collection to comprehensively capture the diverse functions of water within the urban landscape. This study promotes data sharing through academic publications offering a vital secondary data source and methodology for researchers, students and institutions especially in developing countries where urban water metabolism data remains scarce.

1.5.2 Contribution to the urban and reginal planners

The contribution of urban water metabolism studies for urban and regional planners lies in delivering evidence-based quantitative evidences for water-centric urban planning. The analysis results support low-impact urban development, water-sensitive design and planning, improved resource efficiency and targeted water sensitive interventions at the city scale, ultimately strengthening urban water security. The study also employed machine learning to characterize residential water consumption from urban metabolism perspective which in turn helps to make informed decision and developed scenario planning for water sensitive interventions.

1.5.3 Contribution to the policy makers

Current local and national institutional and legislative frameworks often overlook the need for a new urban water management paradigm aligned with water-sensitive urban centers. This study contributes by raising awareness among policymakers by emphasizing the integration of urban water metabolism into actionable water sensitive urban planning interventions. It supports the development of evidence-based policies that foster water-sensitive urban development, ensuring sustainable and long-term urban water security.

1.5.4 Contribution to local community

The study benefits the community by enhancing urban water security through policies informed by urban water metabolism. It identifies areas of water insecurity, highlights the community's role in water sensitivity and promotes awareness to reduce water wastage through conservation practices. Local industries can offer innovative water-saving technologies that help households and institutions reduce water use, lower monthly bills, and safeguard the ecosystem by protecting water sources.

1.6 Scope of the Study

1.6.1. Spatial scope

This study was conducted within the administrative boundary of Adama city with area of 313 km². The study delineated the core, intermediate and peripheral boundary settlements to capture representative samples from each neighborhood and depict the spatial distribution of water consumption and reliability from the center to the periphery. Additionally, the study incorporated the basin boundary to assess water stress at the basin level, overlaying it with the urban center distribution to identify urban centers falling under different water stress classifications with a specific focus on Adama city.

1.6.2. Thematic scope

The thematic scope of this urban water metabolism study includes developing a water stress classification map to identify urban centers at varying levels of water stress, with a focus on Adama city's water stress designation within Ethiopia's spatial water stress classification map. It also examines water consumption and transformation at the city level, from source to end-use, and measures urban water security across four dimensions such as human well-being, ecosystem health, climate change and water-related hazards, and socio-economic dimensions . Additionally, the study characterizes residential water consumption, considering spatial and non-spatial determinants such as socioeconomic, morphological, climatic, topographic and locational variables.

1.6.3. Temporal scope

The temporal scope of this study encompasses both current and historical trends in urban water consumption and transformation for residential and non-residential water users. The analysis of water consumption and transformation focuses on the period from 2022 to 2023, while historical trends related to water consumption, production and non-revenue water are examined from 2013 to 2023. Additionally, the urban water security performance was assessed using data from the 2022-2023 period.

1.7 Limitations of the Study

This study faced limitations stemming from the complexity of urban metabolism research, which spans interdisciplinary fields such as urbanization, water management and water-sensitive planning. Additionally, the approach requires extensive data which is a critical challenge in developing countries like Ethiopia. This kind of phenomenon was presented challenges in data collection. However, recognizing the nature of urban water metabolism, the study employed a mixed-methods approach that combined top-down and bottom-up data collection systems. Additionally, the study focused solely on modeling residential water consumption to demonstrate how urban water consumption is influenced by spatial and non-spatial factors, while overlooking non-residential water consumption. To address this limitation, the study recommends expanding future study to include non-residential water consumption modeling such as commercial, service institutions and industries to provide a more comprehensive understanding of urban water metabolism and enhance urban water security performance at the city level.

1.8 Structure of the Document

Structure of the document is organized based on monograph guideline into six chapters. Chapter one lays the groundwork with the background, problem statement, objectives, research questions, significance, scope, limitations and the structure of the document . Chapter two covers the contextual, theoretical and empirical reviews, identifies research gaps and presents the conceptual framework. Chapter three describes the materials and methods, including research philosophy, design, sampling methods, data sources, data collection techniques, data analysis and presentation and ethical considerations. Chapter four presents the results for each research question. Chapter five analyzes these findings in the context of existing literature, examining their relationships and implications. Chapter six concludes with recommendations and suggestions for future research.

CHAPTER TWO

REVIEW OF LITERATURE

This chapter reviews conceptual, theoretical, empirical and contextual literature, focusing on urban metabolism, water security, and water-sensitive city principles, and identifies research gaps to propose a conceptual framework.

2.1 Conceptual Review

2.1.1 Urban Metabolism

The term "metabolism" originates from the Greek word 'Metabole' which translates to 'Change' (Judge and Dodd, 2020). In biological terms, metabolism denotes the intricate network of chemical reactions transpiring within an organism's body to uphold life (Kornberg , 2024). The biological process involves two fundamental chemical reactions named as anabolism and catabolism (Anne, 2020). The term anabolism refers to the constructive synthesis of vital cellular compounds, whereas catabolism entails the breakdown of complex molecules to release energy (MyJoVE, 2024). Urban metabolism, similar to the human body's functioning, was developed to analyze resource flows and waste in urban areas. Just as humans consume water, energy and food and generate waste, urban centers follow a similar pattern by utilizing resources and making waste to sustain their existence (Kenway et al., 2011 ; Zhang et al., 2015 ; Sanches and Bento, 2020).

The definition of urban metabolism lacks uniqueness because it has been applied across diverse disciplines like industrial, urban, political and social since its inception (Broto et al., 2012). Secondly, there is a lack of consensus on the originator of urban metabolism, leading to diverse interpretations (Sanches and Bento, 2020). For example, Kennedy et al.,(2011) define urban metabolism as the combined technical and socio-economic processes in cities that drive growth, energy production and waste elimination. However, Currie and Musango (2017) challenge this definition arguing that it lacks holistic perspective by focusing solely on industrial ecology. Currie and Musango (2017) define urban metabolism as the complex socio-technical and socio-ecological processes governing material, energy, people and information flows within a city. This broader

perspective includes all urban resource flows. However, due to its complexity, researchers often focus on specific aspects and proposed their own operational definitions.

This study uses Renouf et al.,'s (2017) definition of urban metabolism describing it as the process of resources flowing through being transformed and consumed in an urban area to support technical and socio-economic processes. This widely accepted definition helps to extract the definitions of specific urban metabolism aspects like urban water metabolism. Urban water metabolism refers to the process of water inflow and outflow within an urban system. It examines the consumption, distribution and disposal of waste water from the source to the end users (Renouf et al., 2017).

2.1.2 Evolution of Urban Metabolism

The evolution of urban metabolism has been shaped by various intellectual influences across different fields and periods, resulting in no clear consensus on its pioneers. Kennedy et al., (2011) credit engineer Abel Wolman with conceptualizing urban metabolism in 1965. Wolman hypothesized about a one-million-person American city, aiming to quantify the water, nutrients, and waste produced by its inhabitants. In contrast, Zhang (2013) argues that Karl Marx was the first to explore urban metabolism, examining the interaction between society and the natural environment, which he termed “social metabolism”. Derrible et al., (2021) report that Theodor Weyl, a German chemist and medical doctor known for his expertise in chemistry, sanitation, and waste management, was a pioneer of urban metabolism. In 1894, Weyl published an article titled "Essay on the Metabolism of Berlin," which aimed to quantify the consumption of water, food, and nutrients in the German capital.

Contrarily, Bahers et al., (2022) suggest that Burgess (1925) might be the first to utilize the urban metabolism concept. Burgess suggests that urban spatial development mirrors a process of construction-deconstruction or organization-disorganization. Bahers et al., (2022) argue that this process resembles the anabolism and catabolism observed in biological metabolism. Over many years, urban metabolism has been a subject of study in both social and natural sciences. Kennedy et al., (2011) delineated the course of urban metabolism development into three distinct epochs. The first epoch, dubbed the 'urban metabolism inception period, emerged in the 1970s. During this time, the concept of

biological metabolism was introduced to urban contexts, with notable figures such as Wolman (1965), Karl Marx (1889) and Odum (1996). The second epoch, beginning in the 1980s, is often characterized as a decline period marked by a lack of significant advancements in urban metabolism studies.

Conversely, the third period, emerging in the 1990s and known as the 'resurgence period,' witnessed a revitalization of interest in urban metabolism, leading to its expansion into various fields. Initially urban metabolism rooted in natural science studies, it gradually broadened its thematic scope. For instance, Engineer Abel Wolman (1965) pioneered the application of urban metabolism concepts in quantifying water consumption through material flow analysis (MFA). Similarly, Theodor Weyl (1894) investigated the urban water and food metabolism in Berlin, contributing to the natural science perspective of urban metabolism (Lederer and Kral, 2015).

Burgess (1925) stands out as an early contributor to urban metabolism, known for his influential concentric land use model. Burgess proposed a spatial organization of social classes within cities based on income levels, suggesting that different social groups exhibit distinct lifestyles and resource consumption patterns. He related this spatial distribution of different social group incomes and their incomes with urban metabolism consumption pattern. Additionally, the concept of social metabolism is closely linked to the work of Karl Marx. Marx introduced the notion of 'social metabolism' in the early 19^{th} century, using it to describe how human activities were altering natural landscapes and exploiting materials at an unprecedented rate. Marx argued that human beings played a significant role in reshaping the natural landscape, leading to what he termed a "metabolic rift." This over-exploitation of resources resulted in ecological imbalances and disrupted ecological services (Broto et al., 2012).

Over time, urban metabolism concepts have gradually conjoined into two complementary schools of thought. The first, known as 'Odum's school of thought,' was pioneered by American ecologist Howard Thomas Odum (1996). Odum focused on studying energy metabolism by utilizing solar energy equivalents, known as emergy. The second school of thought revolves around material flow analysis. This approach allows for the quantification of water, material, and nutrient consumption across different spatial scales

(Broto et al., 2012). In alignment with the objectives of this research, which aim to analyze urban water metabolism within the city using urban water metabolism frameworks, hence, this study bases on the material flow analysis approach.

2.1.3 Conceptualizing Urban Metabolism as Analogy to Organism or Ecosystem

Urban metabolism studies have been fundamentally influenced by two key analogies such as the organism analogy and the ecosystem analogy (Table 2.1).

Table 2.1 Differences between 'organisms' analogy and 'ecosystem' analogy

Criteria	**Organism**	**Ecosystem**
Analogy	Biology	Ecosystem ecology
Field of focus	Life processes	Abiotic / biotic interactions
Metabolism meaning	Food/waste	Energy processing and production
Movement	Input-output	Feedbacks
Scope	Black box	Sub-systems
Environmental context of city	Separate but connected	Integrated social-biological-physical

(Source: Adopted from Broto et al., 2012)

The organism analogy compares urban centers to human bodies. In this perspective, urban resource consumption parallels the linear resource flow of the human body, following the 'take-make-dispose' pathway (Moreno et al., 2016). The linear resource flow metaphor, which views waste as a non-useful asset, contradicts sustainable resource consumption goals (Velenturf and Purnell, 2021).The ecosystem advocates for a circular model of resource flows (Broto et al., 2012). The ecosystem metaphor views waste as a valuable asset, shifting from the linear 'take-make-use-dispose' mindset to a circular 'take-make-use-remake' approach. This perspective, which aligns with circular metabolism resource consumption principles, suggests that all outputs can serve as inputs (Lucertini and Musco, 2020 ; Feiferytė-Skirienė and Stasiškienė, 2021).

2.1.4 Urban Metabolism Types and Their Links With Sustainability

Urban metabolism has two primary models called linear and circular (Figure 2.1 and 2.2). The linear model uses resources once and disposes of waste directly into the environment. In contrast, circular metabolism adopts a closed-loop approach, emphasizing reuse and recycling to minimize waste and the environmental impact (Velenturf and Purnell, 2021). Circular metabolism model views waste as a resource, promoting sustainable consumption and follows natural ecosystems(Currie and Musango, 2017). Circular metabolism reduces

dependence on external resources (Currie and Musango, 2017; Mazzarella and Amenta, 2022). Circular metabolism follows a "take-make-use-remake" path, requiring a new economic model for waste reuse and recycling. Thus, the circular metabolism framework aligns with the principles of a circular economy, treating waste as valuable asset (Velenturf and Purnell, 2021 ; Mazzarella and Amenta, 2022). While linear metabolism disregarded waste as potential resources (Kennedy et al., 2011 and Musango et al., 2017). Linear metabolism follows 'take-make-dispose' pathway (Moreno et al., 2016).

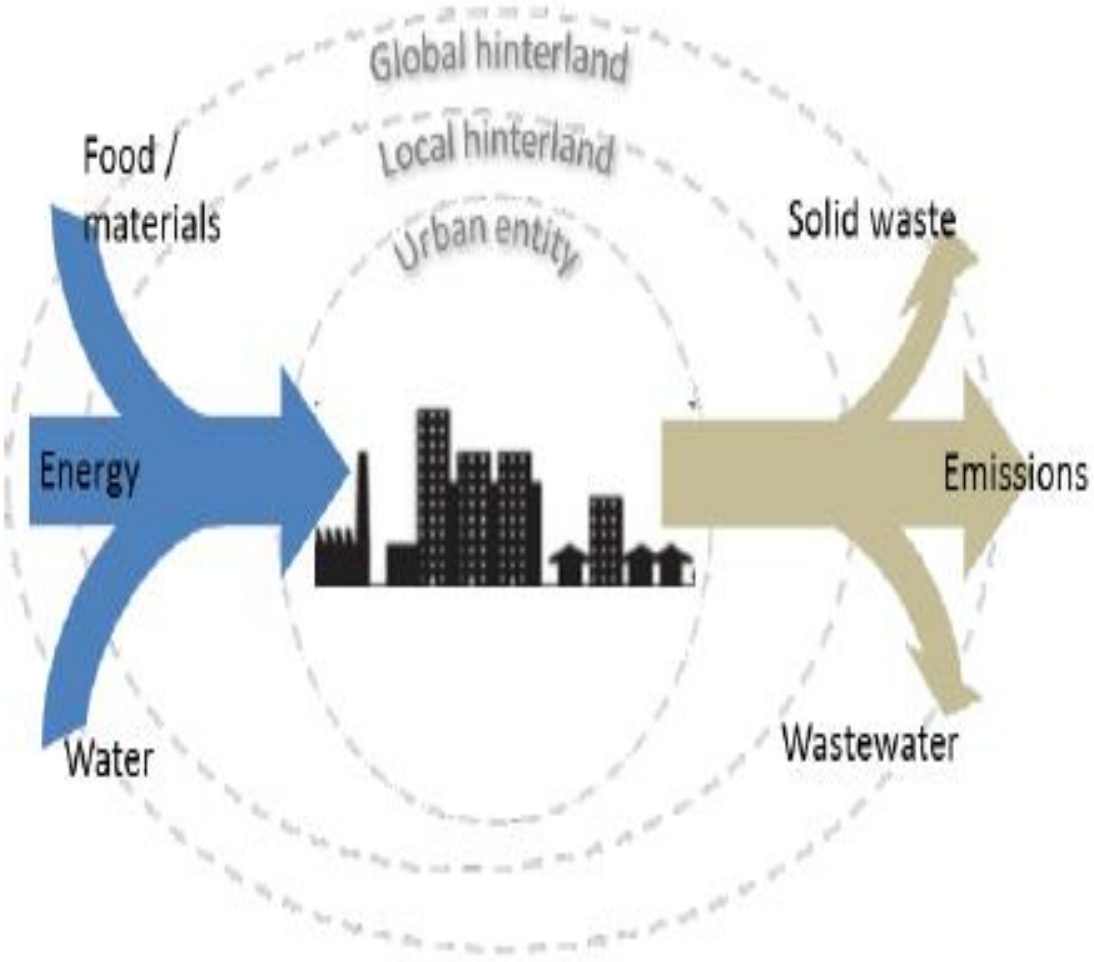

Figure: 2.1 Linear urban metabolism (Renouf et al., 2016)

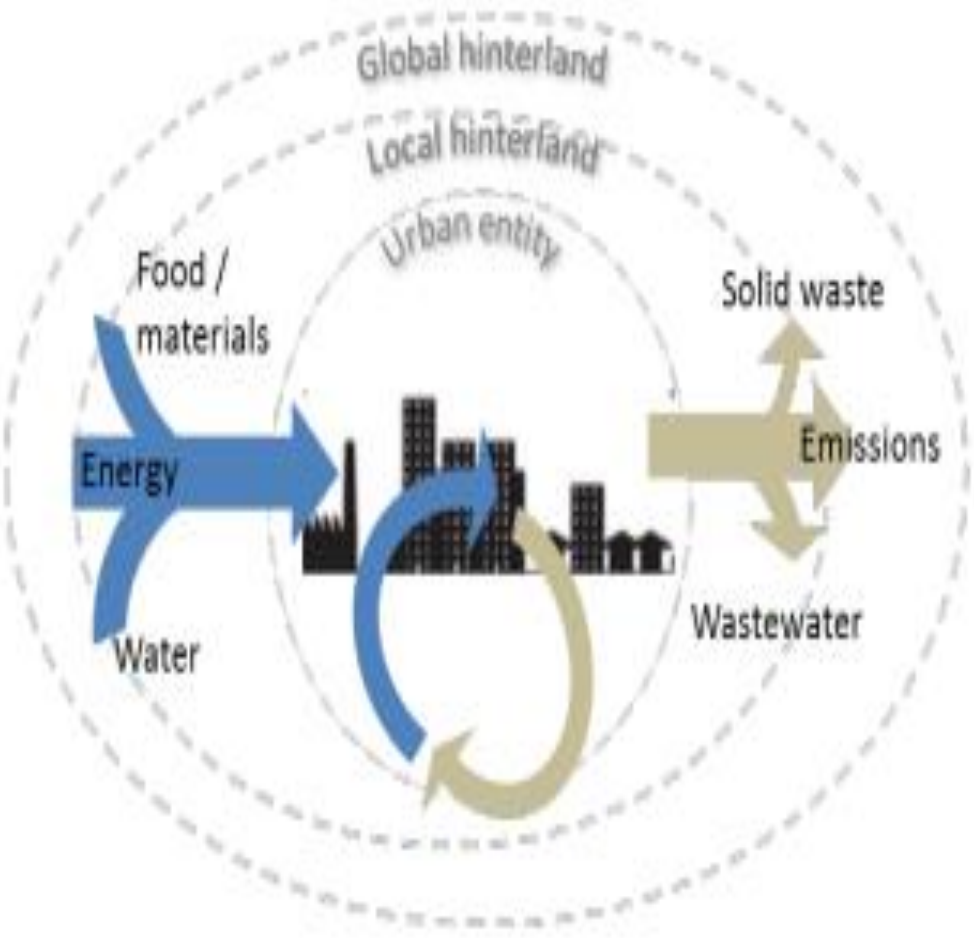

Figure 2.2 : Circular urban metabolism (Renouf et al., 2016)

In today's urbanization, urban areas heavily rely on hinterland resources, leading to significant environmental impacts due to linear resource consumption (Renouf et al., 2017). To address this, a shift to circular metabolism is essential. This approach advocates for resource reuse and recycling, promoting urban self-reliance and reducing waste. Like ecosystems where resources are continuously recycled, circular metabolism offers a sustainable pathway for the entire urban development (Currie and Musango, 2017; Mazzarella and Amenta, 2022).

2.1.5 Water Stress and Water Scarcity

Water-related problems frequently involve terms such as water scarcity, water stress, and "water risks" (Schulte and Morrison, 2014; Falkenmark, 1989 ; UNICEF, 2021 and Peter

Schulte, 2024). Water stress describes a condition where fresh water supply is insufficient to meet the needs of humans and ecosystems. Unlike water scarcity, it accounts for various physical factors such as accessibility and environmental considerations, offering a more comprehensive view (Schulte and Morrison, 2014 ; Peter Schulte, 2024). Water scarcity quantifies available water in relation to human consumption by comparing water usage with the amount accessible in a specific area. This measurable concept provides a consistent way to assess water availability across various locations and times (Peter Schulte, 2024).

Water scarcity can be categorized as economic and physical. Physical water scarcity happens when water resources are overused, making them unsustainable, while economic water scarcity results from poor governance, inadequate infrastructure and limited resources (UNICEF, 2021). According to Falkenmark (1989), an area is considered water-stressed if its freshwater supply is below 1,700 m^3 per capita annually and water-scarce if below 1,000 m^3 per capita annually.

2.1.6 Urban Water Consumption Types and the Notion of End Uses of Water

According to The U.S. Environmental Protection Agency(EPA) (2009), urban water consumption is categorized into residential and nonresidential sectors. Residential water consumption, often referred to as domestic water use, includes indoor and outdoor water usage within residential settlements. Nonresidential water consumption encompasses industrial, commercial, and institutional water use. The commercial sector comprises establishments such as hotels, pensions, restaurants, car washes, cafés, and office buildings. The institutional sector includes public facilities that provide essential services, such as schools, health centers, religious institutions, municipal services and government buildings. Lastly, the industrial sector covers manufacturing and various industrial activities, including heavy and light industry.

In both sectors, water consumption can be categorized into indoor and outdoor uses. Indoor water usage includes activities such as showering, flushing toilets, washing clothes, washing dishes, drinking, and cooking. Outdoor water usage involves activities like car washing, lawn watering, swimming pool services, and watering plants (Water Resources Mission Area, 2019).

The concept of water end uses refers to the specific purposes for which water is consumed by various fixtures and appliances in both indoor and outdoor service areas. Indoor uses include activities such as flushing toilets, showering, bathing, washing clothes, dishwashing, drinking, and food preparation. Outdoor uses encompass watering lawns and gardens, swimming pool services and cleaning outdoor areas (DeOreo et al., 2016; Gato-Trinidad et al., 2011). Appliances that belongs to each water end use are categorized based on flow rate (showers and faucets) and flush volume (toilets) (Pensiri et al., 2016).

2.1.7 Spatial and Non-Spatial Water Consumption Determinants

Water consumption is shaped by a range of factors broadly categorized as spatial and non-spatial. Spatial factors refer to location-specific factors that shape water consumption patterns. Non-spatial factors encompass demographics, socio-economic conditions, consumer behavior and technological inputs that drive urban water consumption pattern regardless of location(Tesfay et al., 2024). Spatial factors influencing water consumption can be broadly categorized into three main components. First, topographic factors encompass physical features of the urban settlement, including slope, aspect, topographic position index, and topographic roughness index mostly governs the water supply flow pressure. Second, climatic factors, including maximum and minimum temperatures and annual rainfall, directly influence daily water consumption patterns. Finally, morphological factors encompass the location and housing conditions of a parcel, including its proximity and accessibility to water sources, housing quality, classification as formal or informal, and the overall area of the parcel (Cominola et al., 2023; Mauro et al., 2021 ; Jorgensen et al., 2009). Non-spatial factors can also be categorized into three main pillars. The first pillar, demographic characteristics, includes factors such as family size, gender, age and educational background. The second pillar, economic aspects, focuses on household income levels and types of income sources. Lastly, the third pillar pertains to the availability of water-efficient appliances in households which significantly impact water consumption patterns (Addo, 2018; Llausàs and Saurí, 2017; B. S. Jorgensen et al., 2013 ; Babel and Shinde, 2011).

2.1.8 Urban Water Security

Understanding and measuring urban water security is crucial for effective water management (Babel et al., 2020; WaterAid, 2012; Nathaniel and Roger, 2012; Khan et al., 2020 and UNICEF, 2021). Scholars have defined water security from various perspectives, such as household water security (Hailu et al., 2020 ; Wutich et al., 2017), environmental water security (Marttunen et al., 2019), water risk security (Jim and Borgomeo , 2013 ; Gheuens , 2019) and urban water security (Aboelnga , 2019 ; Zhu and Chang, 2020). These definitions differ in objectives, scope, and attributes and leads to non-uniform definitions. Meanwhile, UN-Water (2013) proposed inclusive definition and defines it as "the population's ability to ensure sustainable access to sufficient quality water for livelihoods, well-being, and socio-economic development". Depending on this inclusive definition, various authors have crafted their interpretations tailored to specific contexts and dimensions of water security (Hailu et al., 2020; Gheuens , 2019; Aboelnga , 2019 ; Zhu and Chang, 2020). This study adopts Aboelnga's (2019) framework, which assesses urban water security through drinking water, well-being, ecosystem health, climate impacts, hazards, and socioeconomic factors, aligning with the water-sensitive city vision (Figure 2.3).

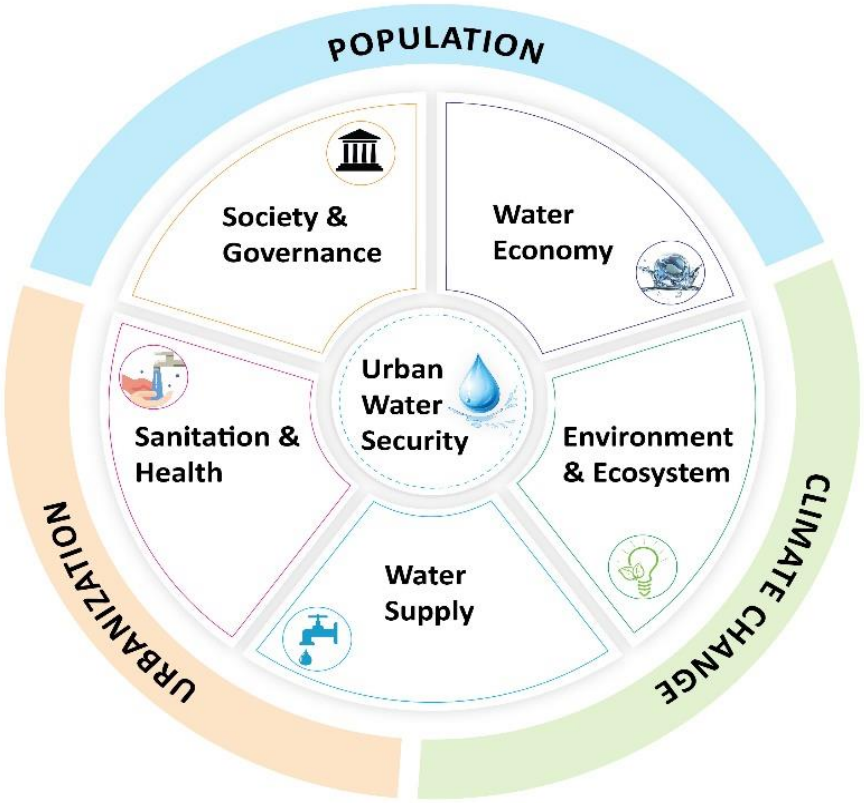

Figure 2.3 : Components of urban water security (adopted from UN-Water, 2013)

2.1.9. The Hydrological Cycle

The natural water cycle, or hydrological cycle, describes the continuous movement of water through the Earth's atmosphere and surface. It involves six key processes including evaporation, transpiration, condensation, precipitation, infiltration and runoff (National Oceanic and Atmospheric Administration, 2019). Mathematically, the cycle follows to the principle of mass conservation, which states that total water inflow (precipitation) must equal total outflow components (runoff, evapotranspiration and storage changes)(National Oceanic and Atmospheric Administration, 2019) (Equation 2.1)

$$P = Q + E + \Delta S \quad (2.1)$$

Were,

P= represents precipitation,

Q= denotes runoff,

E= signifies evaporation,

ΔS =indicates storage in soil, aquifers, or reservoirs.

2.1.10 Urban Water Metabolism Flow and Urban Water Mass Balance

In urban areas, water flows are categorized as anthropogenic or natural(Farooqui et al., 2016). Anthropogenic water flows, managed by urban water infrastructure, include water supply, consumption, wastewater collection, treatment, recycling, and disposal. Natural flows which are part of the natural water cycle includes precipitation, stormwater runoff, infiltration, and evapotranspiration (Renouf et al., 2017; Farooqui et al., 2016). The urban water mass balance method quantifies water input and output flow within urban systems, assuming a steady state where total input (Q_i) equals total output (Q_0) (Kenway et al., 2011; Renouf et al., 2017) (Equation 2.2).

$$Q_i = Q_o \quad (2.2)$$

Where Q_i is the sum of all inputs and Q_o is the sum of all outputs (including losses). Furthermore, water stored (ΔS) within the urban entity can be formulated by Equation 2.3

$$\Delta S = Q_i - Q_o \quad (2.3)$$

$$\Delta S = (P+Cgw+Csw+Drw+Dgw+Dsw+Rw) - (ET+Ww+Rs+Gw+Cufw) \quad (2.4)$$

Where,

ΔS = Water stored or utilized by different subsystem
P = Precipitation or rainfall
Cgw = Centralized groundwater supply
Csw = Centralized surface water supply
Drw = Decentralized rainwater supply
Dgw = Decentralized groundwater supply
Dsw = Decentralized surface water supply
Rw = Recycled water
ET = Evapotranspiration
Ww = Wastewater flow
Rs = Stormwater runoff
Gw = Groundwater infiltration
Cufw = System loss

During the estimation of the urban water mass balance, the value representing water stored or utilized by different subsystems (ΔS) can either be positive or negative. A negative value of ΔS often occurs in urban areas when water demand surpasses the available supply. Additionally, factors such as urbanization, characterized by an increase in impervious surfaces that contribute to runoff, and climate change which can intensify evaporation rates can also lead to negative ΔS values (Oudin et al., 2018; Rodriguez Huerta et al., 2019; Banton et al., 2022).

2.1.11. Water Sensitive City and its Interventions

A Water Sensitive City advocates for a shift in urban water management from mere supply and wastewater disposal to adaptable systems that integrate various water sources, combine centralized and decentralized approaches, and offer diverse community water supply services (Renouf et al., 2017). It integrates sustainable water practices into integrated urban water management, recognizing the natural hydrological cycle and the complex interactions between urban development and water resources(Wong and Brown, 2009). The conceptual foundation of water-sensitive city interventions is based on two key pillars called integrated management and water sensitive urban planning interventions. The management interventions focus on reducing dependence on remote water sources by internalizing water use and diversifying alternative sources such as rainwater harvesting, stormwater runoff, and wastewater reusing and recycling. The water sensitive urban planning interventions emphasizes on water-centric land use planning that protects water ecosystems, along with detailed urban design that incorporates water-saving structures and promotes community engagement in conservation practices (Suresh etal.,2017; Sharifian et al., 2022; Renouf et al., 2017).

2.2 Theoretical Review

2.2.1 Ecosystem Theories and Urban Metabolism

Urban metabolism analysis is commonly linked with key ecological theories, including Metabolic Rift, Urban Ecology, Industrial Ecology, and Urban Political Ecology. These theories help to understand resource flows from the eye of environmental and socio-political impacts. Integrating these theories in to the concept of urban metabolism helps to understand the resource flows from multiple ecosystem dimensions(Pincetl et al., 2012; Nalini and Dutt, 2023 ; Perrotti, 2020). The following section presents the description of each theory in line with the urban metabolism perspectives.

Metabolic Rift Theory: Metabolic Rift Theory, developed by Karl Marx and expanded by John Bellamy Foster (1867) provides a new perspective on social metabolism, highlighting how urban communities become disconnected from their environment due to excessive resource consumption. This process involves extracting natural resources for urban life and disposing of waste in a linear fashion. The theory explains how this leads to resource depletion and aggravates social inequality in urban areas.

The Urban Ecology Theory: Urban ecology theory analyzes the interaction between urban society and the urban landscape, focusing on resource flows and the impacts of resource extraction from the environment (Wilson, 1984 ; Golubiewski, 2012).

Industrial Ecology Theory: Both urban metabolism and industrial ecology aim to optimize resource use. Industrial ecology focuses on maximizing efficiency in industrial processes, while urban metabolism extends this to energy consumption and transformation in urban systems, striving to enhance energy efficiency (Wang et al.,2023). Industrial ecologists use the metabolism metaphor to quantify material and energy flows in urban systems, aiming to reduce material consumption through techniques like Material Flow Analysis (MFA) (Broto et al., 2012).

Urban Political Ecology: Urban political ecology explores how power dynamics and political-economic structures shape resource flow, including distribution, production, and waste management. It underscores the impact of governance systems, like zoning regulations, and exposes social inequities in resource access, crucial for achieving equitable urban development (Newell et al., 2014 ; Wachsmuth, 2012).

The three urban ecology theories provide insights into urban water metabolism. Urban ecology examines the effects of urbanization on water ecosystems and resources. Industrial ecology analyzes water consumption, wastewater generation, and opportunities for reuse, offering a framework for evaluating water security and human well-being. Political ecology focuses on water security through socioeconomic factors such as tariffs, affordability, and governance and highlighting disparities among social groups.

2.2.2 Systems Theory

A system can be defined in various ways depending on the discipline, but the common thread is that it involves two or more independent elements that are interconnected and work towards shared goals. In essence, a system can be viewed as an entity composed of interrelated or interdependent parts (ScottL, 2015). The system theory also emanates from the aforementioned premises that Systems theory is a multidisciplinary approach that explores complex systems across nature, society, and science by focusing on the interactions and relationships among their components (Mariana , 2024). Similarly, Wilkinson et al., (2021) describe systems theory as the study of system components within the context of their relationships, rather than examining them in isolation. Systems theory can be divided into open and closed systems. Open systems interact with their environment and freely exchange resources, while closed systems are more rigid, with very limited interaction or exchange with their surroundings (Serrat, 2021).

An ecosystem is modeled as an open system characterized by circular interactions between biotic and abiotic components, allowing for the free exchange of resources (Derrible et al., 2021). Similarly, an urban ecosystem views urban areas as open systems where interactions with the natural environment support urbanization by sourcing resources like water from the ecosystem (Wang and Dong, 2023). Pincetl et al., (2012) recognized that urban areas function as open systems, exchanging water, energy, food, and waste with surrounding regions. This concept aligns closely with urban metabolism, which examines the flow of resources within the boundaries of urban systems. Similarly, Paola (2021) emphasized that urban metabolism considers urban centers as open systems that exchange resources such as water, energy, food, and materials, while also disposing of waste into the environment. In urban ecosystem theory, complex adaptive systems (CAS) are also

considered. Complex systems involve diverse interactions that are highly dynamic (Ahmad et al., 2024). The adaptive aspect refers to the ability of individuals and groups to adjust their behaviors in response to changes arising from these complex interactions (Sammut , 2015). Hence, the study learnt that urban areas function as open systems characterized by complex interactions with the environment to obtain resources like water.

2.2.3 Water Sensitive City Principles

A water-sensitive approach goes beyond traditional urban water management, which often focuses just on alternative water sources. It emphasizes diversifying water sources within the urban system and reducing reliance on external sources (Renouf et al., 2017). The vision for a water-sensitive city promotes adaptable systems integrating various alternative water sources through decentralized and centralized approaches. It is based on three principles called city as water supply catchments, cities providing ecosystem services, and water-sensitive communities (Wong and Brown, 2009) (Figure 2.4).

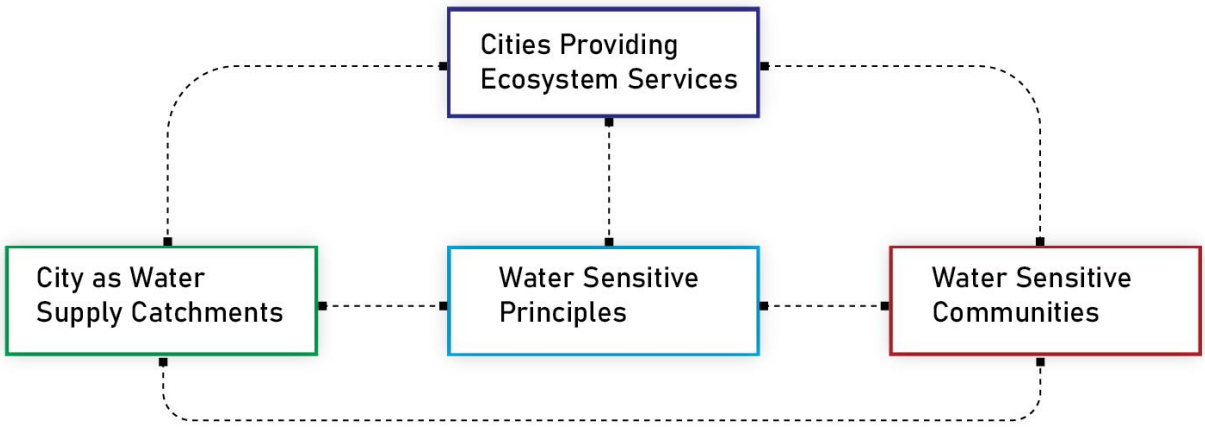

Figure 2.4 : Water sensitive city principles (constructed by the researchers, 2023)

The principle of city as water supply catchments" emphasizes that urban areas can be self-sufficient by generating alternative water sources within their boundaries, supplementing traditional sources. The principle of cities providing ecosystem service highlights urban areas potential to enhance urban ecology by protecting water bodies, integrating green infrastructure, enacting water-conscious planning, and encouraging public participation in maintaining urban environments. The principle of water-sensitive communities promotes a water-conscious mindset and culture. These communities improve attitudes toward water

conservation by embracing diverse alternative sources such as rainwater, stormwater runoff, greywater, and recycled wastewater. By raising awareness, they play a vital role in sustainable water management through water wise consumption and conservation practices.

2.2.4 Water-Sensitive Urban Planning

Water-sensitive planning is a water-centric approach that includes four key pillars such as spatial planning that integrates land use to protect wetlands and support water-sensitive urban design (Renouf et al., 2017); community education to foster a culture of water conservation (Wong and Brown, 2009); a legal framework with regulations for water conservation and sustainable urban design (Fenemor, 2017) ; and technology, such as water-saving devices that can cut consumption by 30-40% (Kenway et al., 2011). These pillars collectively support sustainable urban water management by promoting water-sensitive urban designs, efficient use of water, diversified supply sources like rainwater and stormwater harvesting, and wastewater recycling. Guided by urban metabolism analysis, these strategies encourage decentralized water sources, green infrastructure to reduce runoff, and resource recovery to lower water footprints. Community engagement initiatives further strengthen local stewardship of water resources, ensuring integrated and resilient urban water management (Figure 2.5).

Water-sensitive land use planning is an approach that encompasses the preparation of large-scale city master plans and local development plans at the neighborhood level. This approach is always supported by water-centric strategies aimed at ensuring sustainable water management within urban landscapes through land-use designations. These strategies can extend to watershed protection, wetland conservation, flood control, and the promotion of low-impact urban development scenarios(Serrao-Neumann et al., 2019; Renouf et al., 2018; Atkins et al., 2021; Steven J. Kenway et al., 2022). Literature highlights several key aspects of water-sensitive physical planning, such as integrated water management, which is practically implemented through the management of stormwater, subsurface water, and wastewater in the urban landscape. Flood mitigation is another important component, alongside water conservation and ecological restoration, all

of which form essential parts of water-sensitive land use planning(Zanjani et al., 2021; Kennedy et al., 2011; Pistoni and Bonin, 2017 ; Dar et al., 2023)

A water-sensitive community focuses on fostering a culture of water conservation both indoors and outdoors, as well as protecting water infrastructure, sources, and ecosystems on a larger scale. The primary goal of such a community is to engage individuals and implement conservation practices. This includes simple actions such as turning off running taps, stopping flowing showers, repairing old fixtures, and recycling water. The community plays a crucial role in maintaining the balance between urban water demand and available sources through various conservation techniques. In this regard, raising awareness through different educational mechanisms is vital. Incorporating water-conscious knowledge into school curricula can help build a new generation that is more mindful of water use(Wang et al., 2023)

Water-sensitive technology encompasses products and innovations designed to manage water consumption and transformation in a sustainable manner. These technologies aim to enhance efficiency by minimizing wastage during transmission and end-use. Applications include rainwater harvesting, wastewater treatment, smart landscape watering, and advanced irrigation systems. In water-sensitive urban design, these technologies also involve creating permeable urban surfaces that allow water infiltration to recharge groundwater. Overall, these technologies play a crucial role in conserving freshwater resources and mitigating water stress(Wang et al., 2023; Fu et al., 2023)

Water-sensitive legal frameworks focus on laws, regulations, and regional and national policies that guide sustainable water management and planning. These frameworks originate from national policies addressing water resource management across various spatial scales. Typically, they emphasize water rights and allocation, water quality standards, urban design regulations, water infrastructure development codes, and the roles and responsibilities of sectors directly or indirectly involved in water resource management(Global Water Partnership (GWP), 2024)

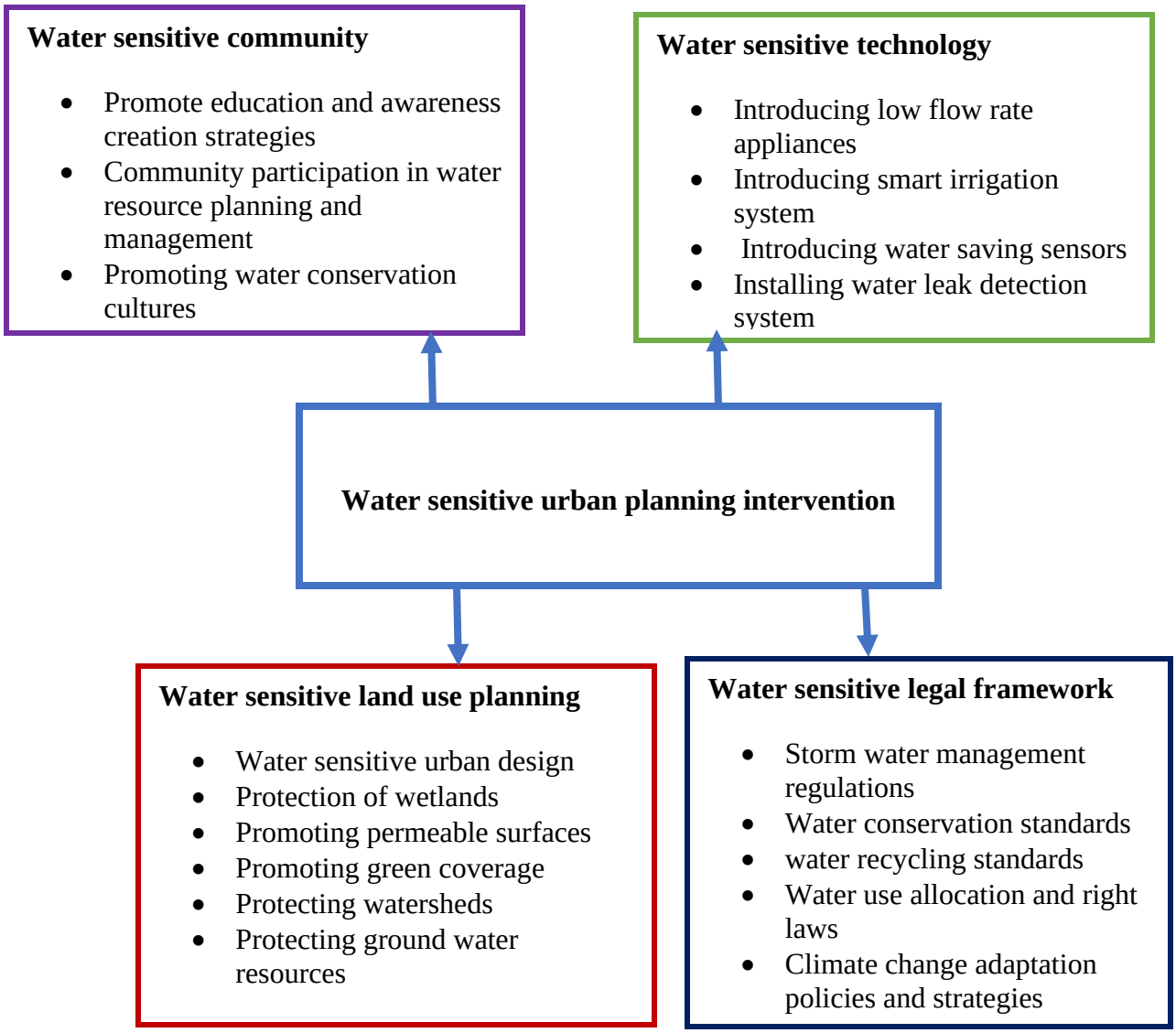

Figure 2.5 : Water sensitive city intervention dimensions (Constructed by the researcher and adopted from Renouf et al., 2017)

2.2.5 Urban Water Management Transition Framework

Traditional water management approaches are increasingly seen as too rigid for the dynamics of urbanization, highlighting the need for innovative policies. In response, Australian researchers developed the "Urban Water Transitions Framework," outlining six phases' cities undergo to achieve improved water resilience (Figure 2.6). This framework guides urban water planners in identifying sustainable city characteristics and necessary strategic enhancements in capacity and institutional structures for resilient water management (Brown et al., 2016).

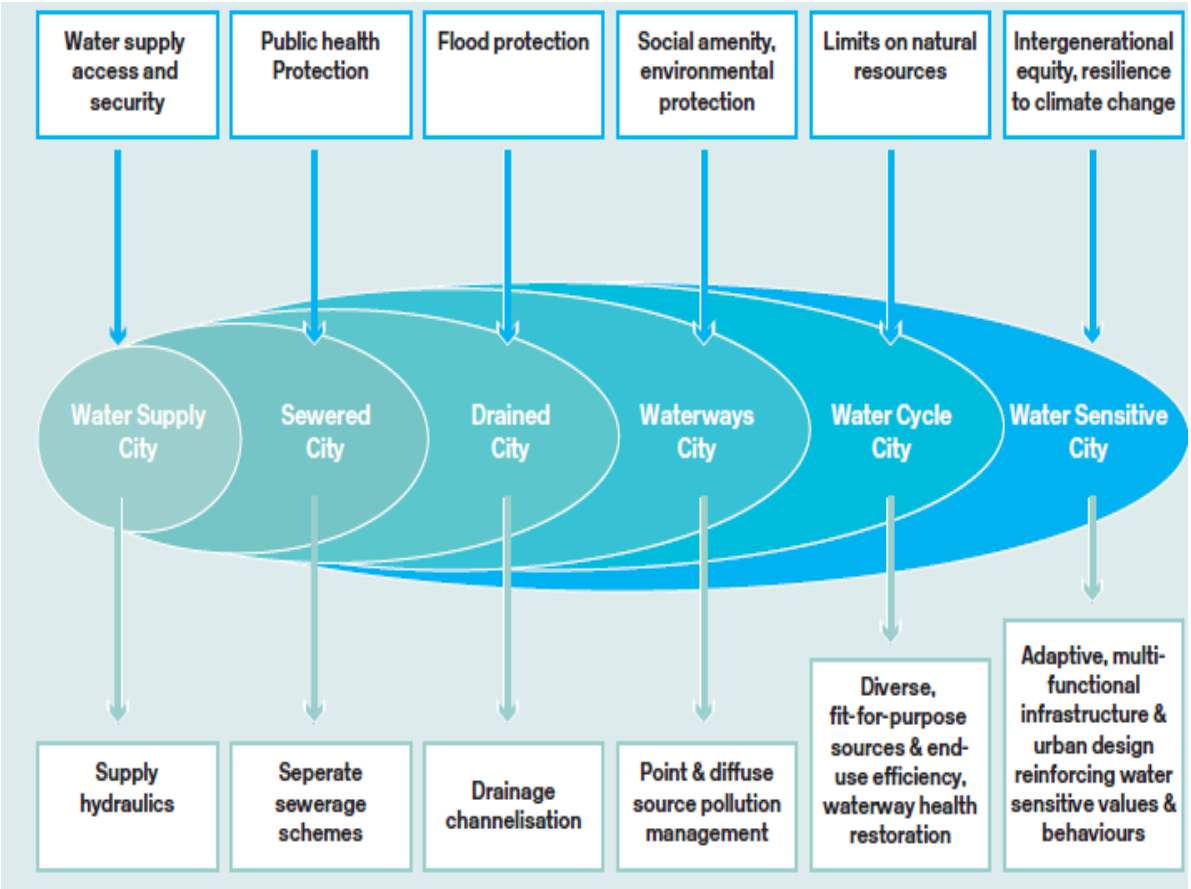

Figure 2.6 : Urban Water Transitions Framework (Brown et al., 2009)

The first phase, Water Supply City, relies on centralized water systems like pipes and reservoirs. However, rapid population growth, urban expansion, and climate change can lead to water scarcity and urban water insecurity necessitating alternative water sources. The second phase, Sewered City, enhances public health by introducing sewerage systems to manage effluents and prevent waste-related diseases. The third phase, Drained City, focuses on flood protection by channeling rivers and managing stormwater, freeing floodplains for urban expansion. In this phase, the community expects affordable water, sewerage, and drainage services. The fourth phase, Waterways City, acknowledges the environmental impacts of water extraction and waste treatment. Urban planners integrate water management into city planning, focusing on preserving water bodies. Efforts include reducing excessive freshwater extraction and protecting water bodies with bio-filtration systems such as rain gardens and artificial wetlands.

In the fifth phase, Water Cycle City, conservation focuses on using diverse sources like stormwater and recycled wastewater. Sustainability is driven by collaborative efforts among government, businesses, and communities. The sixth phase, Water Sensitive City, adopts a holistic approach, balancing urban water needs with livability. It emphasizes water health, flood risk reduction, and green spaces that reuse water. Flexible infrastructure and technology reflect the interaction between society and technology, with active community engagement in water management.

2.2.6 Urban Metabolism Evaluation Framework (UMEF4Water)

The Urban Metabolism Evaluation Framework for Water (UMEF4Water), developed by the Cooperative Research Centre for Water Sensitive Cities, integrates water management with urban planning. It offers a comprehensive view of urban water dynamics, aiding land use and water resource managers in making informed decisions, optimizing water systems, and guiding urban development (Renouf et al., 2017).

According to Renouf et al., (2017), the Urban Metabolism Evaluation Framework for Water (UMEF4Water) applies urban metabolism principles and urban water mass balance for quantification. It enhances techniques for defining urban system boundaries, measuring water flows, and evaluating water performance with precise indicators. By integrating urban planning and water cycle modeling, it offers a valuable evaluation tool for planners and water managers. The framework involves four stages including defining system boundaries, collecting data on water flows, quantifying a water mass balance, and deriving performance indicators (Figure 2.7).

In the Urban Metabolism Evaluation Framework for Water (UMEF4Water), the system boundary varies by scale, such as city-wide or watershed level. Data collection includes both anthropogenic water flows and natural hydrological flows. The framework calculates water mass balance by measuring inflows, outflows, and storage changes. It then measures urban water metabolic performance using indicators grouped into three parameters which includes “water consumption efficiency,” “supply internalization,” and “protecting hydrological flows”

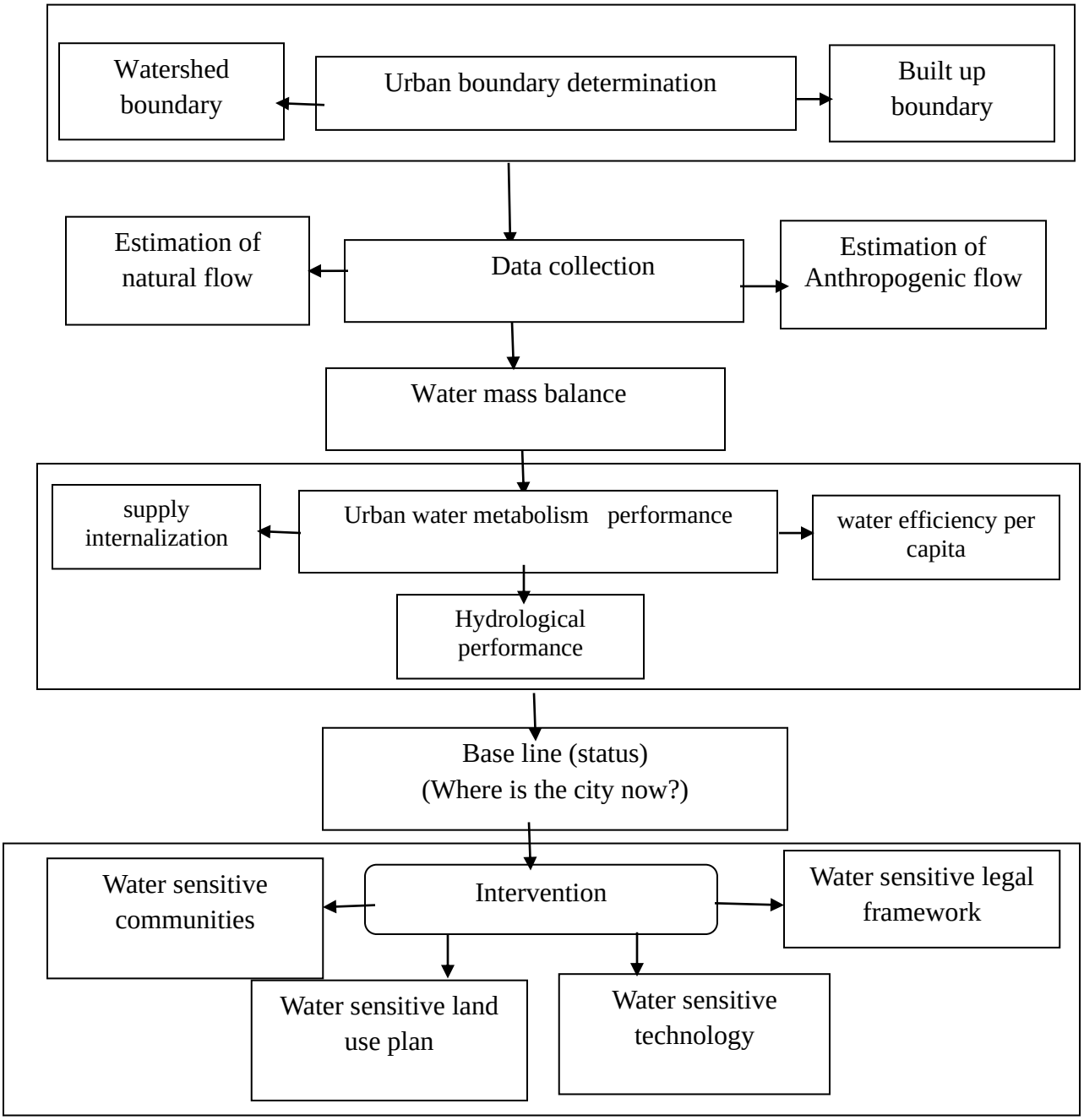

Figure 2.7 : Urban Metabolism Evaluation Framework (Renouf et al., 2017)

2.3 Empirical Literature Review

2.3.1. Water Stress Indicators and Quantification Methods

(i) Falkenmark Indicator and its Thresholds

The Falkenmark index, recognized as the most well-known water stress measure (McNally et al., 2019). It was first introduced by Falkenmark in 1986. The Falkenmark index measures the comparison between a country's total freshwater resources and its population, expressed in cubic meters per capita per year (Equation 2.5).

$$\text{Falkenmark indicator} = \frac{\text{Annual runoff}}{\text{Population size}} \tag{2.5}$$

(ii) Fresh Water Withdrawal-to-Availability Ratio (WTA)

The withdrawal-to-availability ratio (WTA), pioneered by Raskin et al., (1997) and elaborated by Rijsberman (2006) is prominent indicator of water stress. This index defines water stress by comparing the total annual withdrawals of freshwater for domestic (D), industrial (I), and agricultural (A) purposes to the mean annual renewable water resources (MARR) (FAO, 2018) (Equation 2.6).

$$\textbf{Fresh Water Withdrawal to Availability Ratio (WTA)} = \sum_{n=1}^{n} \left(\frac{(\text{DIA})}{MARR} \right) \tag{2.6}$$

Table 2.2 Water stress indicators and their thresholds

Type of indicator	category	Implications for water stress
Falkenmark Indicator	>1,700 m^3 per capita /year	no stress
	1000-1700 m^3 per capita /year	stress
	500-1000(m^3 per capita /year	scarcity
	<500 m^3 per capita /year	absolute scarcity
Fresh Water Withdrawal-to-Availability Ratio (WTA)	<20%	no stress
	20-40%	Moderately stressed
	>40%	'Severely stressed'
Freshwater withdrawal-to-availability ratio (WTA) with environmental water Requirements	0-20%	no stress
	25- 50%	low stress
	50-75%	medium stress
	75-100%	high stress
	>100%	critical

(Falkenmark, 1986 ; Rijsberman, 2006 ; Smakhtin et al., 2004)

(iii) Fresh Water Withdrawal-to-Availability Ratio (WTA) with Environmental Water Requirement

The water stress index, developed by Smakhtin et al.,(2004), refines the withdrawal-to-availability ratio by incorporating environmental water requirements (EWR). Endorsed by the UN as an indicator of sustainable water use, it measures the ratio of total freshwater withdrawals (TFWW) to total renewable freshwater resources (TRWR), adjusted for environmental flow requirements usually represent 20-50% of TRWR (Eqaution2.7).

$$\text{Fresh Water Withdrawal-to-Availability Ratio (WTA)} = \frac{\text{TFWW} * 100}{\text{TRWR} - \text{EFR}} \qquad (2.7)$$

2.3.2 Water Security Indicators and Quantification Methods

Measuring water security aids to generate quantitative water management evidences for strategic decision support system (Hoekstra, 2018; Dickson et al., 2016). Measuring water security process heavily relies on indicators (Jensen and Wu, 2018 ; Mishra et al., 2021). Depending on the objective of their studies, researchers use various measurement indexes such as water stress (Falkenmark,2001;Vörösmarty et al., 2005; Smakhtin et al., 2004), water resource vulnerability (Chhetri et al., 2020 ; Hung et al., 2021), economic water scarcity (Damkjaer and Taylor, 2017), and water poverty (Sullivan, 2002). At the city level, indicators such as the City Blueprint index (Leeuwen et al., 2012 ; Koop and Leeuwen, 2015), the Sustainable City Water Index (Arcadis, 2016), and Urban Water Security Indices (Aboelnga et al., 2020; Aboelnga et al., 2019; Zeitoun et al., 2016 ; Jensen and Wu, 2018).

Developing robust water security indicators requires integrating various metrics and potentially adding new variables (Aboelnga et al., 2020, Aboelnga et al., 2019 and Zeitoun et al., 2016).The Integrated Urban Water Security Index (IUWSI), proposed by Aboelnga et al. (2019) and tested in water stress developing countries, is a recognized method for quantifying urban water security. It categorizes indicators into drinking water and human well-being, ecosystems, climate change and water-related hazards, and socioeconomic factors. The IUWSI employs the analytic hierarchy process (AHP) to rank and weigh the influence of various indicators on overall water security. Zeitoun et al.

(2016) also categorized urban water security into five grades such as poor, fair, reasonable, good, and excellent.

Water security is assessed on a grading scale where each range signifies a different level of security and management effectiveness. A score below 1.5 is classified as "poor" indicating that water security is insufficient to meet basic human needs, with significant challenges due to inadequate governance and management across all areas. A score between 1.5 and 2.5 is considered "fair," suggesting that while water security is not as poor, significant concerns still persist across multiple dimensions. The "reasonable" category, with scores ranging from 2.5 to 3.5, implies that water security meets basic needs but has shortcomings affecting resilience and sustainability. Scores from 3.5 to 4.5 are rated as "good," reflecting that effective policies and management ensure urban water security across most dimensions, though some areas still need improvement. Lastly, scores beyond 4.5 are labeled as "excellent," indicating that the city is well-managed, water-secure, meets current demands, and is resilient to future risks, demonstrating high security across all dimensions. Appendix III details the indicators, variables, units, and scores for drinking water and human well-being, ecosystems, climate change and water-related hazards, and socioeconomic perspectives

2.3.3 Urban Metabolism Research Landscapes and its Advancement from Global Perspective

Urban metabolism research, initially influenced by pioneers like Abel Wolman (1965), Karl Marx (1983) Theodor Weyl (1894), and Ernest Burgess (1985), has seen a resurgence in recent decades. This field has expanded in scope, methodology, and interdisciplinary applications, driven by the need for cities to adopt sustainable and resilient resource consumption behaviors. The focus is on developing methods to quantify resource flows in urban areas and their surroundings(Kennedy et al., 2010; Zhang, 2013; Renouf et al., 2017 and Farooqui et al., 2016). Key thematic areas include the study of sustainable development through urban metabolism indicators.

(i) **The connection between urban planning and urban metabolism**: This area explores how urban planning and design can integrate to metabolic principles to enhance resource efficiency and sustainability (Zanjani et al., 2021; Kennedy et al., 2011; Pistoni and Bonin, 2017 ; Dar et al., 2023).

(ii) **Water-sensitive planning and urban metabolism**: This theme explores how urban metabolism intersects with water management to build urban areas that can better withstand and adapt to water-related challenges (Serrao-Neumann et al., 2019; Renouf et al., 2018; Atkins et al., 2021; Steven J. Kenway et al., 2022)

(iii) **Urban metabolism and environmental sustainability**: Researchers in this field investigate how urban metabolism can contribute to broader sustainability goals, ensuring that cities can support human and environmental health (Currie et al., 2015 ; Ulgiati and Zucaro, 2019; Céspedes Restrepo and Morales-Pinzón, 2018; Palme and Salvati, 2020 ; Raina et al., 2023 ; Guibrunet and Allen, 2014).

(iv) **Urban morphology and urban metabolism**: This area examines how the physical form of cities influences their metabolic processes, aiming to enhance resource flows and sustainability. These interconnected themes in urban metabolism research improve the understanding of how cities can achieve greater sustainability and resilience (Kolkwitz et al., 2023; Pinho et al., 2010; Heidi Scott; 2022; Weinstock, 2011).

(v) **Water-energy nexus and urban metabolism**: Understanding the interaction between water and energy in urban metabolism is crucial for developing sustainable urban infrastructure. Recognizing these interconnections allows cities to devise strategies that enhance resilience, optimize resource use, and promote sustainable development (Fan et al., 2019, S. J. Kenway; 2013; I. Chen, 2020 ; Hu et al., 2018).

Despite considerable progress over the past decades, research on water metabolism remains underexplored (Musango et al.,2017). Kennedy et al., (2011) for example, conducted an extensive review of urban metabolism studies and found that while the field has grown significantly in the last 15 years, urban water metabolism is still in its infancy. The review of 60 research papers revealed that only (5%) focused on water, with the remaining 95% addressing energy and other aspects of metabolism. Similarly Chen & Chen (2015) reviewed 30 urban metabolism studies and found that only (7%) dealt with water metabolism. This highlights the need for more research in this area, particularly

since existing studies are predominantly concentrated in developed countries. In developing countries, water metabolism remains un explored issue (Currie et al., 2015).

Urban metabolism has evolved into a robust framework for studying resource flows in cities (Kennedy et al., 2010; Renouf et al., 2017 ; Musango et al.,2017). Recent studies focus on analyzing resource consumption such as water, energy, and food and waste production in urban areas (Kennedy et al., 2010; Renouf et al., 2017). Urban metabolism research is grounded in two main approaches such as one based on Odum's work (1971), which uses energy equivalents solar or emergy (Kennedy et al., 2010), and another rooted in mass flux and material flow analysis (MFA), quantifies resource flows like water, food, and waste in terms of mass flux (Wolman, 1965; Kennedy et al., 2011). These perspectives complement each other and both aiming to measure urban sustainability (Pincetl et al., 2012).

Water metabolism studies have employed various approaches to enhance efficiency in urban centers. Lundie et al., (2004) used Life Cycle Assessment (LCA) to analyze Sydney's water supply, finding it essential for tracking and predicting water resource developments. Their study focused on inflows and outflows, treating the city as a black box. Paolini and Cecere (2015) examined water's role in urban development in Rome, identifying water as a key limiting factor. They advocated for water-centric urban planning and employed water-sensitive urban design (WSUD) and tissue analysis to study water metabolism.

Khalil and Attia (2015) investigated water metabolism in Cairo's informal areas, finding higher consumption in the central business district compared to peripheral informal settlements. Kennedy et al., (2011) emphasized water metabolism as crucial for sustainability. Serrao-Neumann et al., (2019) , Renouf et al., (2018) , Atkins et al., (2021) and Steven J. Kenway et al., (2022) emphasized urban metabolism as essential for urban planning and environmental assessment, stressing its importance for policymakers. However, urban metabolism studies in Africa face challenges such as inadequate municipal data and difficulties in tracing water flows (Currie and Musango, 2017).

Currie et al., (2015) ,Ulgiati and Zucaro (2019) , Céspedes Restrepo and Morales-Pinzón (2018) , Palme and Salvati (2020), Raina et al., (2023) and Guibrunet and Allen (2014)

emphasized that urban metabolism encompasses sustainability themes, helping to establish sustainability indicators that can develop decision support tools for decoupling resource consumption. According to Currie et al., (2015) , a major challenge for urban centers today is the persistent dependency on external ecosystem services, leading to unbalanced resource consumption. Chen and Chen (2015) expressed deep concern about resource consumption patterns, noting that inefficient metabolism negatively impacts sustainability. Additionally, current trends in resource consumption and waste disposal are exceeding the capacity of the surrounding environment(Ferronato and Torretta, 2019).

Gandy and Ltd (2004), Kolkwitz et al., (2023), Pinho et al., (2010), Heidi Scott (2022) and Weinstock (2011) work on urban morphology and urban metabolism. Gandy and Ltd, (2004), highlighted that water is not a simple material. It forms the base for the social fabric and acts as a network connector among city resource flows. However, the relationship among urbanization, space, and water has been shaped by conventional thinking and laissez-faire policies. Traditional water management approaches are proving inadequate in the face of rapid urbanization, steady resource consumption driven by population density, climate change, and higher living standards(Currie et al., (2015). Farooqui et al., (2016) argue that alternative water sources are essential to meet the growing water demand. To address this, it is essential to quantify water from various sources using metabolism methodology, as urban metabolism is key for tracking and measuring water flow in urban areas (Pincetl et al., 2012).

Renouf et al., (2017) introduced the 'Urban Metabolism Evaluation Framework' (UMEF4Water), which uses the urban water mass balance method to quantify water flow in cities and their surroundings. They argued that this approach offers a more holistic view than traditional supply-demand methods by evaluating the entire urban water system. Since then, various methods and frameworks have been developed to assess urban water sustainability. The next section reviews these approaches.

Urban metabolism, though an emerging concept, has rapidly become one of the fastest-growing fields in the contemporary world. Its advancement is reflected in interdisciplinary approaches, advancement in tracking resource flow visualization, planning and design

integration, metabolic metrology, smart urban metabolism and big data and metabolism (Dijst et al., 2018; Sven Eberlein ,2028; Rolf Halden, 2020 and Shahrokni et al., 2015).

Dijst et al., (2018) emphasized that urban metabolism was originally centered on the natural sciences, focusing on natural forces that determine resource flows, such as energy and material cycles. However, he argued that urbanization and industrialization are key factors influencing resource flow, including people, goods, and information. These factors directly and indirectly impact resource flows in urban areas. From this standpoint, he developed an interdisciplinary approach that integrates both the natural and social dimensions influencing urban resource flows.

Sven Eberlein (2018) argued that for a long period, urban metabolism remained an academic exercise and was not connected to real-world applications. However, urban metabolism has slowly advanced and emerged as a method of visualizing resources. This progress includes the development of Urban Metabolic Information Systems (UMIS), notably represented by Sankey diagrams.

Rolf Halden (2020) reported that urban metabolism metrology an emerging discipline, plays a crucial role in understanding the human condition in urban areas globally. The analysis of urban metabolism metrology is essential for gaining evidence-based understanding into the water cycle and the associated hydrological and meteorological information

Shahrokni et al., (2015) reviewed the progress of urban metabolism and highlighted that it faced data shortages due to its lack of integration with information technology. They also noted that urban metabolism was not effectively contributing to the advancement of smart city innovation.

Yamagata et al., (2020) emphasizes that when urban metabolism is supported by big data analytics, it becomes crucial to develop real-time resource monitoring systems. These systems can predict future resource needs, aid in urban planning, improve decision-making for policy development, and establish sustainability performance indicators for urban areas

2.3.4 Methods for Measuring Urban Metabolism

(i) **Material Flow Analysis (MFA)**

Material Flow Analysis (MFA), based on thermodynamic principles, tracks resource flows in urban areas by equating input flows with output flows plus stocks. It quantifies resource dynamics over time and space, especially useful for studying Urban Water Metabolism. Key indicators include total material consumption, water use, and waste generation. However, MFA faces challenges such as data scarcity at the local level and complications from dynamic administrative boundaries.

(ii) **Input-Output Analysis (IOA)**

Input-output analysis, as outlined by Musango et al., (2017) tracks material flows between economic sectors, focusing on resource flows related to products and sectors. It quantifies interconnections, identifies key drivers of resource use, and assesses how changes in one industry affect others.

(iii) **Ecological Footprint Analysis (EFA)**

This approach assesses the environmental impact of human actions, offering insights into sustainability and highlighting areas where ecological limits are exceeded.

(iv) **Life Cycle Assessment (LCA)**

Life Cycle Assessment (LCA) evaluates a product's entire life cycle, from resource extraction to disposal, by measuring energy, water, material use, and emissions. Standardized by ISO 14040, LCA helps identify sustainable production processes. Despite its value, LCA is resource-intensive and time-consuming, which can be challenging in data-scarce countries.

(v) **Hybrid Methods**

Each approach has its strengths and weaknesses, suggesting that no single method provides a complete understanding of metabolic activity. Many researchers advocate for hybrid approaches, combining either two or more of material flow analysis (MFA), life cycle assessment (LCA), and water footprint analysis (WFA) (Musango et al., 2017). While each method has its pros and cons, the choice depends on data availability and the resource in question. For this study, MFA is the most suitable, as it effectively tracks water flow within urban systems, providing valuable insights into consumption, usage patterns and resource flows.

2.3.5 Urban Water Consumption Modeling Techniques

Accurate, evidence-based models for predicting future water consumption are crucial for effective water management (Yousefi et al., 2020). Water consumption modeling has advanced significantly in recent decades (Thakur et al., 2023 and House et al., 2010). The models range from linear regressions to complex machine learning algorithms(Adamo et al., 2020). Generally, water consumption models can be categorized into deterministic and probabilistic models (Rezaali et al., 2021). Deterministic models use fixed rules or equations and historical data for predictions, resulting in a single outcome, with linear regression being a prime example (Power et al., 2007). In contrast, probabilistic models account for randomness and provide a range of possible outcomes rather than a single result (Simplilearn, 2013).

Machine learning stands out as a prominent application of probabilistic modeling (Rezaali et al., 2021).In essence, machine learning generates predictions, and its efficacy is measured by how well it generalizes to previously unseen data (KDnuggets, 2019). Recent developments indicate a proliferation of water consumption models, including Deep Neural Network (DNN), Machine Learning (ML), and Hybrid models. Presently, these models are geared towards identifying the primary drivers of water consumption and forecasting water usage (Grespan et al., 2022; Alshaikhli et al., 2021; Stelzl et al., 2021 ; Lawens and Mutsvangwa, 2018). The rise of machine learning and deep learning, driven by data-driven research, is transforming the modeling of nonlinear data and complex systems (Kim et al., 2022 ; Xiang et al., 2020). Recently, there has been a noticeable shift from linear methods to artificial intelligence (AI) based approaches in water consumption modeling, with increasing focus on machine learning and hybrid models (Bata et al., 2020; Ibrahim et al., 2020 ; Almobarek, 2021).

Machine learning, a subset of artificial intelligence, enables computers to predict future events based on past data (Nabi Javaid, 2018). It aims to develop systems that learn from data, identify patterns, and make decisions with minimal human intervention(Vijay, 2022). Marr (2022) outlines six key steps in building a machine learning model such as defining the problem, identifying data inputs and outcomes, preparing data, splitting data into training and test sets, selecting the algorithm, and evaluating performance. Machine learning algorithms are categorized into supervised and unsupervised learning. Supervised

learning uses labeled data to predict outcomes, while unsupervised learning finds patterns without predefined labels. Random Forest a popular supervised learning algorithm, uses decision trees for both classification and regression tasks (Donges, 2021). Random Forest effectively handles datasets with continuous variables for regression and categorical variables for classification (Sakshi , 2021 ; Sruthi , 2021).

For this study, where the target variable is daily water consumption (a continuous measure in liters), Random Forest regression is the optimal choice. It models the relationship between dependent and independent variables and is favored for its accuracy and simplicity in predicting continuous variables(Anon, 2021; Delua , 2021; Donges , 2021 ; Bakshi, 2020). Additionally, "R" software supports Random Forest (Simplilearn, 2021).

2.3.6 Methods to Estimate Water Consumption for End Uses of Water

(i) Quantification of water end usage for flow rate and volume-based discharge

Flow rate-based appliances commonly include showers and taps. To estimate the water discharged by these appliances, two key factors are required such as the flow rate (liters per minute) and the duration of use (in minutes). On the other hand, toilets are an example of volume-discharge appliances. Similarly, calculating the water discharged by toilets involves two quantities such as the flush volume (liters per flush) and the number of flushes (Tables 2.3 and 2.4) (Environmental Protection Agency and Program , 2017).

Table 2.3 Flow rate and flush volume requirements by the fixtures under different specification

Fixture type	**Water requirement by conventional fixture**	**Water requirement** by low **flow fixture**
Faucet	8.64 liter per minute	5.84 liter per minute
Showerhead	9.73 liter per minute	7.78 liter per minute
Toilet	6.22 liter per flush	4.97 liter per flush

(Environmental Protection Agency and Program, 2017)

Table 2.4. Average use-time (faucets and showerheads) and number of uses (toilets)

Fixture type	Variable (Unit)	Time of use /number of **uses**
Faucet	Time of use (min/guest/day)	1.6
Showerhead	Time of use(min/guest/day)	8.5
Toilet	Flushes (flushes/guest/day)	4.0

(O'Neill and Siegelbaum and the RICE Group , 2002)

(ii) Quantification of water end usage for kitchen appliances

Total kitchen water consumption depends on the number of meals and the water required for each meal (Dziegielewski, 2000 ; Sirikan, et al., 2018).

(iii) Quantification of water end usage for landscape

Water use in landscaping is shaped by multiple factors, including soil type, plant species, slope, the extent of the landscaped area, irrigation efficiency, and weather conditions (EPA, 2017). The most common methods for quantifying water use in landscaping are drawn from Dennis (2014) and FEMP (2010). Key attributes influencing water usage include the size of the landscaped area (measured in square meters), evapotranspiration rates (liters per square meter), irrigation efficiency (which can reach up to 85%), plant factors (PF), and climate factors (CF) (Richard et al., 2015)

Table 2.4 Average ETO for different agro-climatic areas in millimeters per day

Region	**Mean daily temperature (°C)**		
	Cool (~10°C)	Moderate (20°C)	Warm (> 30°C)
Humid and sub-humid	2-3	3-5	5-7
Arid and semi-arid	2-4	4-6	6-8
Humid and sub-humid	1-3	2-4	4-7
Arid and semi-arid	1-2	4-7	6-9

(Richard et al., 2015)

Dennis (2014) suggests that categorizing plants into similar groups allows for accurate determination of the plant factor (PF) using the Simplified Landscape Irrigation Demand Estimation (SLIDE). Dennis provides a list of plant type groups and their corresponding PF values as follows:

- For turfgrass, the plant factor (PF) ranges between 0.6 and 0.8.
- For various tree and shrubs, the plant factor (PF) ranges between 0.5 and 0.7
- For flowering/foliage plants, the plant factor (PF) ranges between 0.7 and 0.8.
- For highly drought-tolerant plants, the plant factor (PF) ranges between 0.3 and 0.4

Countries gather climate data through their meteorological agencies. In Ethiopia, this role is fulfilled by the Ethiopian Meteorology Agency, which offers location-specific weather information. For instance, the e climate condition for Adama city is detailed in Table 2.6.

Table 2.5 Average climate condition for Adama city

Month	Avg. Temperature °C (°F)	Precipitation / Rainfall mm (in)
July	20.7 (69.3)	59 (2.3)
August	20.2 (68.4)	88 (3.5)
September	20.7 (69.3)	69 (2.7)
October	20.7 (69.3)	19 (0.7)

(Climate-Data.org, 2023)

(iv) Quantification of water end usage for laundry

The water required for laundry depends on the number of loads, water usage per load, and the type of washing machine. Water consumption is typically estimated using these factors (Alhudaithi et al., 2022). Washing practices and water use vary significantly between residential and non-residential settings. In residential areas, particularly in developing countries, traditional methods such as river washing result in highly variable water usage. By contrast, in institutional settings, water use is more standardized to meet minimum requirements. Technological advancements have consistently improved the water efficiency of washing machines over time. For instance, the Department of Environment and Natural Resources (2009) reported that older machines required 21 to 29 liters of water per kilogram of clothing. More advanced models, as noted by Centre et al., (2013), consume as little as 7 liters per kilogram, while the latest innovations, according to Bobák et al., (2010), have achieved remarkable efficiency, using just 5 to 6 liters per kilogram of laundry.

Table 2.6 Reference weight for the majority bed services

Type of closes	Estimated kg
Towel big	0.60
Towel medium	0.25
Towel small	0.10
Bed linen	0.60
Duvet/Bed cover	0.80
Pillow cloth	0.10
Table close	0.60

(True Northen Hospitality , 2023; In The Wash, 2019)

(v) Quantification of water end usage for cleaning grounds

Water usage for cleaning areas like lobbies, walkways, and circulation spaces depends on area size, cleaning efficiency, water-saving measures and specific cleaning requirements.

(vi) Quantification of water end usage for swimming pools

Water usage in swimming pools is influenced by factors such as evapotranspiration, backwashing frequency, pool area, splash-out loss, and makeup water per backwash (Silva et al., 2021 ; Alhudaithi et al., 2022; Joong ; James, 2008; Maglionico and Stojkov, 2015).

2.3.7 Factors that Influence Water Consumption

Recent research shows that water consumption is influenced by various physical, socio-demographic, and climatic factors (Cominola et al., 2023; Mauro et al., 2021 ; Jorgensen et al., 2009). These impacts vary based on socioeconomic status, climate conditions, lifestyle and psychological characters (Addo, 2018; Llausàs and Saurí, 2017; B. S. Jorgensen et al., 2013 ; Babel and Shinde, 2011). Despite efforts, there is a growing need to study water consumption from contextual, technological, socioeconomic, and climatic dynamics perspectives (Cominola et al., 2023 ; Bich-Ngoc and Teller, 2018 ; Villar and Pérez , 2018).

Domene and Saurı (2006) studied the impact of urbanization on residential water usage in Barcelona, using descriptive statistics and regression analysis. They found that income, housing type, household size, outdoor service type, and garden plant types significantly affect water consumption. Similarly, Alharsha et al.,(2022) used multiple linear regression (STEPWISE) to study per capita water consumption in Sirte, Libya, finding that showed that larger family sizes reduced per capita water consumption, while household income had no significant impact.

Murwirapachena (2021) analyzed residential water consumption and the adoption of water-efficient technology in Johannesburg using probit regression models, finding older male respondents with lower incomes more likely to adopt water-efficient practices.

Gondo et al., (2020) studied water consumption in Karoi Town, Zimbabwe, using descriptive and inferential statistics, identifying age, gender, and female-headed households as significant factors. Zeroual et al., (2021) used artificial neural networks and

principal component analysis in Sedrata city, identifying family size, monthly income, housing units, house size, building size, and number of rooms as key factors. Kulinkina et al., (2016) observed water consumption patterns in public pipes in Ghana, noting reduced usage during the rainy season and further decreases with the presence of hand-dug wells.

Bich-Ngoc and Teller (2018) reviewed factors affecting household water consumption, identifying economic, socio-demographic, physical, technological, climatic, and spatial factors as significant. But they noted inconsistencies in findings. Willis et al., (2011)found larger family sizes correlate with higher water use, despite decreasing per capita consumption. Conversely, developed countries with smaller households often have higher overall water consumption (Corbella and i Pujol, 2009 ; Dalhuisen et al.,2003). The influence of income on water usage varies. Corbella & i Pujol (2009) and Dalhuisen et al. (2003) found income significant, whereas Willis et al. (2011) did not detect differences between high- and low-income groups.

Educational background impacts water usage inconsistently(Bennett et al.,2012). Housing conditions, including the number and quality of rooms significantly influence water consumption (Bich-Ngoc and Teller , 2018). New, high-quality houses tend to use more water (Peters and Chang, 2011). High-efficiency fixtures can save 9-12% of water, and replacing all appliances with high-efficiency ones can reduce indoor water use by 35-50% (Inman et al., 2014). Climatic factors significantly affect water consumption (Bich-Ngoc and Teller, 2018).

2.3.8 International Practices in Water Sensitive Implementations

As climate change worsens global water stress, consequently countries are adopting innovative water management approaches to move away from conventional methods towards water-sensitive management. For example, the USA introduced Low-Impact Development (LID), the UK implemented “Sustainable Urban Drainage Systems” (SUDS), New Zealand developed Low Impact Urban Design and Development” (LIUDD), China pioneered the concept of water sponge cities, Australia adopted Water Sensitive Urban Design (WSUD), and South Africa introduced Water Sensitive Planning (WSP).

(i) USA's Low-Impact Development (LID) Water Management Approach

Low Impact Development (LID) is a prominent water-sensitive management strategy in the USA and Canada. It involves utilizing planning and engineering methods as part of green infrastructure to control stormwater runoff. LID is widely embraced in urban areas due to its ability to reduce flood risks, preserve natural resources, and encourage environmentally friendly development (Y. Chen et al., 2016). Despite its benefits, some critics argue that LID's emphasis on on-site water conservation neglects broader watershed (Shafique and Kim, 2015).

(ii) UK's Sustainable Urban Drainage System (SUDS)

In the UK, Sustainable Urban Drainage Systems (SUDS) were introduced as a proactive water-sensitive management approach, designed to improve drainage and reduce surface runoff in urban areas (Andoh and Iwugo, 2002). SUDS are increasingly recognized as effective tools for flood risk reduction. Beyond flood prevention, SUDS offer additional benefits in that they improve water quality, utilize natural elements like trees, vegetation, green roofs, ponds, and wetlands to achieve sustainable drainage and create aesthetically pleasing green spaces that serve as community hubs and wildlife habitats (Funke and Kleidorfer, 2024).

(iii) New Zealand's Low Impact Urban Design and Development (LIUDD)

The New Zealand Research Science and Technology Institute introduced Low Impact Urban Design and Development (LIUDD) as a water-sensitive management strategy (Ignatieva et al., 2008). LIUDD is characterized by key principles such as the first emphasizes alignment with local government plans, while the second encourages collaborative learning. Similar to other water-sensitive approaches, LIUDD offers unique benefits by enhancing environmental performance by reducing sediment loads, stormwater flows, and impervious surfaces. It also preserves streams in natural states and it retains native vegetation where feasible (van Roon and van Roon, 2005).

(iv) China's Concept of Sponge City (SC)

The sponge city concept aims to transform urban areas into water-sensitive environments. Integrating this concept into urban planning helps cities effectively store runoff, maintaining water balance (van Dijk and Zhang, 2019). Zevenbergen et al., (2018) emphasizes the importance of the sponge city approach for managing water quality and quantity in urban settings. They outline three main benefits such as mitigating flood impacts, enhancing urban resilience to water flow extremes, and promoting water conservation through innovative planning and design practices.

(v) Australia's Water Sensitive Urban Design and Planning (WSUDP)

Australia is a leader in implementing Water Sensitive Urban Design and Planning (WSUDP), a comprehensive approach that integrates all aspects of the urban water cycle for sustainable community development (Brown et al., 2016). WSUDP enhances previous methods like Low-Impact Development (LID), Sustainable Urban Drainage Systems (SUDS), and Low Impact Urban Design and Development (LIUDD). Key lessons from Australia's WSUDP include its holistic and integrated approach to water flows, compliance with national legislative and water-sensitive guidelines which includes water-sensitive planning, community involvement, legal frameworks, and innovative technologies.

(vi) South Africa's Water Sensitive Urban Design and Planning (WSUDP)

South Africa, ranked among the top 30 most water-stressed countries globally, has embarked on significant efforts to address water stress (Armitage et al., 2014). One such effort is the introduction of Water Sensitive Urban Design and Planning (WSUDP). Inspired by Australia's WSUD, the South African Water Research Commission introduced WSUD in early 2014. This approach stems from Integrated Urban Water Management (IUWM) principles, aiming to integrate the urban water cycle with the landscape. WSUDP seeks to connect water management and planning through Water Sensitive Planning (WSP). Key lessons from South Africa involve transitioning from water-wasteful to water-sensitive practices, encouraging integrated water management from catchment to tap, and promoting knowledge sharing via platforms such as communities of practice, university collaborations and research centers.

2.4 Contextual Review

2.4.1 The Interdependence of Ethiopian Urban Centers and Water Bodies

Water availability has always been fundamental to the establishment of permanent settlements. Historically, when populations were smaller, proximity to rivers, springs, shallow wells, and lakes was crucial for urban development. In Ethiopia, urban centers can be classified based on their relationship with water bodies such as those linked to large water bodies like lakes, and those relying on nearby sources such as rivers, springs, and groundwater.

Cities like Bahir Dar, Hawassa, Arba Minch, and Bishoftu have flourished near significant water bodies. BahirDar's growth is tied to Lake Tana, which serves as a primary water source and a major tourist attraction via lake side development (McCartney et al., 2010). Hawassa city, located on the shore of Lake Hawassa, owes much of its establishment and tourism opportunities to the city (Reta and Soromessa, 2024). Arba Minch is renowned for its proximity to Lakes Chamo and Abaya, which have been vital to its tourism attraction and economic development (Teklemariam and Wenclawiak, 2004). Bishoftu also boasts multiple lakes, including Lake Bishoftu, Lake Hora, Lake Babogaya, and Lake Kuriftu which are now responsible to lake front water development (Hagerbigegn, 2016) Many urban centers in Ethiopia are closely linked to nearby rivers, a common factor in their development. For instance, Mekelle is connected to the Elala River, Gondar to the Angereb River, Dire Dawa to the Dechatu River, Jimma to the Gilgel Gibe River, Gambela to the Baro River, Addis Ababa to the Akaki River, Adama to the Awash River, and Kombolicha near the Borkena River. Additionally, numerous expanding urban centers are founded on the availability of groundwater resources, highlighting the critical role of water sources in urban establishment and growth.

Urbanization in Ethiopia significantly impacts water bodies, as growing cities increase water demand, affecting both surface and groundwater sources (Bulti and Abebe, 2020). Uncontrolled expansion and informal settlements lead to the loss of wastelands and reduce groundwater recharge due to increased impervious surfaces (Baye et al., 2020). The current urban development often neglects water sensitive development approaches such as low impact development (LID) and sustainable urban drainage systems (SUDS), which are essential for effective stormwater management and environmental sustainability. To

achieve sustainable development and improve water conservation, Ethiopia needs a more integrated approach that supports water-sensitive planning and comprehensive urban watershed management.

2.4.2 Urbanization and Water Supply Situation in Ethiopian Urban Centers

Patrick et al., (2015) reported significant urban growth in Ethiopia, with cities such as Hawassa, Mekelle, Adama, and Bahir Dar undergoing rapid increases in both population and land area. By 2040, Hawassa's population is expected to grow more than sixfold, Mekelle's nearly fivefold, and Adama and Bahir Dar almost fourfold. Land expansion will also be substantial, with Hawassa's built-up area increasing nearly ninefold, Bahir Dar's over sixfold, and Adama and Mekelle's by fivefold compared to 2010. This rapid growth poses critical challenges for water supply and urban infrastructure planning.

In Ethiopia, urban water supply challenges are aggravated by a lack of alternative water sources, particularly in arid and semi-arid regions with limited surface and groundwater resources (Beker and Kansal, 2024). Aging infrastructure further complicates the issue, with outdated systems leading to significant water leakage estimated at 20% to 40% (Yitbarek, 2022). Additionally, institutional weaknesses, including a shortage of technical professionals and limited funding that hinder effective water network expansion and periodic maintenance(Beker and Kansal, 2024).The lack of investment in water supply infrastructure has resulted in inadequate upgrades, failing to keep pace with the demands of growing populations and expanding urban areas (Millennium Water Alliance, 2019).

Water stress is increasing in Ethiopia as a growing population aggravates the strain on limited surface and groundwater resources, leading to more urban centers facing water supply shortages(Zablon , 2021). The lack of water-centric planning has prevented the adoption of water-sensitive city principles, resulting in the loss of crucial wetlands and groundwater due to uncontrolled urban expansion. Insufficient implementation of alternative water harvesting methods further strains the already limited water supply(Abraha et al., 2024) . Additionally, weak enforcement of water-centric policies and legal frameworks hinders the development of sustainable urban water systems, undermining efforts to effectively manage and conserve water resources (Ministry of Water and Irrigation, 2020).

Urban centers in Ethiopia are grappling with a severe water supply problem, marked by a widening gap between supply and demand. This disparity is growing over time, with Addis Ababa facing a shortfall of over 40% (Ambelu, 2024), Mekelle about 43% (Mekelle City Water Supply and Sanitation Office, 2021), Dire Dawa 33% (Ayele et al., 2023). and Arbaminch 14% (Timotewos et al., 2023). Many urban areas, especially smaller and emerging ones, struggle with inadequate water infrastructure, relying on decentralized systems or communal sources such as springs and shallow wells. This highlights the urgent need for improved water supply solutions across the country.

Rapid urbanization and industrial growth in Ethiopian urban centers are driving increasing water demand, while supply remains stagnant and sources degrade in both quantity and quality due to poor management. Urban centers largely depend on centralized municipal pipelines, with inadequate development of alternative water sources. A study by the Ministry of Water and Irrigation (2016) reveals that water consumption and management in these urban areas follow a linear pattern, leading to significant pollution from waste discharge. For example, Addis Ababa recycles only 0.43%, Mekelle 0.35%, Bahirdar and Hawassa 0.22%, Gondar 0.07%, and Dire Dawa just 0.05% of their total wastewater potential. In summary, in Ethiopian urban centers, water supply issues are aggravated by rising demand due to demographic, economic, and spatial changes, while the supply system remains unchanged. Poor watershed and wetland management have led to unreliable wells and groundwater depletion. Consequently, residents often purchase water from vendors at 15 to 20 times the municipal rate and spending up to20- 40% of their monthly income on purchasing water from venders.

2.4.3 Ethiopia's Water Resource Policies, Strategies, Regulations and Practices

In Ethiopia, the Ministry of Water, Irrigation, and Energy (MoWIE) oversees water management policies. The 1999 Ethiopian Water Resources Management Policy, supported by the 2001 Water Sector Strategy, aims to promote equitable water allocation, conservation, transboundary cooperation, disaster mitigation, institutional strengthening, and innovation. It focuses on ensuring water resources contribute to socio-economic development while prioritizing efficiency, equity, and environmental sustainability.

The policy views water as a finite, essential resource for life, development, and the environment, aligning with the UN's call for equitable access to safe, affordable drinking water and sanitation. Based on Integrated Water Resources Management (IWRM), it emphasizes gender inclusivity by prioritizing women and youth in water-related development. The policy promotes evidence-based management, grounded in equity, efficiency, reliability, and sustainability, while recognizing water's diverse values

The policy outlines strategies to achieve national water development goals by integrating stakeholders and aligning with Ethiopia's socio-economic plans. It promotes coordinated water management across sectors like health, agriculture, and energy, prioritizing conservation and sustainable use of freshwater. All water projects must undergo viability studies and environmental impact assessments, backed by meteorological and hydrological data. The policy prioritizes household water needs, food security, and ecosystem preservation while fostering inter-regional and transboundary cooperation. It emphasizes sustainable groundwater management, technology adaptation, stakeholder participation, and private sector involvement, with a strong focus on climate resilience and disaster preparedness.

The Ministry of Water, Irrigation, and Energy (MoWIE)(2020) identified the need for the "Ethiopian Water Resources Management Policy". Those rationales include lack of a comprehensive water management strategy, inefficient resource use, the absence of a water-centered national development plan, imbalanced basin-level water usage, inadequate maintenance systems, and unsustainable, ad hoc developments. To address these issues, the country has implemented policy, regulatory, and institutional frameworks for improved water governance.

The Growth and Transformation Plan (GTP) emphasizes watershed management through land rehabilitation, soil and water conservation practices, and land closure programs. Ethiopia's water governance framework is anchored in Proclamation No. 197/2000, which ensures equitable water allocation to support broad-based economic development. Additionally, the Ethiopian River Basin Law (Proclamation No. 534/2007) promotes sustainable water management by establishing River Basin Councils and Authorities for effective oversight across basins (Federal Democratic Republic of Ethiopia (FDRE), 2000).

In summary, Ethiopia's water resource policies and regulations play a key role in water management, but their effective enforcement is crucial. While sectoral laws, such as river basin regulations, aid in resource management and dispute resolution, the current frameworks lack a clear focus on urban water management. Given the rapid urbanization and increasing water demand in cities, the policies must be updated to incorporate water-sensitive management approaches that address the specific challenges of urban water use and planning.

2.4.4 Water Stress and Water Metabolism Research Developments in Ethiopia

Water stress is a growing global issue, and in Ethiopia it is becoming central issues in universities, research institutions, and government bodies. However, existing water risk studies in Ethiopia are often fragmented and lack a comprehensive view of how water risks escalate from national to basin levels and affect urban water security at the city region scale.

Global institutions like the World Resources Institute (WRI) have highlighted Ethiopia's rising water stress due to uneven resource distribution, climate change, and growing demand. To address the growing challenges, the WRI recommends three strategies that includes implementing balanced water management to ease pressure on specific basins, building urban water resilience, and promoting nature-based solutions for sustainable water management. This approach focuses on protecting and restoring natural ecosystems through water-sensitive watershed management, with strong community involvement. The World Resources Institute (WRI) notes that Ethiopia’s twelve river basins face significant water stress, impacting 27 million people. To tackle this, the WRI advocates for water-sensitive strategies, including sustainable city-region land use planning, watershed management, and nature-based solutions in urban areas. These efforts aim to improve water security and resilience in both rural and urban settings across Ethiopia.

Urban water metabolism research in Ethiopia is still in its early stages. While it has recently gained some attention at Addis Ababa University and in smaller towns, it remains underexplored. Notable research that integrates urban water metabolism and water sensitive planning is lacking.

2.4.5 Previous Urban Metabolism and Water Related Research Development in Adama City

Research on urban water in Adama has mainly focused on water quality, customer satisfaction, water supply governance, and flood hazard analysis. Key studies on water quality include works by Temesgen Eliku and Hameed Sulaiman (2015) Fekrudin Ismail and Sisay Demeku (2019) , Keredin Temam et al., (2019) and Abelkassim and Reddythota (2024). Customer satisfaction with the water supply system has been examined by Beshir et al., (2024), while Ayessa Leta Merga (2019) focused on the water supply distribution network. Ketema's (2021) provided understandings into urban governance and water supply service delivery.

Temesgen Eliku and Hameed Sulaiman (2015) studied the physico-chemical and bacteriological quality of drinking water at its sources and within households in Adama Town. Their findings revealed that tap water samples contained 5.8% total coliforms (TC), 17.3% fecal coliforms (FC), and 7.7% fecal streptococci (FS) exceeding WHO and National standards.

Fekrudin Ismail and Sisay Demeku (2019) evaluated the water supply performance of Adama city. The study rated water tariff performance as good but found operational personnel performance to be poor. Per capita water consumption was also rated poor, averaging 38.25 L/day, while the distribution system experienced a significant 34.67% water loss.

Beshir et al., (2024) assessed customer satisfaction with Adama's water supply system, finding that all service quality dimensions significantly influenced satisfaction at a 5% significance level. Tangibility, responsiveness, and assurance had the strongest impact. However, reliability, tangibility, and responsiveness scored below 50% on the Customer Satisfaction Index, indicating dissatisfaction, while assurance and empathy scored 50% or higher, reflecting satisfactory levels.

Ayessa Leta Merga (2019) examined the characteristics of Adama's water supply network. The study highlighted significant challenges, including pressure shortages caused by uneven topography and undersized pipes, water losses reaching up to 45.46%, and low or zero flow in some areas due to pipe congestion. Additionally, the study revealed Adama's

lack of an alternative water source, warning of severe consequences during failures of the Awash River supp

Ketema (2021) analyzed Adama City's decentralized water supply governance and found it to be ineffective. The study revealed a lack of legal and administrative autonomy, with all administrative, institutional, and political decisions heavily influenced by the Regional Water Bureau.

Leta et al., (2024) analyzed flood-resilient neighborhoods in Adama City and found that well-planned areas with shorter block sizes, smaller dimensions, frequent intersections, and proper road networks were more effective at managing water drainage and reducing flood risks. In contrast, neighborhoods with haphazard settlements, irregular block systems, long blocks, and roads ending in dead ends were more prone to water accumulation and flooding during heavy rainfall.

Bulti and Abebe (2020) examined the impact of urbanization on runoff in Adama and found a linear relationship between increased impervious surfaces and higher runoff levels. Leta and Adugna (2023) examined urban flood vulnerability through the lens of the social-ecological-technological systems framework. They identified several factors contributing to flood risks in Adama, including its location on a low-lying floodplain, unregulated urban growth without adequate stormwater drainage systems, deforestation of nearby mountains and ridges and limited green infrastructure. Bulti et al., (2021) also identified climate change as a significant contributor to flood occurrences in Adama city.

To sum up, Adama City has frequently been studied for water supply and flood vulnerability, but research on urban water metabolism to support water-sensitive planning is limited. Efforts to integrate multiple water resource flows and address urban water security remain inadequate, highlighting a pressing need for studies linking urban metabolism with water-sensitive planning.

2.5 Research Gaps and Study Foundation

This study addresses the research gap of lacking baseline water stress data across Ethiopian urban centers, which is essential for guiding future water-sensitive planning and management. By examining the detailed urban water flow in real urban systems, the study also examines the underexplored area of urban water metabolism. Although urban metabolism has been studied for decades, primarily in developed countries, it remains poorly understood and often treated as an academic exercise, with many studies focusing on hypothetical rather than real-world applications. Despite growing interest, water metabolism is less examined. For example, Kennedy et al. (2011) found that only 5% of 60 reviewed papers focused on water and Chen and Chen (2016) noted that just 7% of 30 studies addressed urban water metabolism.

Urban metabolism is an emerging field and water sensitive planning decision tool, but its methods and frameworks require further development and verifications. The urban water metabolism evaluation framework is essential for assessing water flows in urban areas, yet it relies heavily on top-down data, lacking detailed information on decentralized and centralized water supplies. This limits its ability to fully address water management challenges like water security. Additionally, private and recycled water supplies are often overlooked due to insufficient grassroots data. Hence, refining the framework requires improved data collection methods that integrate both top-down and bottom-up approaches. A key research gap in urban metabolism is the limitation of current top-down approaches, which lack the detailed grassroots data needed to address water, energy, and nutrient flow challenges. While bottom-up data collection is resource-intensive, it offers deeper insights into water issues. Bridging this gap requires a hybrid approach that combines the strengths of both methods.

This research also stems from the gap in exploring the interface between urbanization and water management through the lens of water-sensitive planning. While water-sensitive city planning remains underdeveloped, most efforts focus on urban design rather than the broader relationship between urban areas and their watershed sources. Consequently, urban areas often lack precise data on water inflows and outflows, relying on rough estimates for water resource planning.

It is also understood that water consumption patterns and stress levels vary by location, necessitating localized research for accurate modeling. In Ethiopia, a major gap exists in mapping water stress at the national level and its alignment with urban centers. Studies often fail to track water flows comprehensively, leading to insufficient data for effective urban water management. The lack of city-level water metabolism data hinders informed decision-making for water-sensitive urban planning, especially in rapidly growing cities like Adama. While Addis Ababa University has provided insights for small towns, the application of urban metabolism approaches to large cities remains underexplored, limiting understanding of water security and the need for targeted planning interventions.

2.6 Conceptual Framework of the Study

The conceptual framework arises from the need to address the identified research gaps through clearly defined objectives. It is grounded in the integration of conceptual, theoretical, and empirical literature. Theoretical foundations such as systems theory, ecosystem theory, and water-sensitive city theory, along with key frameworks like the urban water metabolism evaluation framework and water-sensitive city principles, are central to this approach. The empirical review draws on previous studies of urban water metabolism and water-sensitive planning, identifying research gaps and shaping the proposed conceptual framework for the study.

The conceptual framework begins by assessing water stress, tracking water flow, and evaluating both natural and human-induced inflows and outflows. It is structured around four key subsystems including the "water supply subsystem," which covers source types, intake, treatment, storage, and distribution for both centralized and decentralized sources; the "demand subsystem, focusing on water consumption patterns and conservation attitudes; the transformation subsystem, which examines how water is processed through linear or circular methods and the "wastewater subsystem, which addresses the recycling and reuse of water within the urban system. This conceptual framework used water mass balance to quantify natural and human-induced flows, measuring urban water security across drinking water, ecosystems, climate change, and socioeconomic indicators. It identifies water consumption determinants (independent variables) and measures household water consumption (dependent variable).

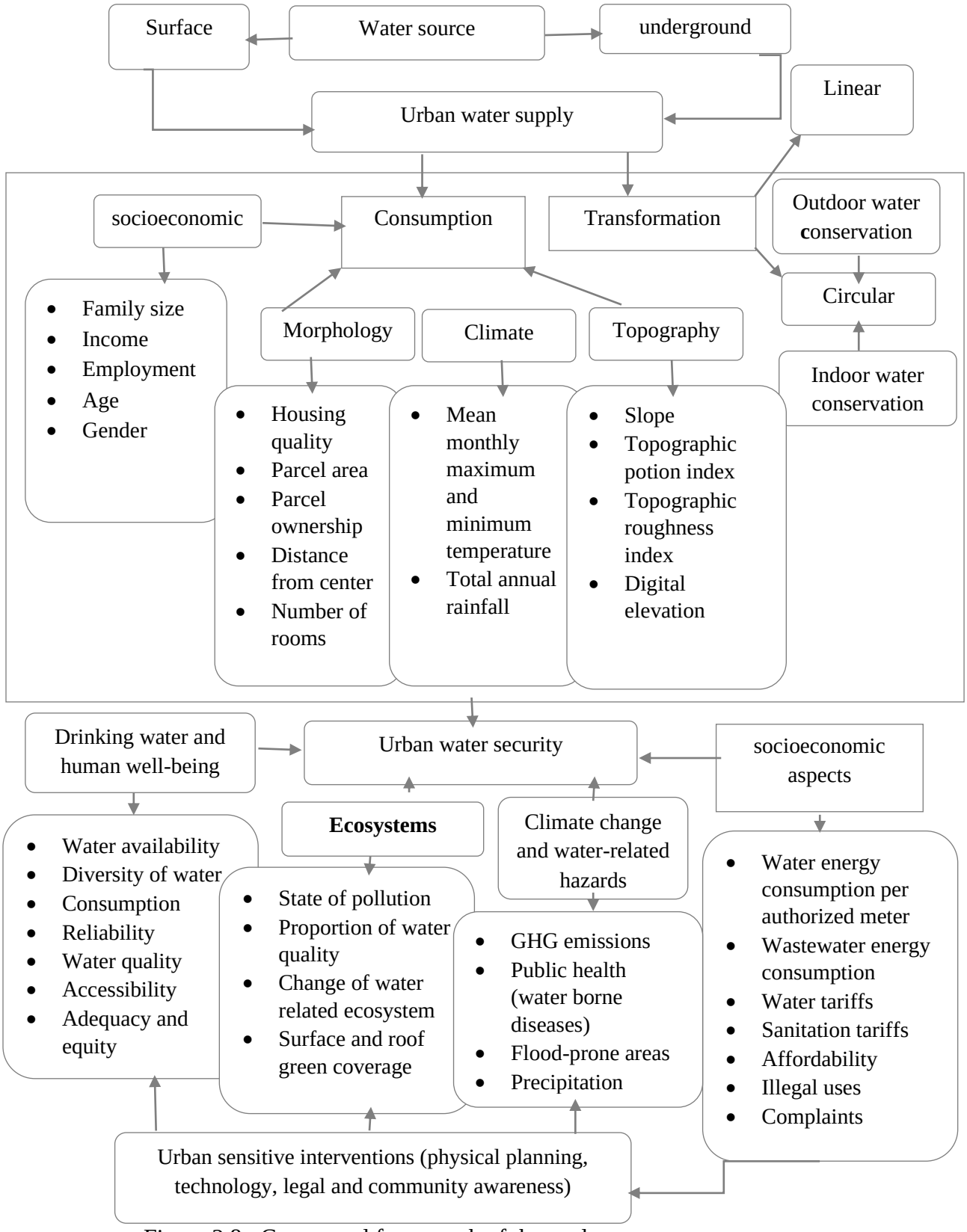

Figure 2.8: Conceptual framework of the study

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of the Study Area

The case study city, Adama, is crucial urban centers in Ethiopia serves as a major hub for trade, industry, education and health services. It is also a prominent conference city, attracting various national, regional and local events. Strategically located, Adama is well-connected to Addis Ababa via an expressway, enhancing its accessibility and integration with the Adis Ababa. Adama is situated at 8.54°N latitude and 39.27°E longitude, with an average elevation of 1,712 meters above sea level. Adama has a semi-arid to sub-humid microclimate characterized by rainy and dry seasons. The city experiences average annual temperatures ranging from 19 to 22 degrees Celsius and receives an average of 721 mm of rainfall each year. As one of Ethiopia's fastest-growing cities, Adama has an annual growth rate of 4.6%, the city is home to 431,442 residents and covers an area of 31,304 hectares (Figure 3.1). Currently, the only water supply source for the city is Awash River. Although Adama city's primary source of drinking water was underground for years, by now ground water source is not an option for the city's water supply. Out of the total nine boreholes only six are functional the six functioning boreholes combined daily production, with intermittent flow is about 3024 m^3 per day. Awash River which is influenced by seasonal variability is the main water source for the city which has production capacity of 43,000m^3 per day. Six service reservoirs are also part of the water supply system for the city of Adama and are situated in areas that are acceptable for water distribution. Each of the reservoirs has a potential capacity of 25 m^3, 500m^3, 1000m3, 1500m^3, 400m^3 and 6000m^3. The limited availability of alternative water sources and the seasonal variability of the Awash River are intensifying water insecurity in the study areas. Addressing this issue requires water-sensitive urban planning interventions.

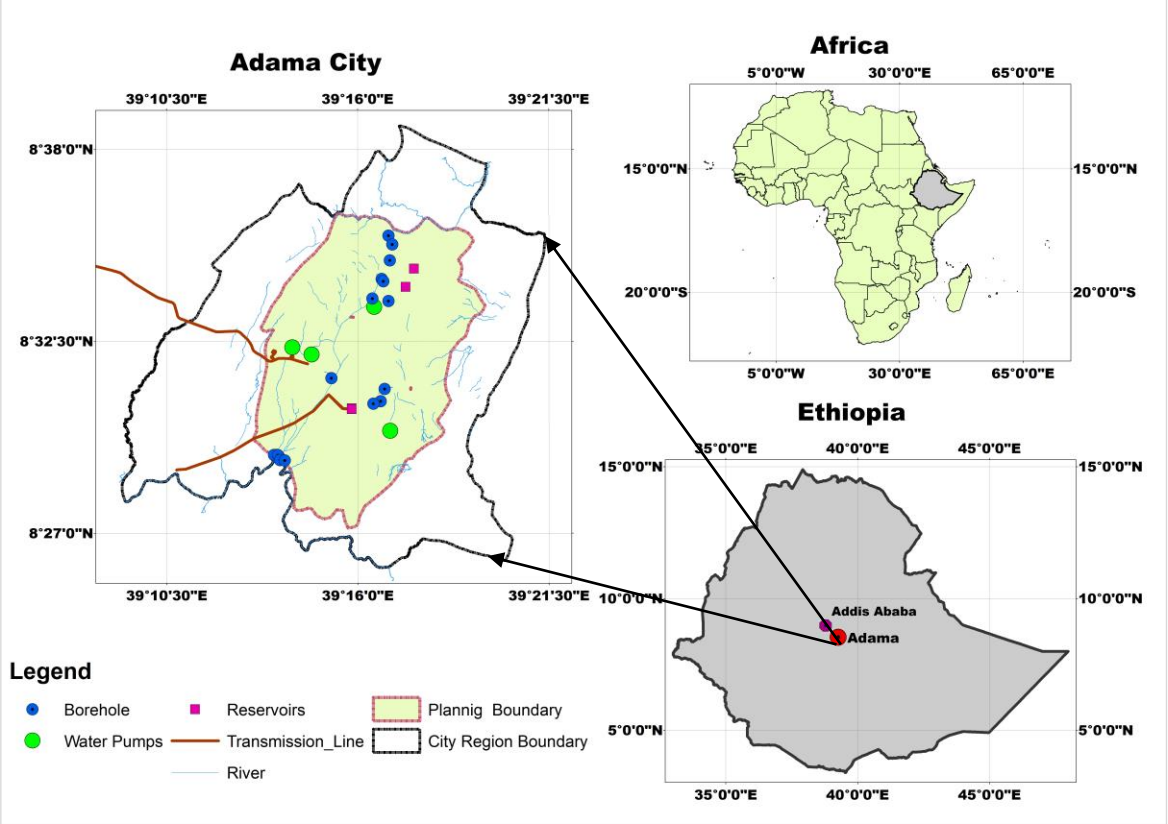

Figure 3.1: Location map of Adama City

3.2. Research Philosophy

This research integrates the water stress mapping with the urban metabolism framework and water sensitive principles which began by the quantification of urban water resource flows using urban water mass balance method and quantification of the performance of urban water security of Adama city using the integrated urban water security index .By auditing water inflows and outflows, it provides understandings into water consumption and transformation, aiding in strategic planning for water-sensitive cities. Combining system and positivist perspectives, it views urban centers as interconnected ecosystems and relies on objective, measurable data from water mass balance and geospatial analysis, aligning with the positivist emphasis on empirical evidence for reliable, replicable conclusions. The study maintenance strict ethical standards, including voluntary consent from data providers and adherence to rigorous methodologies.

3.3 Methods to Develop a Water Stress Map and Determine Adama City's Water Stress Level within Ethiopia's Water Stress Spatial Classification Map

3.3.1 Spatial and non-Spatial Data Sources

Adama city's water stress designation was determined by creating a basin-level water stress map of Ethiopia and overlaying the spatial distribution of urban centers to locate Adama and other urban centers on the water stress map. To create the water stress map, several datasets were used, such as population data with 1 km by 1 km grid raster format, estimated runoff for each basin, geographic boundaries of the basins, and the locations of urban centers represented as point vector data. Additionally, raster data on the annual spatial distribution of rainfall, groundwater potential zones and flood-prone areas were collected and utilized to identify urban centers located in water risk areas (Table 3.1)

Table 3.1 Spatial and non-spatial data sources

Type	Data description	Format	Sources/Link/
Spatial	Groundwater Potential Zone	Raster	Ethiopian Geological Survey
	Ethiopian population density	Raster	https://www.worldpop.org/geodata/summary/ (WorldPop (www.worldpop.org)
	Annual spatial distribution of rainfall	Raster	FAO(https://wapor.apps.fao.org/catalog/WAPOR_2/ \ and https://www.ethiogis-mapserver.org/
	Major River Basins	Vector	Ministry of Water and Energy
	Boundaries (country, basin and regional boundaries	Vector	Ethiopian Ministry of Urban Development andConstruction (MUDC)(https://www.ethiogis-mapserver.org/login.php)
Non spatial	Population statistic	Document	the Central Statistics Agency of Ethiopia (CSA) https://www.statsethiopia.gov.et/
	Manuals, directives and proclamations	Document	From all related sectors
	Water stress indicators and indexes	Document	Published articles, books and reports
	Basin level master plan analog maps	Maps	Ministry of water resources
	Basin level master plan report	Document	Ministry of water resources

3.3.2 Data Analysis and Presentation Methods

(i) Quantification method for the water stress

Water stress was measured at both the country and basin levels using two complementary indexes called the Water Stress Index with and Environmental Water Requirement and "Water Availability Per Person Index (Equation 3.1 and 3.2).

$$\text{Fresh Water Withdrawal-to-Availability Ratio (WTA)} = \frac{\text{TFWW} * 100}{\text{TRWR} - \text{EFR}} \quad (3.1)$$

$$\text{Falkenmark indicator} = \frac{\text{Annual runoff}}{\text{Total pupulation}} \quad (3.2)$$

The Water Stress Index with Environmental Water Requirement, endorsed by the UN as a measure of sustainable water use, was employed to assess the gross national water stress level from 1997 to 2023. This index was calculated as the ratio of total freshwater withdrawn (TFWW) to total renewable freshwater resources (TRWR), adjusted for environmental flow requirements (EFR). Meanwhile, to estimate the water stress at the basin level, the Water Availability Per Person Index was used, allowing for a more localized assessment of water stress conditions within each basin. The indicators and thresholds used for each index are provided in Table 3.2.

Table 3.2 Water stress indicators and their thresholds

Type of indicator	Category	Water stress level
Falkenmark Indicator	The per capita annual water availability is greater than 1,700 cubic meters.	no stress
	The annual per capita water availability ranges from 1000 to 1700 cubic meters.	stress
	The annual per capita water availability ranges from 500 to 1000 cubic meters.	scarcity
	The annual per capita water availability is less than 500 cubic meters.	absolute scarcity
Freshwater withdrawal-to-availability ratio (WTA) with environmental water Requirements	0-20%	no stress
	25- 50%	low stress
	50-75%	medium stress
	75-100%	high stress
	>100%	critical

(ii) Spatial data input preparation and spatial mapping method for identifying water stressed areas

A spatial water stress distribution map for Ethiopia was developed using key data layers, including population density and major river basins. Basin-level water stress was calculated in ArcGIS using the Water Availability Per Person Index, combining total runoff and population data. Attributes were assigned to represent water stress levels and the map was visualized with appropriate symbology to show water stress variations across basins. Using the Falkenmark Indicator, water stress levels were classified based on per capita annual water availability >1,700 m^3 (no stress), 1,000–1,700 m^3 (water stress), 500–1,000 m^3 (scarcity) and <500 m^3 (absolute scarcity). A water stress map was created in ArcGIS and overlaid with Ethiopian urban areas to analyze urban water stress levels .

(iii) Methods to identify urban centers exposed to water risks areas

The study assessed urban centers' water risks using GIS by overlaying urban locations with rainfall distribution, groundwater potential and flood zones. Urban centers were categorized based on rainfall coverage (minimum to maximum), groundwater potential (low, moderate and high) and flood risk levels (major, moderate, minor and safer). This approach was used to identify urban centers including Adama city which are vulnerable to water related risks.

3.4 Method to Track and Trace City-Wide Water Consumption Characteristics

3.4.1 Method for Identifying and Mapping Local Water Sources

The study employed both top-down and bottom-up methods to collect city-wide water consumption data. The top-down approach utilized municipal water supply databases for sector analysis, while the bottom-up method involved surveys, interviews and water bill records. GIS, remote sensing and GPS was used to map water sources. Additional data was sourced from the Adama city asset management database.

3.4.2 Methods to Determine Sample Size for Residential and Non-Residential Users

The sampling classification is based on water consumption, which is divided into two categories such as residential and non-residential water users. Residential water users encompass both indoor and outdoor services, while non-residential water consumption includes commercial, institutional and industrial sectors. For non-residential water usage,

particular attention was given to the primary and most intensive water users. Hence, the target population (N) includes all water users in Adama city, with approximately 95,823 households and 1,800 non-residential sectors (Table 3.3 and Table 3.4)

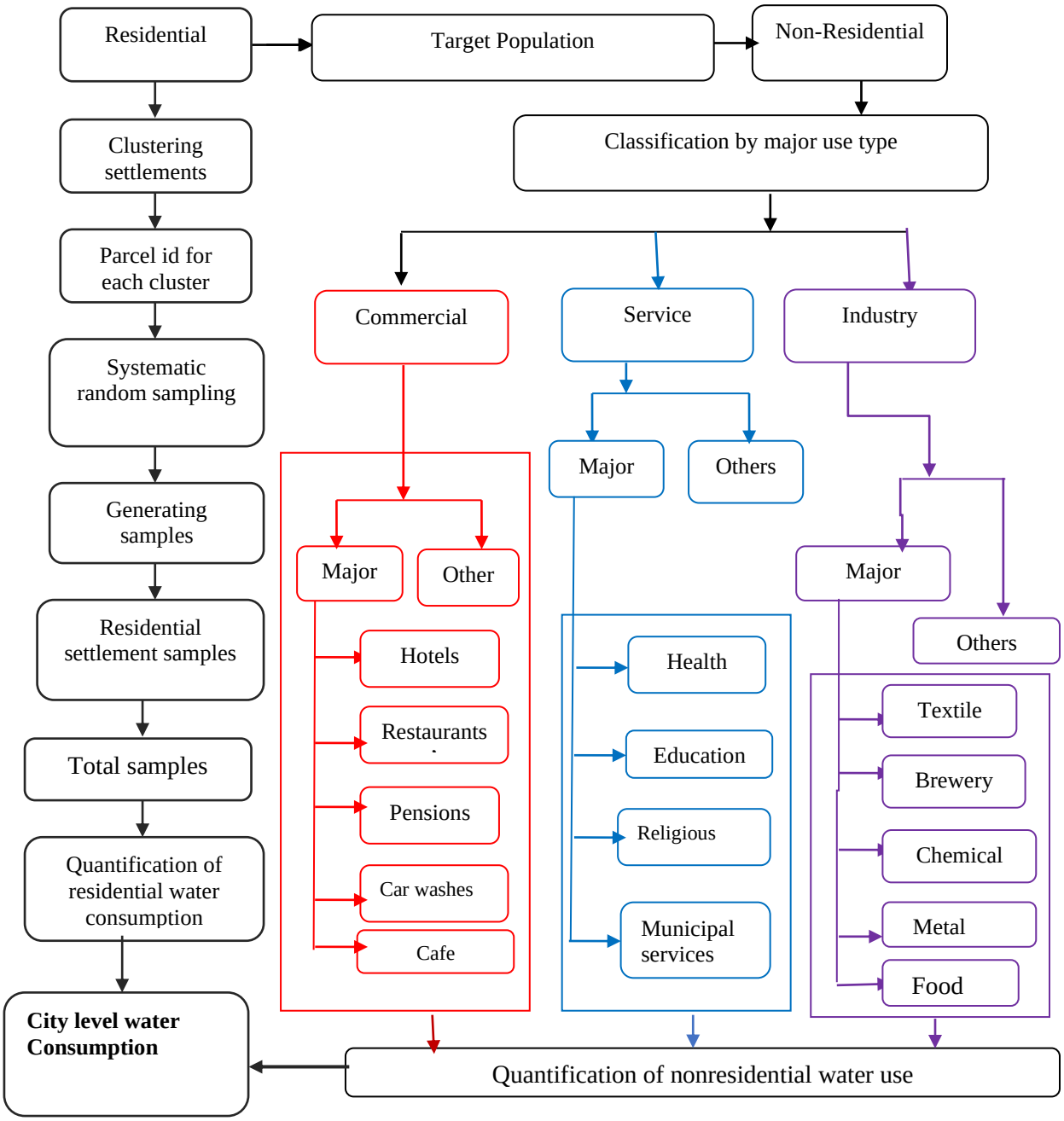

Figure 3.2: Sample design for sample selection for residential and nonresidential users

(i) Method For Determining Sample Size of Residential Water Users

The sampling process involved selecting residential communities listed in the municipal land inventory database. A total of 400 households were chosen using Excel's random number generator through simple random sampling. To ensure the representativeness of the sample, the settlements were categorized into central, intermediate and peripheral areas, to capture the spatial variations in water consumption and reliability. From Adama city's total population of 95,823 households, the sample included 141 households from central areas, 149 from intermediate areas and 110 from peripheral areas (Figure 3.3) and (Table3.3).This approach provided a detailed and comprehensive understanding of water use patterns across different neighborhoods of the city. The sample size was determined using equation 3.3

$$n = \frac{N}{1+N(e^2)} \quad (3.3)$$

Where, N is population size, n is sample size and e is margin of error (5%)

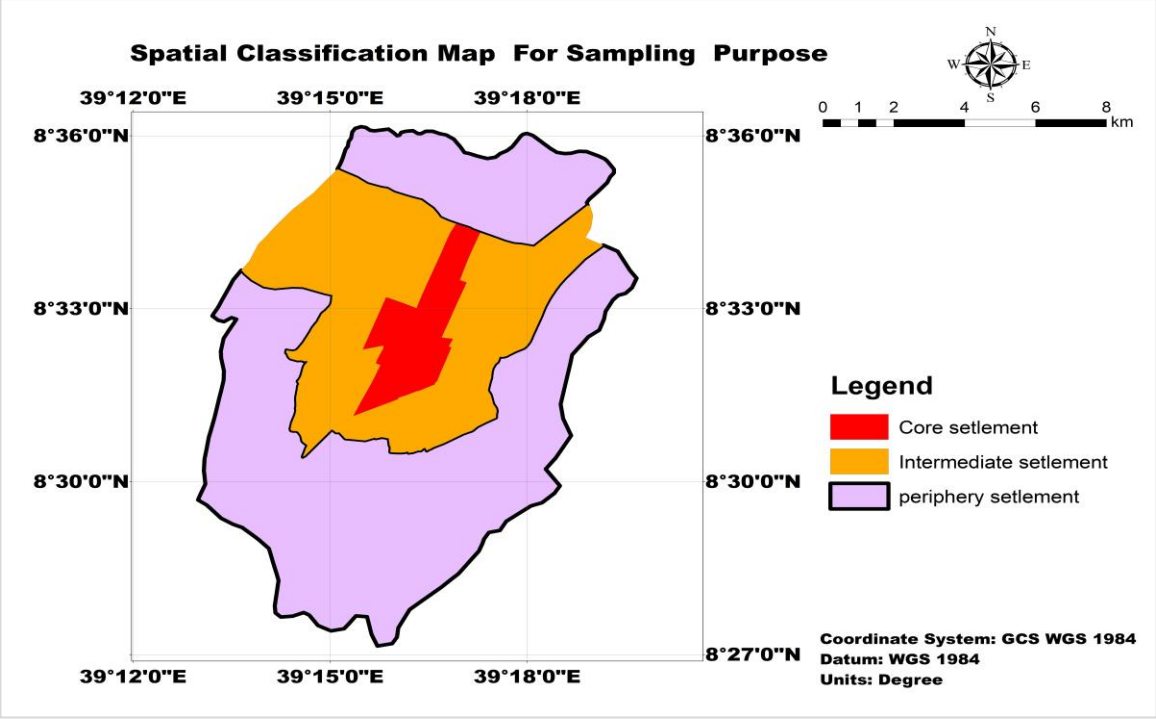

Figure 3.3: Spatial classification (central, intermediate and periphery) map of Adama city (Delineated by city experts' judgment using areal image of the city, 2020)

Table 3.3 Sample size proportion of residential water users at three spatial scopes

Zone	Local administrative areas	Total population	Household	Sample size in HH
Central settlement	Barreechaa	29,646	6,588	28
	Daddacha	32,045	7,121	30
	Biiqqaa	28,215	6,270	24
	Odaa	17,363	3,858	16
	Gurmuu	11,147	2,477	10
	Badhaatuu	18,386	4,086	17
	Gada	16,954	3,768	16
	Sub total	**153,756**	**34,168**	**141**
Intermediate Settlement	Gooroo	30,109	6,691	28
	Dagaagaa	30,252	6,723	28
	Irreecha	34,854	7,745	32
	Angaatuu	33,209	7,380	31
	Caffee	17,226	3,828	16
	Migira	15057	3346	14
	Sub total	**160707**	**35713**	**149**
Periphery Settlement	Migra	6453	1434	06
	Gaara Lugoo	31,421	6,982	29
	Dhaka Adil	2,538	564	3
	Dabe Solloque	7,083	1,574	7
	Boku Kebele	6,845	1,521	6
	Melka Adama	2,637	586	3
	Rural gandas	59761	13,280	56
	Sub total	**116,739**	**25, 942**	**110**
Grand total		**431,202**	**95,823**	**400**

(Source: Adama City Structural plan report ,2020)

(ii) Method for Determining Sample Size of Non-Residential Water Users

Non-residential water consumption was categorized into commercial, institutional, and industrial (CII) sectors. The commercial sector includes hotels, restaurants, cafes, and car wash facilities. The institutional sector covers government services like education, healthcare, municipal and religious institutions. The industrial sector consists of the textile, food and beverage, chemical industries and metal processing. Table 3.4 shows the proportion of the sample size for each non-residential user category.

Table 3.4 Sample size proportion of nonresidential water users

Sector	Total institutions	Sample size
Commercial		
Hotels	235	46
Pensions	211	42
Restaurants	576	115
Café	523	104
Carwashes	131	26
Subtotal	**1677**	**333**
Government Institutions(services)		
Education		
Elementary **school**	15	15
Secondary **school**	9	9
TEVET	01	01
Baoding	01	01
University	01	01
Subtotal	**27**	**27**
Government health institutions		
Hospital	01	01
Health center	08	08
Sub total	**09**	**09**
Religion institutions		
Orthodox church	26	26
Mosque	28	28
Subtotal	**54**	**54**
Industries		
Food processing and soft drink	06	03
Chemicals	04	02
Metal **and Engineering**	18	10
Textiles	05	03
Sub total	**33**	**18**
Grand total		**441**

(Adama Town Water Supply and Sewerage Service Enterprise, 2020)

To capture water consumption across different hotel statuses, hotels were categorized into three types including ranked hotels with official certificates, secondary hotels similar hotels without a ranking certificate but lacking certificate and the third is standard or ordinary hotels. Similarly, industrial and manufacturing sectors were classified by water demand including high (textile, food and beverage, chemical and metal processing), medium (construction, auto manufacturing), and low (electronics) (WWAP, 2015).

3.4.3 Method to Quantify Water End-Uses at Each Appliance

(i) Quantifying average daily water consumption for flow rate-based appliances

Average daily water consumption from showers or taps was estimated using flow rate (liters/min) and use duration (minutes) (Equation 3.4).

$$WC_{flow\ based\ appliance} = \sum_{1}^{i}((qi * ti) * Nav) \quad (3.4)$$

Where,

WCf is the total average water consumption via all flow rate appliances (Liter/day)

q_i is shower and taps average flow rate (Liter /minute)

t_i the average time flow (min/ person)

N_{av} is the average water users in number

(ii) (Quantifying average daily water consumption for volume discharge appliances

To estimate toilet water discharge, flush volume (liters per flush) and daily flushes were considered (equation 3.5)

$$WC_{Volume\ based\ appliance} = \sum_{1}^{j}((Vj * Nj) * Nav) \quad (3.5)$$

Where,

WCv is the total average consumption via all flush volume appliances (Liter/day)

V_j is quantity of water used per flush (i) (Littre/use)

N_j is average frequency to use the appliance per day

N_{av} is the mean number of users per day

(iii) Quantification of water end usage for kitchen appliances

Kitchen water consumption was estimated based on the number of meals and water required per meal (equation 3.6).

$$WC_k(L/day) = AWC_{meal} * N_{meals} * KEFV \quad (3.6)$$

Where,

WC_K is the average water usage in kitchen (Liter/household or institution/day)

AWC_{meal} is the average water required by each meal (Liter/meal)

N_{meals} is number of meals used by users (meals/household or institution/day)

KEFV represents the kitchen efficiency value, expressed as a percentage (80%)

(iv) Quantification of water end usage for landscape

Landscape water use was estimated based on landscape area, evapotranspiration, irrigation efficiency, plant factors, and climate factors (equation 3.7)

$$WC_{LS} = LSCA * \frac{EVTR}{LWE} * PFV * CFV \quad (3.7)$$

Where,

$WC_{LS\ is}$ average water usage per day at residential or nonresidential landscape

LSCA is the area of the households' or institutions' landscape in square meters

EVTR is the evapotranspiration rate to Adama measured in liters per square meter.

LWE is landscape watering efficiency with a common value of 85%

PFV represents the plant factor value, which varies depending on the type of plant

CFV represents the climate factor value, which varies depending on the local climate

(v) Quantification of water end usage for laundry

Laundry water use was estimated based on the number of loads, water per load, and washing machine type (equation 3.8)

$$WC_l(l/day) = FL_{per\ day} * WR_{pl} * MEF \quad (3.8)$$

Where,

WCl is the average daily water usage for laundry

FL_{perday} is the number of loads per day in the household or institution

WR_{pl} is the water required per load

MEF is the value of laundry machine efficiency factor ranges maximum up to one.

(vi) Quantification of water end usage for cleaning grounds

Ground cleaning water use was estimated based on area size, cleaning efficiency, water-saving measures, and specific requirements (equation 3.9).

$$WC_{gc}(l/day) = GA * WR_{GC} * GCEF \quad (3.9)$$

Where,

WC_{gc} is the average water consumption per day for ground cleaning purposes

WR_{GC} is the water required to wash a unit area (liter/m^2)

GCEF is ground cleaning watering efficiency with a common value of 85%

(vii) Quantification of water end usage for swimming pools

Swimming pool water use was estimated based on evapotranspiration, backwashing frequency, pool area, splash-out loss, and makeup water per backwash (equation 3.10)

$$WC_{sp}(l/day) = (PA * EVR) + (PA * SOLR) + (NB * MWR) \quad (3.10)$$

Where,

WCsp is the average daily water usage for swimming pools

PA is the area of the households' or institutions' pool in square meters

EVTR is the open water evaporation rate measured in L/m^2/day

SOLR is the splash-out loss rate and it is measured in in L/m2/day

NB is the quantity of backwashes performed per day

MWR is the makeup water requirement per backwash (liters per backwash)

3.4.4 Methods for Measuring Water Conservation Practices

A seven-point Likert scale was used to measure water conservation practices, allowing respondents to indicate how frequently they engage in specific water usage actions. The scale ranges from 1 ("Never") to 7 ("Always"), with each point representing a different level of engagement including 1 (Never), 2 (Rarely), 3 (Occasionally), 4 (Sometimes), 5 (Often), 6 (Usually) and 7 (Always). A seven-point Likert scale enhances sensitivity and reflects real-world behavior and minimizes respondent frustration (chartexpo, 2024). Pimentel (2019) proposed cutoff point intervals to enhance the descriptive interpretation of weighted means providing a clearer understanding of the data (Table 3.5).

Table 3.5 Seven-point Likert scale cutoff points for decision

Likert scale	Interval	Difference	Description
1	1.00-1.85	0.85	Very bad
2	1.86-2.71	0.85	Rather bad
3	2.72-3.57	0.85	Bad
4	3.58-4.43	0.85	Neither good nor bad
5	4.44-5.29	0.85	Good
6	5.30-6.15	0.85	Rather good
7	6.16-7.00	0.84	Very good

(Pimentel , 2019)

3.4.5 Data Analysis and Presentation Method for Tracking and Tracing Water Consumption

The analysis began by classifying water consumers into residential and non-residential groups. GIS, remote sensing, GPS, and Adama city's asset management data were used to map water sources and the supply network. The Sankey model was then employed to trace and visually represent the flow of water from sources to end-use consumption. The second step focused on quantifying water production, consumption and non-revenue water, along with examining usage patterns among residential and non-residential users. Material Flow Analysis (MFA) tracked city-wide consumption, while SPSS was used to analyze trends and correlations in water production and consumption using descriptive statistics. Spatial variation was mapped with Kriging interpolation and group disparities were analyzed with one-way ANOVA and independent samples T-tests. The third part evaluated water conservation practices among residential and non-residential users using a seven-point Likert scale to measure the frequency of conservation activities. SPSS was employed for data cleaning, handling missing values, detecting outliers and performing descriptive analysis to examine correlations between factors and the dependent variable (water consumption par day in liter).

3.5 Method to Quantify Urban Water Security Performance

3.5.1 Method to Quantify Anthropogenic and Natural Water Flows

Anthropogenic and natural water flows were analyzed to evaluate urban water security performance from urban water metabolism perspective using the urban water mass balance quantification method. The first step involved was defining the urban system boundary which was established based on the city's administrative limits (Figure 3.4). Next, data on anthropogenic and natural water flows were collected. Anthropogenic water consumption data including residential, commercial, institutional and industrial sectors, were sourced from the city's water supply database, surveys and monthly billing records. This information was supplemented by data from city reports, academic journals, official publications and national statistical records. For natural water flows, variables such as annual precipitation, runoff, evapotranspiration, infiltration, and changes in water storage were quantified using hydrological models and empirical formulas (Table 3.6).

Table 3.6 Type and sources of data for water mass balance quantification

Parameters	Data description	Type of data/unit/	Sources
	Land use	Raster	Adama city administration
	Population statistics	Report	Adama city structural plan
Land use and population	City region boundary	shape file	Adama city structural plan
	Water shade boundary	shape file	Researchers GIS output
	Population density	Raster	Adama city structural plan
Anthropogenic flow	Centralize surface water (Cs)	Volume (m^3)	Adama City Water Supply
	Centralized ground water (Cg)	Volume (m^3)	Adama City Water Supply
	Decentralized ground water (Dg)	Volume (m^3)	Survey
	Decentralized surface water (Ds)	Volume (m^3)	survey
	Decentralized rainwater (Dr)	Volume (m^3)	Survey
	Centralized recycled water (Rw)	Volume (m^3)	Survey
	System loss/leakages (unaccounted for water or nonrevenue water) (Cufw	Volume (m^3)	Adama City Water Supply and Sewerage Service Enterprise
Hydrological water flow	Precipitation (P)	Volume (m^3)	Estimation from model
	Evapotranspiration (ET)	Volume (m^3)	Estimation from model
	Surface runoff (Rs)	Volume (m^3)	Estimation from model
	Groundwater infiltration(G)	Volume (m^3)	Estimation from model

The runoff was estimated using the Soil Conservation Service Curve Number (SCS-CN) method (Equation 3.11- Equation 3.13)

$$Q = \begin{cases} \frac{(P-Ia)^2}{(P-Ia)+S} & for\ P > Ia \\ 0 & for\ P < Ia \end{cases} \quad (3.11)$$

$$Ia = 0.2S \quad (3.12)$$

$$S = \left(\frac{25{,}400}{CN} - 254\right) \quad (3.13)$$

Where,

Q Runoff (mm)

P Rainfall (mm)

S Potential maximum retention (mm)

Ia Initial abstraction

Runoff was estimated by first delineating nine watersheds using ArcGIS, each linked to a specific outlet, which facilitated runoff calculations for each watershed (Figure 3.4).

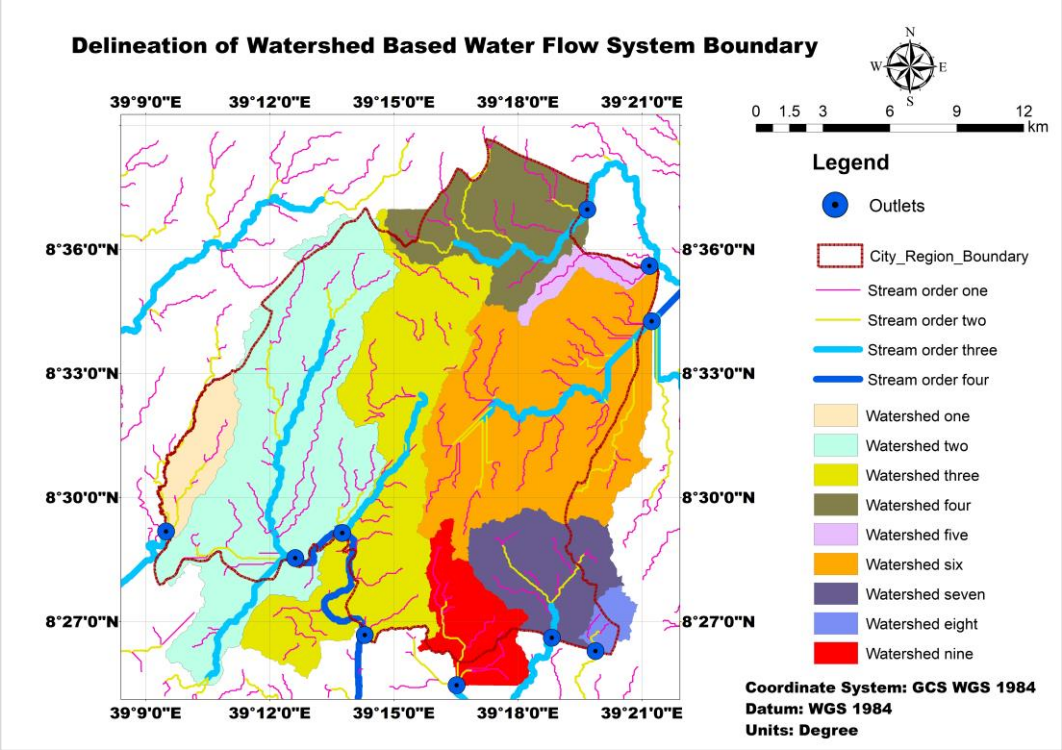

Figure 3.4: Water flow urban system boundary of Adama city
(Geospatial analysis by the researchers, 2023)

The city's hydrological soil groups were classified using the USDA Soil Conservation Service method (The U. S. Department of Agriculture (USDA), 1986) (Table 3.7) with the hydrological soil map shown in Figure 3.5.

Table 3.7 Hydrologic soil (HSG) and their implication for runoff estimation

Soil group	Description	Runoff potential	Water transmission
A	Sand, loamy sand or sandy loam	Low	High rate
B	Silt loam or loam	Moderate	Moderate rate
C	Sandy clay loam	Moderate	Moderate rate
D	Clay Loam, silty clay loam, sandy clay, silty clay, or clay	High	Low rate

(The U. S. Department of Agriculture (USDA), 1986)

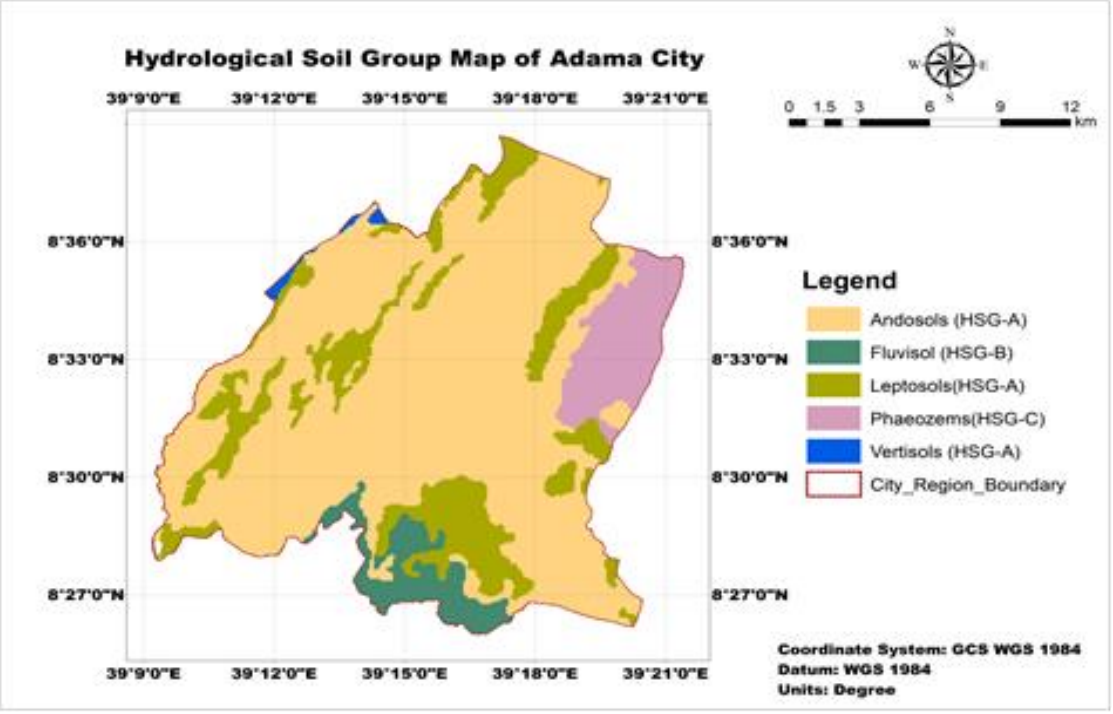

Figure 3.5 : Soil type map of Adama city (FAO GIS dataset, 2014)

The curve number for each watershed was calculated based on the land use and land cover derived from the city's land cover map Figure 3.6 and Table 3.8

Table 3.8 Land use and land cover and their curve numbers

Land use land cover	**Detailed cover**	**Description**	**Soil group and CN**			
Streets and roads	Asphalt	Asphalt paved surface	A 98	B 98	C 98	D 98
	Cobblestone	Gravel surface	76	85	89	91
	Unpaved	Soil cover surfaces	72	82	87	89
Urban districts	Commercial	Commercial surfaces (85% impervious)	89	92	94	95
	Industrial (72%) impervious)	Industrial (72% impervious)	81	88	91	93
	Services (imperious)	Services (72% impervious.)	81	88	91	93
	Residential	Town houses) (65% imp pervious)	77	85	90	92
Agriculture	Cultivated Agricultural Land	Agricultural land for crops	60	72	80	84
Range land	Trees and Bushes	<50% ground cover)	48	67	77	83
Water body	Open water bodies, wetlands, ponds, etc.	Open water bodies: lakes, wetlands and ponds, etc.	100	100	100	100
Trees	small trees	Small trees with heavy grazing	45	66	77	83
Bare land	Bare soil	Bare soil with no any grass or plant coverage	77	86	91	94

(The U. S. Department of Agriculture (USDA),1986)

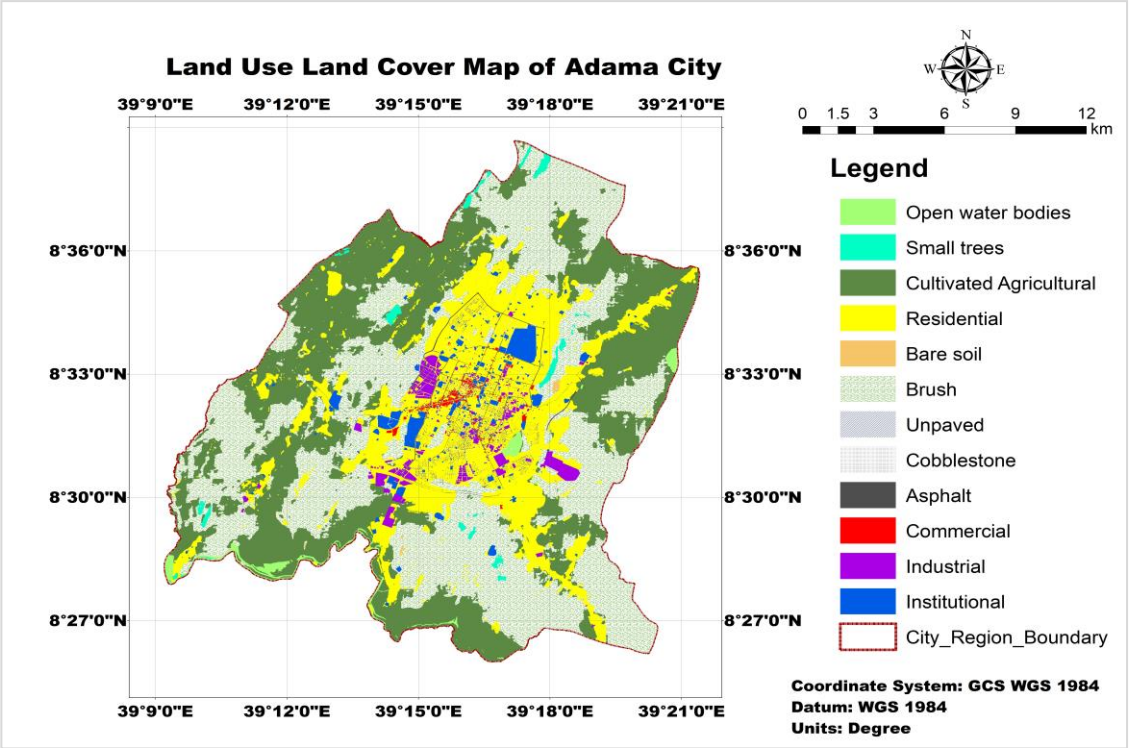

Figure 3.6: Land cover and use map of Adama city (2023)
(Geospatial analysis by the researchers, 2023)

$$CNw = \sum_{i=1}^{n} CN1 * Ai/A \quad (3.14)$$

Where,

CNw is weighted curve number

A_i is individual area at induvial curve number

A is total area of the watershed

Potential evapotranspiration (PET) was estimated using the Hargreaves-Samani method (Equation 3.15).

$$PET = 0.0023 * (Tmax - Tmin)^{0.5} * (Tave + 17.8) * Ra \quad (3.15)$$

Where,

PET is the potential evapotranspiration in (mm/day)

Ra is the extraterrestrial radiation per square meter per day.

Tmax is daily high temperature in °C.

Tmin is daily low temperature in °C.

Tave is the average temperature, calculated as (Tmax + Tmin)/2

Infiltration was estimated by calculating the difference between effective rainfall and runoff (Equations 3.16 and Equation 3.17).

$$ER = P - Ia \quad (3.16)$$

Where,

ER is effective rainfall

P is total precipitation

Ia is initial abstraction

Infiltration is the difference between effective rainfall and runoff in a given watershed. Basing on equation 3.16 infiltration was determined using equation 3.17.

$$I = P - Ia - R \quad (3.17)$$

Where,

I is effective rainfall

P is total precipitation

Ia is initial abstraction

3.5.2. Method to Measure Water Security Performance of Adama City

(i) Indicators, variables and representation of the variables' score

Urban water security was evaluated using four key indicators such as drinking water, ecosystems, climate change and water hazards and socioeconomic factors. Appendix V outlines the indicators, variables, units and scoring criteria with rating scales adapted from Aboelnga et al. (2020), Zeitoun et al. (2016) and Babel et al. (2020).

(ii) Method for weighing indicators using Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) model was employed to determine the relative weights of indicators through pair-wise comparisons. A nine-point scale proposed by Saaty (2008) was used to measure the relative importance of the indicators (Table 3.9).

Table 3.9 Nine-point scale of relative importance pair-wise comparison

Descriptions of preference	Scale
Equally important	1
Equally to moderately	2
Moderately	3
Moderately to strongly	4
Strongly	5
Strongly to very strongly	6
Very Strongly	7
Very Strongly to extremely	8
Extremely strong	9

(Saaty, 2008)

Based on the nine-point scale proposed by Saaty (2008), linguistic variables were also determined for comparing each attribute (Table 3.10).

Table 3.10 Proposed AHP linguistic variables

Linguistic variables	Ranking	Reciprocal numbers
Equal importance	1	(1)
Moderately	3	(1/3)
Strong	5	(1/5)
Very strongly	7	(1/7)
Extremely	9	(1/9)
Intermediate	2,4,6.8	(1/2,1/4, 1/6, 1/8)

(Linguistic variables designed by the researchers, 2023)

To calculate score weights, expert opinions were converted into an expert judgment matrix. The weights for the main indicators and variables were normalized by dividing each criterion by the sum of the values in its column. The average of the normalized values in each row is then calculated to determine the weight indictors (equation 3.18).

$$Nw_i = \frac{w_i}{\sum_{j=1}^{n} w_j}, i = 1,.....n \quad (3.18)$$

Where,

Nwi is the normalized weight

Wi is sum of the weight in the column

N is number of indicators

The consistency ratio (CR) was calculated to measure the reliability of pairwise comparisons, reflecting how consistently variables are ranked. A lower CR signifies greater consistency, while a higher CR indicates inconsistency. In the Analytic Hierarchy Process (AHP), a CR below 10% is considered acceptable for reliable results. The formula for CR is provided in Equation 3.19.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (3.19)$$

Where,

CR is the consistency ratio.

λ is the random index, which serves as a reference value

n is the number of variables.

(iii) Method for grading urban water security performance level of Adama city

The Integrated Urban Water Security Index (IUWSI) was calculated by applying the weights of each indicator derived from the AHP model to their corresponding scores (equation 3.20).

$$IUWSI = \sum_{i}^{n} \frac{(UWSI * W1) + (UWSI2 * W2) + \cdots .. (UWSIn * Wn)}{\sum_{i}^{n} Wi} \quad (3.20)$$

Where,

IUWSI is an integrated urban water security index

Wi is the weight of each indicator

UWSI is the calculated urban water security index score of each indicator

Urban water security levels were graded on an integrated urban water security index (IUWSI) in a scale of 1.5 to 4.5, where higher values represent better urban water security (Table 3.11)

Table 3.11 Urban water security grades and their implication

Grade of urban water security	Level of water security	Implication for future intervention
<1.5	Poor	water security is poor when it fails to meet basic human needs, with inadequate governance and management posing significant challenges in all areas.
1.5–2.5	Fair	significant concerns persist across multiple dimensions.
2.5–3.5	Reasonable	water security meets basic needs but has shortcomings that affect resilience and sustainability.
3.5–4.5	Good	Effective policies and management ensure urban water security across most dimensions, though some areas need improvement.
>4.5	Excellent	A well-managed, water-secure city meets current demands and is resilient to future risks, showing high security across all dimensions.

(Aboelnga et al., 2020 ; Zeitoun et al., 2016) ; Babel et al., 2020)

3.5.3 Data Analysis and Presentation Method for Measuring Water Security

The study utilized the Urban Water Security Assessment Framework developed by Aboelnga et al. (2019) and applied the Integrated Urban Water Security Index (IUWSI) to evaluate water security in Adama city. Key indicators analyzed included drinking water, and human well-being, ecosystem, climate change and water related hazards and socioeconomic factors. Each indicator was weighted and graded according to the criteria outlined in Table 3.11.

3.6 Method to Characterize Water Consumption by Integrating Spatial and Non-Spatial Water Consumption Determinants

3.6.1 Method to Identify Water Consumption Determinants with Random Forest Machine Learning Techniques

(i) Spatial and non-spatial data sources

Water consumption determinants were identified using random forest machine learning. Spatial and non-spatial data were obtained from socioeconomic, building and parcel, climatic and topographical datasets. Socioeconomic variables, such as household size and income were gathered using household level surveys. Building and parcel characteristics, including housing conditions, number of rooms, parcel area, parcel ownership, proximity to the city center and water service reliability were also gathered using filed survey and observation method (Table 3.12). To make the data compatible with the Random Forest machine learning algorithm, non-spatial data were converted into spatial format using the ArcGIS platform (ArcGIS 10.7).

Climatic data (temperatures and rainfall) were sourced from the National Meteorology Institute of Ethiopia, while topographical factors (elevation, slope, topographic position and ruggedness index) were derived from a 20m resolution Digital Elevation Model (DEM). Spatial interpolation and rasterization of these factors were conducted in ArcGIS platform (ArcGIS 10.7) with further data processing was performed in R software version 4.05 (It was utilized version 4.0.5 of R (https://www.r-project.org/ along with the "caret" package for implementation) to produce an aggregated raster. Lastly, attribute values from this raster were exported to Excel, forming the regression matrix for training, cross-validation and model testing.

Table 3.12 Data sources and feature types for the water consumption modeling

Type of data	Sub attribute	Data type	Source of data/provider/
Households Socioeconomic	Household size	Continuous	Household survey
	Household income	Continuous	Household survey
Building and Parcel Characteristics Features	Housing condition features	Poor housing condition Fair housing condition Good housing condition Very good housing condition	Household sample survey followed by observation
	Number of rooms	Continuous	Household survey
	Parcel legal status features	Categorical (Coded values) Formal informal	Household survey
	Area of parcel features	Continuous	Household survey
Distance from the center of the city feature	Center Intermediate Periphery	Categorical (Coded values) Periphery Intermediate Center	Household sample survey followed by observation
Water service continuity (reliability) features (variable)	Reliability 1 Reliability 2	Categorical (Coded values) Reliability 1= refers to households that receive water no more than three times per week Reliability 2= refer to households that receive water three times per week	Household sample survey followed by observation
Climatic Features	Mean monthly minimum temperature	Continuous (raster)	Historical 10 years of data from 2013-2022 obtained from the National Metrology Institute of Ethiopia (NMIE)
	Mean monthly maximum temperature	Continuous (raster)	
	Annual total rainfall	Continuous (raster)	
Topography	DEM	Continuous(raster)	
	Aspect	Continuous (raster	
	Topographic Position Index (TPI)	Continuous(raster)	
	Topographic Ruggedness Index	Continuous(raster)	
	Slope	Continuous(raster)	

(The National Metrology Institute of Ethiopia (NMIE) and Field survey, 2023)

(ii) Model Execution Method

Data splitting into train and test procedure: Building a model depends on training data whereas prediction depends on testing data(Bernardo, 2022).In data partitioning determining the partition ratio is important(Brownlee, 2020). Scholars use various splitting ratios such as 80:20 and 70: 30 (Jordan, 2017). But depending the size of the data ratio is not consistent across all researchers(Joseph, 2022).This study also considered 90:10 which implies that 90% of the dataset passed in the training dataset and 10% in the testing dataset.

Model training procedure: Following the splitting process, cross validation was done using the random forest technique or the Bagging (Bootstrap Aggregating). In the random forest regression, a Bootstrap is constructed to get R^2, MSE, and RMSE(Brownlee, 2018).

Random forest algorism method: The Random Forest algorism sums the prediction of N decision trees to produce the entire prediction of target (dependent variable). For regression-based prediction, the final prediction output (Yx) is the average prediction value of all trees $f_i(x)$ which is resulted from the prediction of i^{th} tree from the feature x (equation 3.21)

$$Y(x) = 1/\mathrm{N} \sum_{i=1}^{N} (Fi(x) \tag{3.21}$$

Model evaluation against the test data procedure: The hydroGOF package in "R" was utilized to assess the goodness of fit between observed and simulated values. Additionally, the model evaluation involved calculating the "Mean Error (ME)", "Mean Absolute Error (MAE)", "Root Mean Square Error (RMSE)", "Normalized Root Mean Square Error (NRMSE)", and the "Coefficient of Determination".

3.6.2 Method to Characterize Urban Water Metabolic Performance of Adama City

This study characterized the urban water metabolic performance of Adama city using the methodology developed by Renouf et al., (2017) (Table 3.13).

Table 3.13 Urban water performance indicators

Indicators	Method	Formula
I. Population and water use intensity		
Population density (people/km2)	Population/area	Pop/A
Intensity of water use (GL/km2)	Total water use/area	(C + D)/A
II. Water system centralization		
Water supply centralization (%)	Centralized supply/total water use	C/ (C + D) *100
Rainfall harvesting potential (%)	Decentralized water/rainfall	D/P*100
III. Rainfall potential for water supply		
Centralized supply replaceability (%)	Rainfall/centralized water	P/C*100
Total use replaceability (%)	Rainfall/total use	P/ (C + D) *100
IV. Wastewater potential for water supply		
Centralized supply replaceability (%)	Wastewater flow/centralized water supplied	W/C*100
Total use replaceability (%)	Wastewater flow/total water use	W/ (C + D) *100
V. Stormwater potential for water supply		
Centralized supply replaceability (%)	Stormwater flow/centralized water supplied	Rs/C*100
Total use replaceability (%)	Stormwater flow/total water supplied	Rs/ (C + D)

(Reproduced from Renouf et al., 2017)

3.6.3 Data Analysis, Software Used and Output Data Presentation Method

This method characterizes water consumption by identifying both spatial and non-spatial factors. It also analyzed spatial disparities in water consumption by developing hypotheses related to spatial distance and morphological elements such as building quality and parcel ownership. Accordingly, the analysis addressed three main hypotheses which includes firstly, regarding distance from the city center, the null hypothesis (Ho) postulates that water consumption doesn't show significance difference as distance increase from the center of the city to the periphery. In contrast, the alternative hypothesis (H_1) suggests that water consumption shows significance difference as distance increase from the center to periphery.

Secondly, the method examines the relationship between water consumption and housing quality. In this case, the null hypothesis (Ho) suggested that water consumption doesn't show significance difference with the housing quality conditions (houses in very good, good, fair and bad) have no significance difference in their water consumption. Conversely, the alternative hypothesis (H_1) suggested that water consumption shows

significance difference with the housing quality condition (houses in very good, good, fair and bad condition) have significance difference in their water consumption. Lastly, the analysis considers parcel ownership, with the null hypothesis (Ho) suggesting that water consumption doesn't show significance difference with in the formal and informal housing ownership. The alternative hypothesis (H_1) suggesting that water consumption shows significance difference with in the formal and informal housing ownership.

SPSS was used for initial data cleaning, handling missing values, outlier detection, and conducting descriptive analysis and correlation assessments. To analyze water consumption disparities based on distance from the center, housing conditions, and parcel characteristics, descriptive statistics, including mean and standardization were employed. A one-way ANOVA test was conducted to determine if significant differences in water consumption exist as distance from the center increases and across different housing conditions. An Independent Samples Test was used to examine differences between formal and informal parcels. Additionally, a Post-HocTukey's HSD test was applied to assess significant differences among the groups. Random Forest Regression was used to produce raster surface water consumption, leveraging its ability to handle continuous variables like daily water use in liters and to identify relationships between dependent and independent variables. ArcGIS 10.7 facilitated geospatial analysis, integrating spatial and non-spatial data to create thematic maps of water consumption determinants which were key inputs for generating the final consumption raster map.

3.7 Data Quality Analysis Method

This study focuses on established quantitative data quality assessment methods, including the data cleaning procedure, handling missing data, detecting outliers, assessing reliability, normality, checking for homogeneity of variance and performing statistical tests. Specifically, Independent-Samples T-Test was used to compare the means of two independent variables, while One-Way ANOVA was employed to compare the means across multiple independent variables. To mitigate overfitting in the Random Forest algorithm, K-Fold Cross-Validation was implemented as a technique to enhance model performance.

The data cleaning procedure was mainly conducted to identify and correct data entry errors. The data cleaning step was conducted by visualization of the data in spread sheet which helps to identify the missing value and outliers. The missing values resulting from incorrect data entry were identified by looking at the frequencies for each variable in SPSS. After looking through the number of "Valid and Missing" values derived from the frequencies result, just two missed values were discovered. To correct the missed values, the original questionnaires were tracked down using their unique ID and the correct recording was completed. Reliability was assessed using Cronbach's Alpha to evaluate the consistency of the questionary.

Outliers were identified using the Z Score method, where a data point is flagged as an outlier if its Z score exceeds 3 or falls below -3 (Selva, 2023; Iden, 2021). The Z score is calculated by subtracting the mean (μ) from the raw measurement and dividing by the standard deviation (σ) (equation 3.22). In the presence of two outlier, the researcher replaced them by median value imputation approach rather than total removal

$$Z = \frac{X-\mu}{\sigma} \qquad (3.\ 22)$$

CHAPTER FOUR

RESULT

4.1 Respondent Profile and Survey Response Rate

A door-to-door household questionnaire survey was used to acquire the residential water consumption characteristics of the households. A guided map was created to search the sampled households. If they were not at their house, a convenient time and appointment were made. This strategy resulted in a response rate of 100%. According to the analysis of the household questionnaire survey, just 28% of the 400 sample households are headed by women, while 72% of the households are headed by men. 79% of respondents reported they are married, 14% are widowed, and 7% are divorced. In terms of respondents' educational backgrounds, 16% of respondents have a degree or higher, 4% diploma and certificate, 34% have finished elementary school, 28% have finished high school, 11% can read and write, and 7% are illiterate. Furthermore, 35% of household heads work for themselves, 15% work for the government, 26% work for businesses and 16% are unemployed and the rest 8% other sectors.

The nonresidential water consumption survey engaged a range of key informants, including 333 commercial institution managers, 27 heads of educational institutions, 9 health institution administrators, 54 religious leaders and 18 industrial institution heads. Additionally, 26 experts provided quantitative data on urban water security across four dimensions. These included 7 specialists from the water supply office (comprising the operation and maintenance head, 2 technicians, 2 plan and budget experts and 2 water quality experts), 12 professionals from urban planning and land development (including experts of urban planning, engineering, land management, infrastructure, greenery and beautification, finance and administration) and 7 recognized individuals from each sub-city.

4.2 Adama City's Water Stress Designation Within Ethiopia's Spatial Water Stress Classification Map

4.2.1 Ethiopia's Water Stress Classification Map Based on the Falkenmark Water Stress Indicator

The results from the water stress map in Figure 4.1 and Table 4.1 indicated that 56.8% of Ethiopia's population lives in areas facing at least water scarcity which account for 63.2% of the country's total land area.

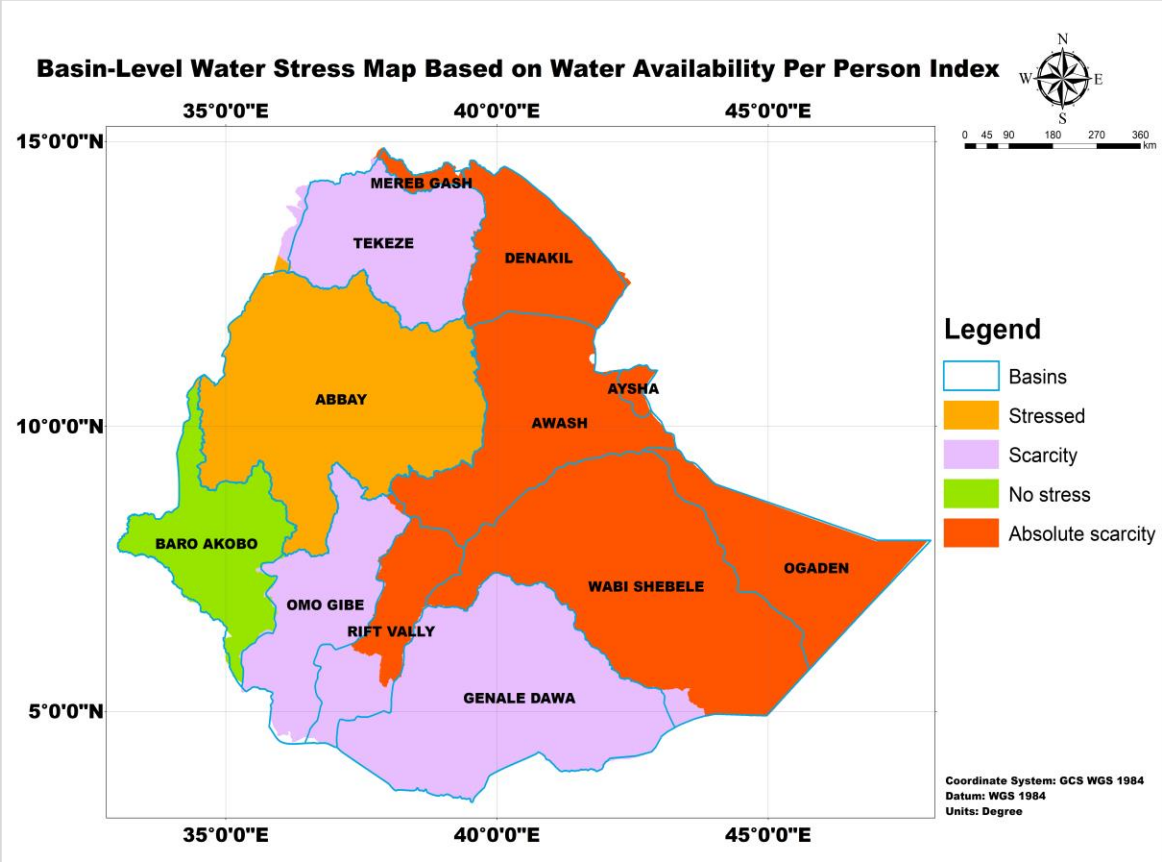

Figure 4.1 Water stress classification map based on the Falkenmark water stress indicator

Table 4.1 Level of water stress, area coverage and population distribution

Stress level	Total population	Percent share (population)	Total Area (km^2)	Percent share (Area)
Stressed	27,125,642	24.6%	200,718	15.3%
Absolute scarcity	23,812,046	21.7%	496,873	37.9%
Scarcity	38,593,253	35.1%	338,805	25.3%
No stress	5,332,450	4.8%	75,604	5.7%
Total	**110,000,000**	**100%**	**1,112,000**	**100%**

4.2.2 Adama City's Water Stress Designation with in Ethiopia's Spatial Water Stress Classification Map

Figure 4.2 revealed that Adama city falls within the absolute scarcity water stress classification. Furthermore the study asserted that 75.86% of the urban areas are located in water scarce category (Table 4.2).

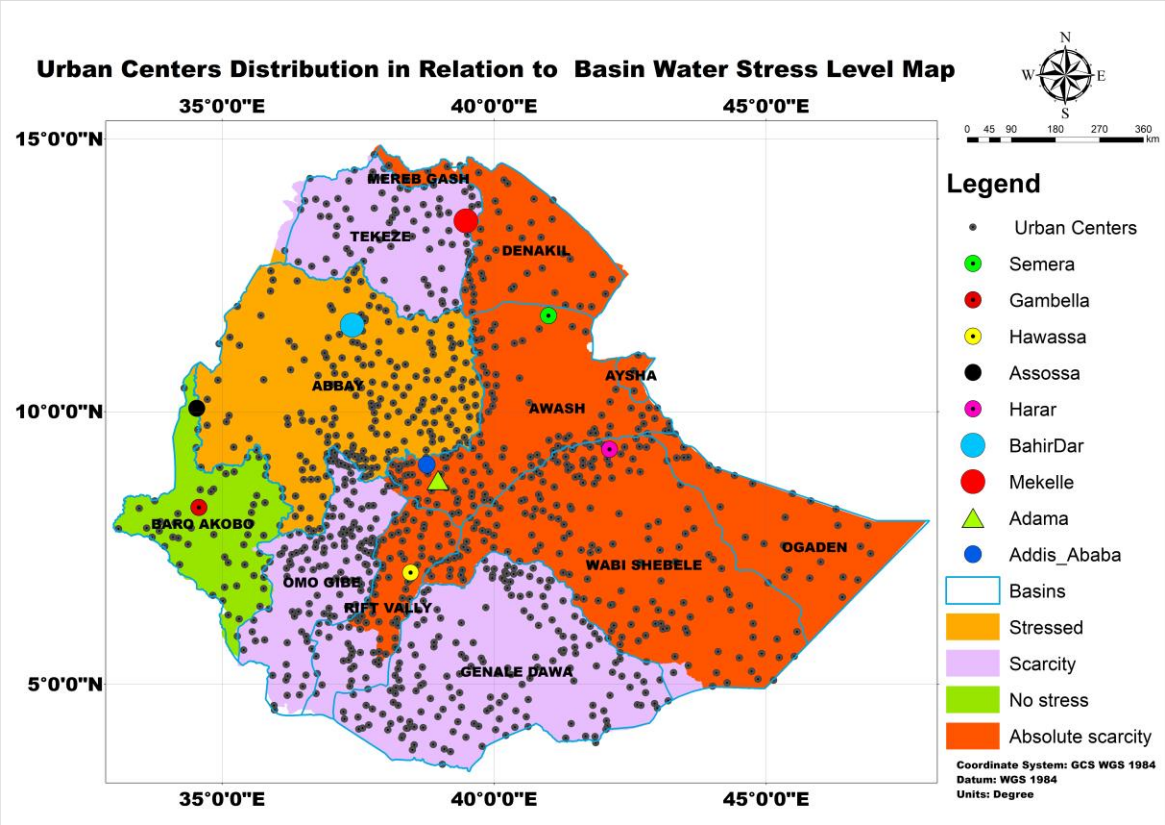

Figure 4.2 : Urban centers distribution in relation to major river basin water stress map

Table 4.2 Urban centers distribution in relation to major river basin water stress level map

Water Stress category	Number of urban centers	Percentage (%)
Absolute water scarcity	427	38.15
Water scarce	422	37.71
Water-stressed	208	18.64
No water stress	62	5.50
Total	**1,119**	**100.00**

4.2.3 Adama City's Geographic Position within Ethiopia's Water Risk Zones

(i) Location of Adama city in groundwater potential zones

Figure 4.3 indicated that Adama city's location falls within the moderate to high groundwater potential zones. Meanwhile, Table 4.3 and Figure 4.3 indicate that 77% of the total population and 79.65% of the urban population reside in areas with moderate to high groundwater potential. Conversely, 23% of the total population and 20.35% of the urban population are located in low groundwater potential areas. Furthermore, 33% of urban centers, totaling 369 centers are located in areas with low groundwater potential.

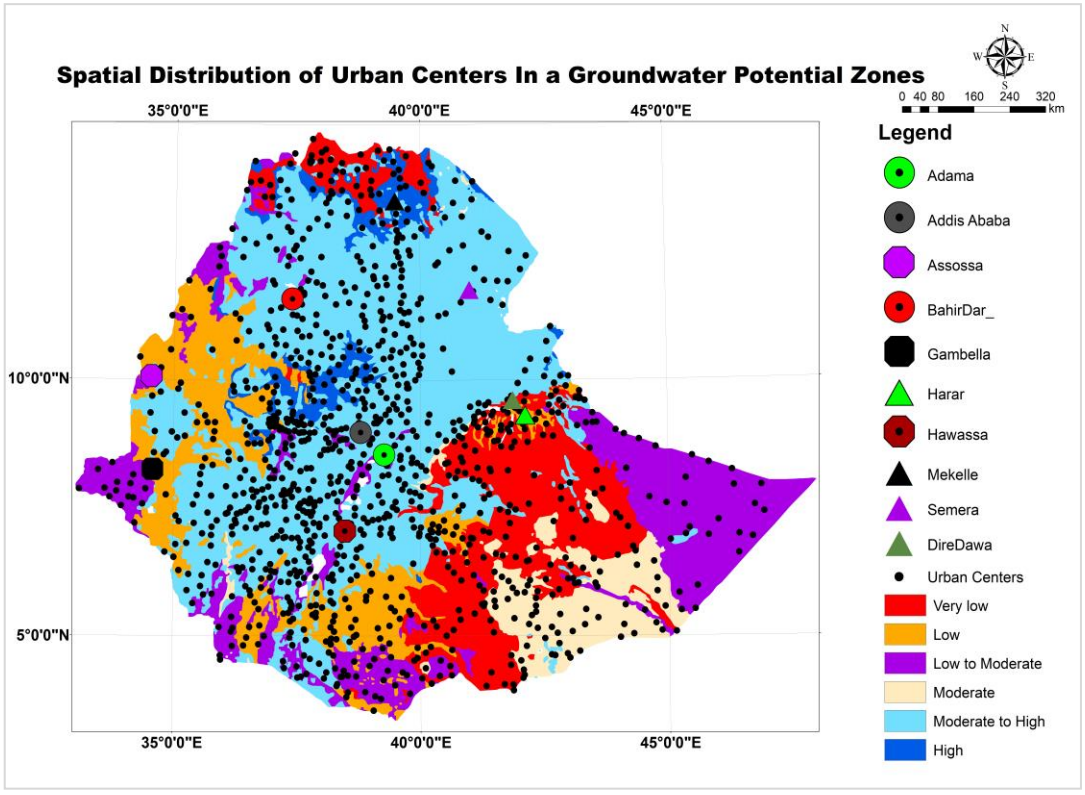

Figure 4.3 : Spatial distribution of urban centers in a groundwater potential zones

Table 4.3 Spatial distribution of urban centers in a groundwater potential zone

Category	Total Population	Percentage of total population	Percentage of urban population	Number of urban centers	Percentage of urban centers
Low groundwater potential zones	25,562,371	23%	20.35%	369	33%
Moderate to high groundwater potential zones	84,437,629	77%	79.65%	750	77%
Total	**110, 000,000**	**100%**	**100%**	**1119**	**100%**

(ii) Location of Adama city within annual rainfall spatial distribution pattern

Adama city receives an average of 721mm of rainfall each year . Furthermore, Table 4.4 and Figure 4.4 revealed that 71.67% of urban centers are located in areas receiving less than 200 mm of annual rainfall.

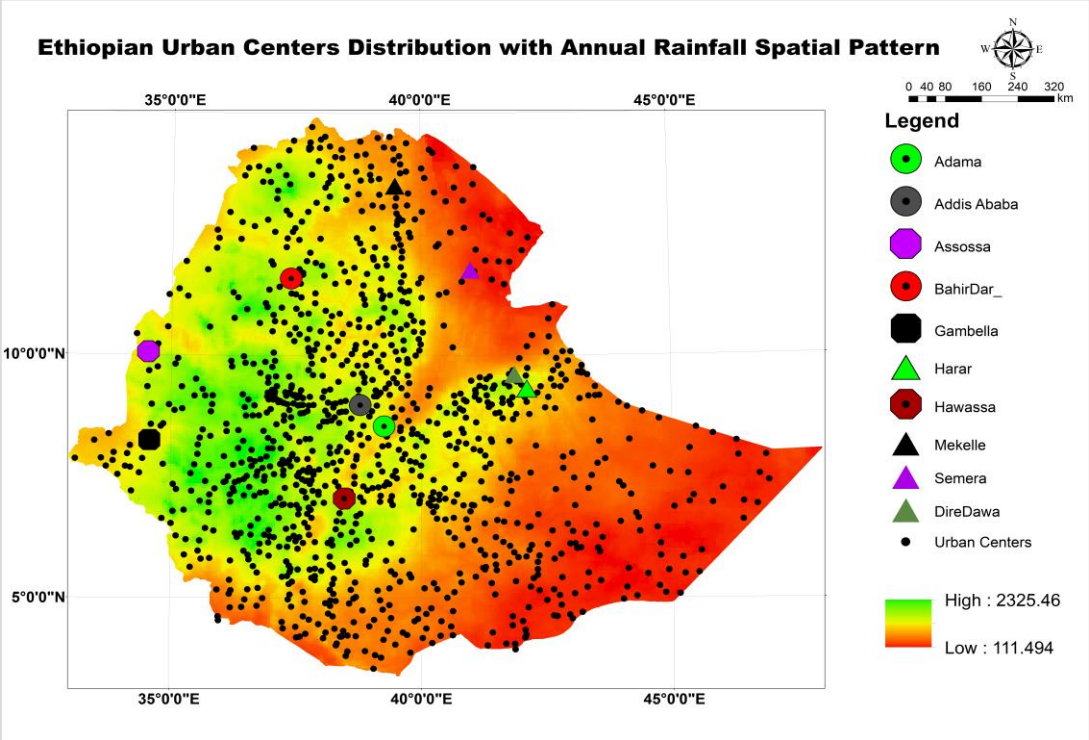

Figure 4.4: Ethiopian Urban Centers Distribution with Annual Rainfall Spatial Pattern

Table 4.4 Ethiopian urban centers distribution and annual rainfall spatial pattern

Rainfall range	Number of urban centers	Percentage (%)
Less than 100mm	315	28.15%
100mm to 200mm	487	43.52%
Over 2300mm	317	28.33%
Total	**1119**	**100**

(iii) Location of Adama city in relation to flood prone zones

The findings presented in Figure 4.5 indicate that Adama city is situated in a moderate flooding zone in Ethiopia. Additionally, both Table 4.5 and Figure 4.5 confirm that 72% of urban areas lie within flood-prone zones, spanning from minor to major flood risk areas.

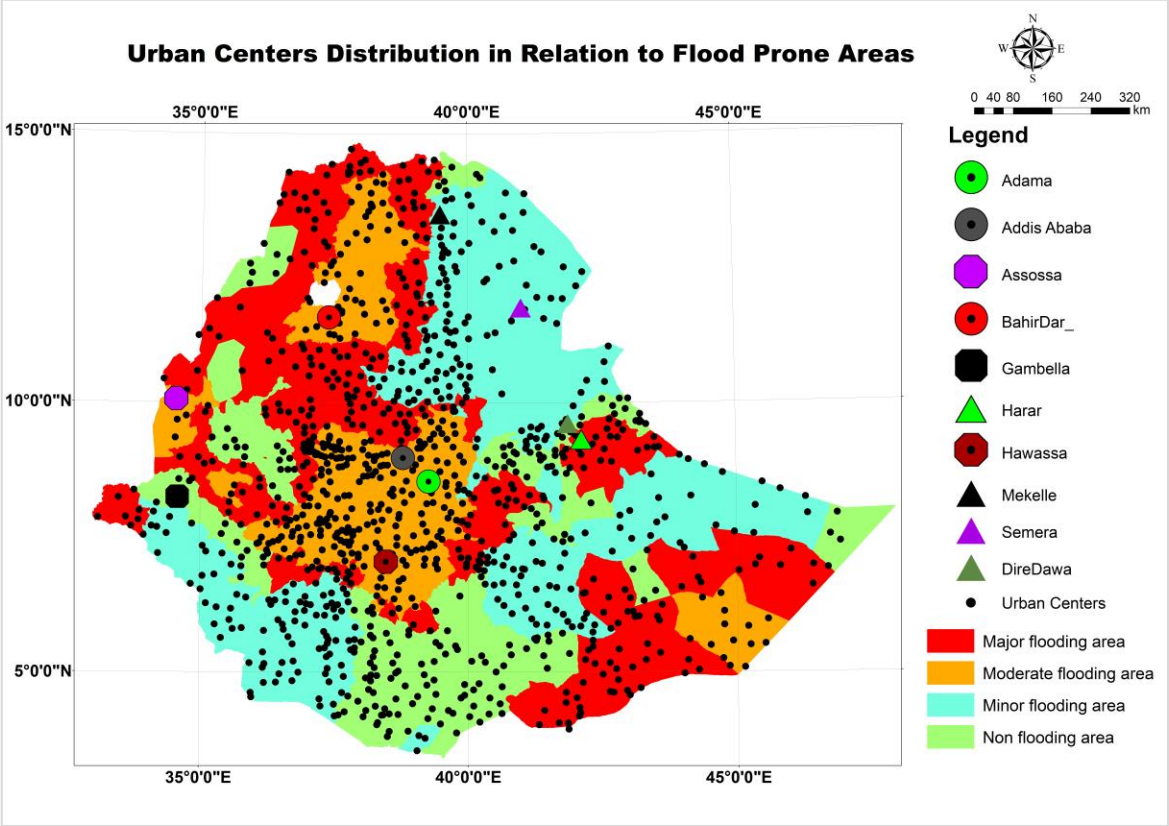

Figure 4.5: Urban centers distribution in relation to flood prone areas

Table 4.5 Urban centers distribution in relation to flood prone areas

Flood zone	Number of urban centers	Percentage (%)
Major flood zones	307	27%
Moderate flood zones	317	28%
Minor flood zones	186	17%
Safest flood zones	309	28%
Total	**1119**	**100%**

(iv) Spatial distribution of urban centers across Ethiopian major river basins

Table 4.6 and Figure 4.6 indicate that the Abay Basin has the highest share of urban centers at 17%, followed by Genale-Dawa at 16%, Omo-Gibe at 13%, and Danakil, Ogaden, and Aysha collectively at 15%.

Table 4. 6 Distribution of urban centers in the Ethiopian major river basins

Basin	Number of Urban Centers	Percentage (%)
Abay	194	17
Genale-Dawa	175	16
Omo-Gibe	140	13
Awash	115	10
Wabishebele	114	10
Baro-Akobo	55	5
Mereb Basin	8	1
Rift Valley	61	6
Tekeze	78	7
Danakil, Ogaden, and Aysha	178	15
Total	**1119**	**100**

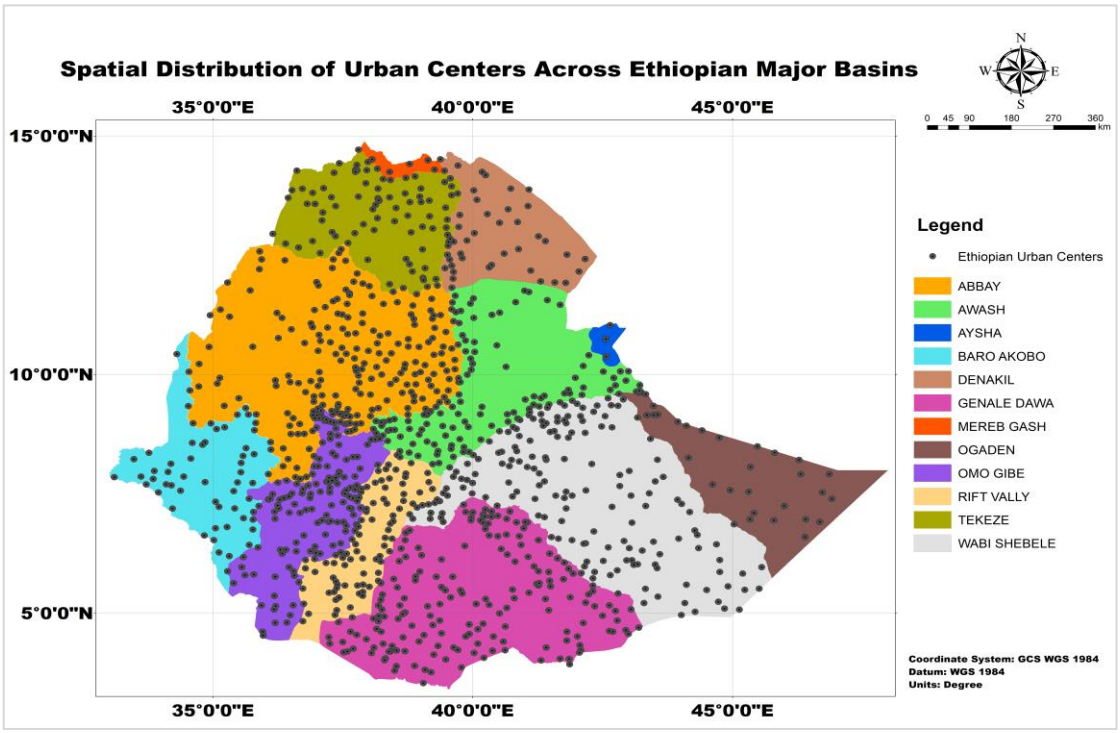

Figure 4.6: Spatial distribution of urban centers in the Ethiopian major river basins

Table 4.7 shows that the Awash basin where Adama city is located, Mereb, Rift Valley, Wabishebele, Danakil, Ogaden, and Aysha basins are facing absolute water scarcity. The Genale Dawa, Omo-Gibe and Tekeze basins are classified as water scarce, while the Abay basin is experiencing water stress. The Baro-Akobo basin is the only basin not under water stress.

Table 4.7 Water stress level at major river basins of Ethiopia

Name	Population Density/km^2	Total population	Annual runoff (x106m^3)	Stress (m^3 per capita /year)	Implication
Abay	162.15	27125642	52.60	1623.50	stressed
Awash	168.52	15901125	4.60	242.20	absolute scarcity
Baro-Akobo	85.95	5332450	23.60	3705.37	no stress
GenaleDawa	56.58	8103026	5.88	607.54	scarcity
Mereb	171.46	846950	0.26	257.02	absolute scarcity
Omo-gibe	228.25	14944033	16.96	950.18	scarcity
Rift valley	293.22	12947176	5.64	364.71	absolute scarcity
Tekeze	117.46	8850880	7.63	721.75	scarcity
Wabishebele	71.99	12067381	3.16	219.24	absolute scarcity
Danakil	39.82	2467128	0.86	291.85	absolute scarcity
Ogaden	21.28	1373863	0.00	0.00	absolute scarcity
Aysha	21.90	40343	0.00	0.00	absolute scarcity
Total		**110, 000,000**	**121.19**		

4.3. Tracking and Tracing Water Consumption from Source to End Use

4.3.1 Tracking and Tracing Water Consumption of Adama City

(i) Tracking water supply sources, internalization and diversification

Figure 4.7 indicates that Adama's water supply network covers only 45% of the city. Of the nine boreholes, only six are operational, yielding around 3,024 m³ of water daily, but declining capacity and rising fluoride levels are reducing their effectiveness. The city now mainly depends on the Awash River which is located 11 km away. Adama's aging water distribution system, predominantly made up of unplasticized polyvinyl chloride (uPVC) pipes which account for over 66% of the network.

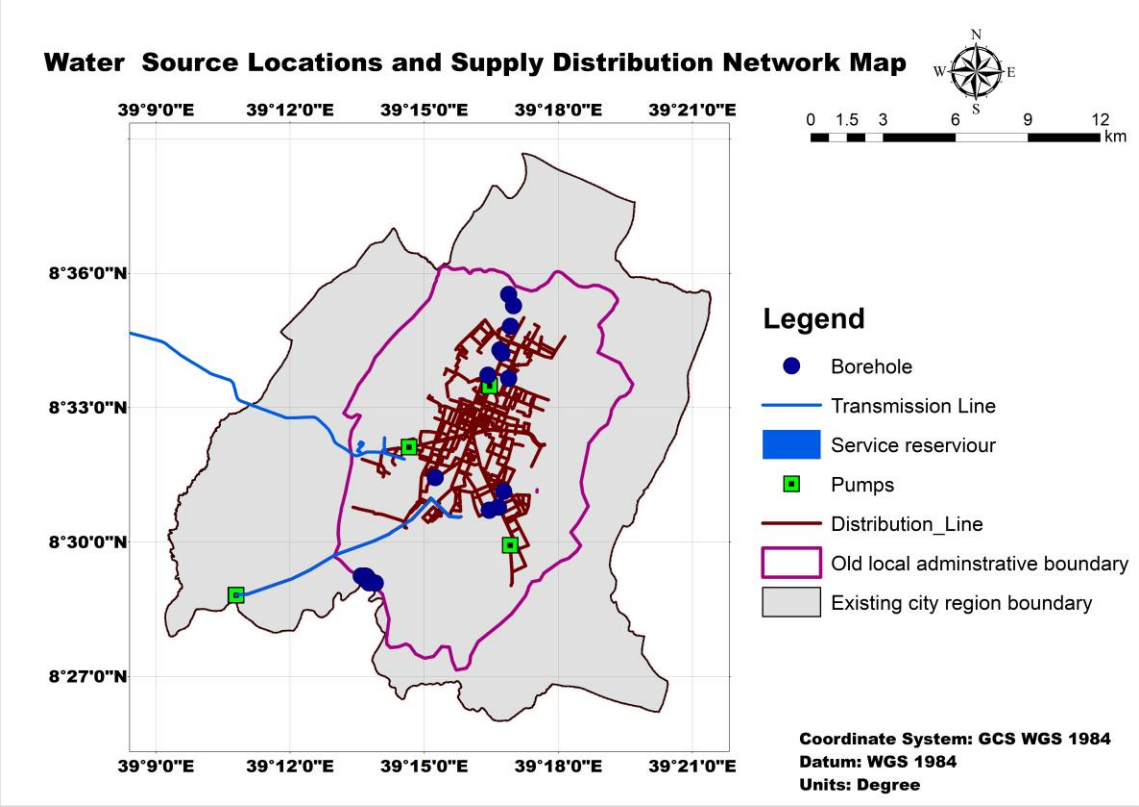

Figure 4.7 : Water Supply source locations and distribution network map of Adama city

The Sankey model diagram in Figure 4.8 shows that Awash River provides 43,300 m³ of water per day. After treatment and delivery through six pump sets, about 9-10% of this water is lost in transmission, resulting in 41,228 m³/day reaching the city. The overall consumption is 32,982 m³/day with an additional 20% lost in the distribution system. The highest water consumers are residential areas (24,126 m³/day), followed by 4,990 m³/day and 3,512 m³/day for commercial and service sectors, respectively

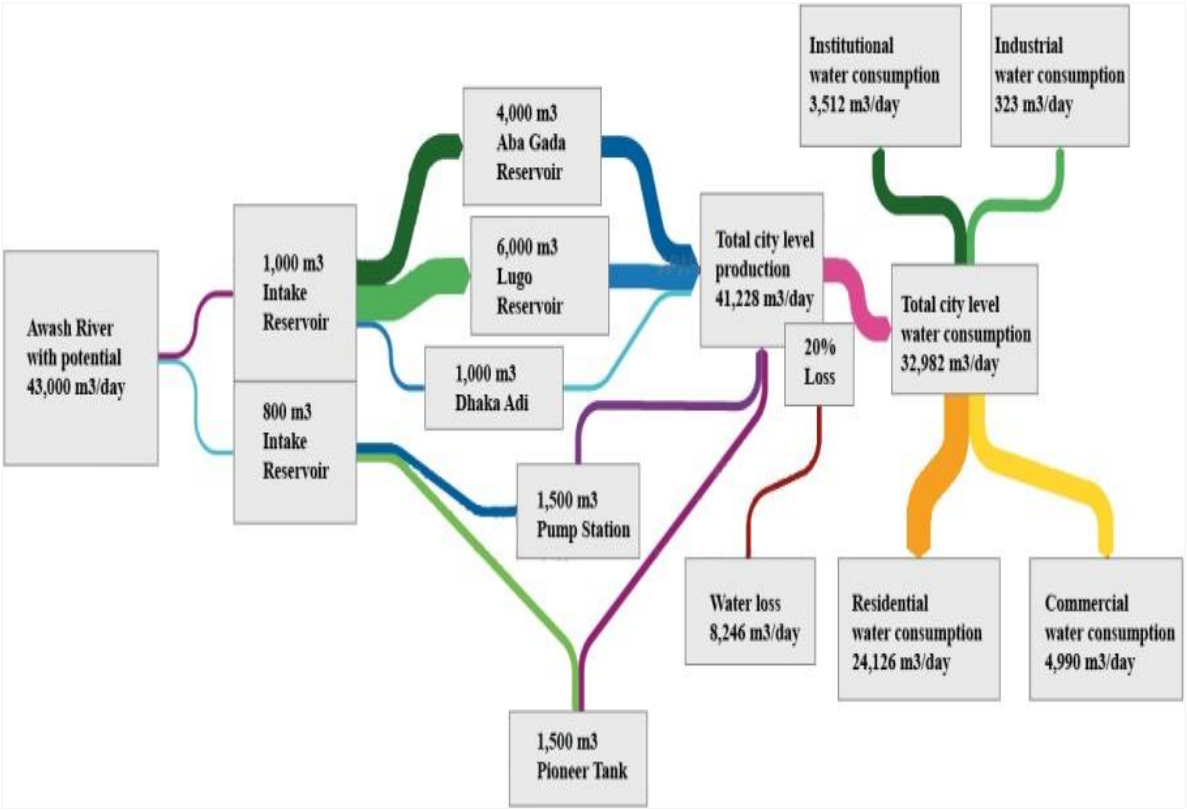

Figure 4.8 : Water supply flow from source to service reservoirs and customers

The analysis result shows that in 2023, the daily demand was 66,013 m³, with a shortfall of 24,785 m³ leaving 38% of the demand unmet. The Water Supply and Demand Balance Index (SDBI) for Adama is then found to be 0.62.

Table 4.8 reveals that Adama's water supply is mainly sourced from centralized systems, with 17.568 million m³/year from the Awash River and boreholes. Decentralized ground water sources, including Industrial Park boreholes, hotels and other industries, contribute 9.43 million m³/year. Recycled water accounts for 1.4 million m³/year and rainwater harvesting provides 0.45 million m³/year. The total centralized and decentralized water consumption of the city is found to be 28.85 m^3 /year.

Table 4.8 City level water supply sources, internalization and diversification

Type of sources	**Unit**	**Quantity**
Centralized water		
Centralized surface water (from Awash River)	M^3 /year	$15.48*10^6$
Centralized groundwater water (from boreholes)	M^3 /year	$1.088*10^6$
Sub total		$\mathbf{17.568*10^6}$
Decentralized ground and surface water sources		
Industrial Park boreholes	M^3 /year	$7.5*10^6$
Other industries	M^3 /year	$1.3*10^6$
Hotel boreholes	M^3 /year	$0.018*10^6$
Water supply for urban greenery (from Awash)	M^3 /year	$0.459*10^6$
Sub total		$\mathbf{9.43*10^6}$
Recycled water (Rw)		
Recycling in industrial Park	M^3 /year	$0.756*10^6$
Household water recycling	M^3 /year	$0.164*10^6$
Adama science and technology university	M^3 /year	$0.478*10^6$
Subtotal		$\mathbf{1.4*10^6}$
Decentralized rainwater harvesting		
Household-level roof water harvesting	M^3 /year	$0.287*10^6$
Industries	M3 /year	$0.17*10^6$
Subtotal		$\mathbf{0.45*10^6}$
Grand Total	**M3 /year**	$\mathbf{28.85*10^6}$

(ii) Tracking water production, consumption, and non-revenue water

Table 4.9 shows that over the past 30 years, Adama city's population increased 15-fold, while water production tripled and consumption doubled. Despite these increases 20% of the water still goes to wastage.

Table 4.9 Population growth, water production, consumption, and non-revenue water (NRW) (2013-2023)

Year	Population	Production (m^3peryear)	Consumption (m^3per year)	NRW (m^3 per year)	Rate NRW (%)
2013	283,000	6549811	5870000	679811	11.58
2014	295,000	6376766	5101412.8	1275353.2	20.00
2015	307,000	6826007	5460805.6	1365201.4	20.00
2016	320,000	7572768	6058214.4	1514553.6	20.00
2017	334,000	9400000	7520000	1880000	20.00
2018	348,000	12725867	10180693	2545174	20.00
2019	362,000	13782322	10,787,558	2, 994764	22.00
2020	378,000	14085850	11268680	2817170	20.00
2021	394,000	14576609	11,661,287	2915322	20.00
2022/23	431, 442	14 842289	11873832	2968457	20.00

Table 4.10 indicates that from September 2022 to August 2023, residential usage accounted for the majority of Adama city's water consumption at 73.2%. Annually, the service sector consumed 8.53%, while the commercial sector used 15.13%.

Table 4.10 The proportion of water consumption by sector (m3/year) in Adama city

Sector	Average Annual water consumption (m^3/year)	Proportion of water consumption
Residential	8,685,708	73.15
Services	1,012,838	8.53
Commercial	1,796,511	15.13
NGO	49,870	0.42
Religious	53,432	0.45
Community	148,423	1.25
Industry	116,364	0.98
Others	10,686	0.09
Total	**11,873,832**	**100**

Table 4.11 conforms the months with the highest water consumption. July leads with a total of 1,287,632.75 m^3/year, followed closely by October with 1,285,484.75 m^3/year. September also shows significant consumption, amounting to 1,284,294.75 m^3/year. August, while slightly lower, still represents a substantial usage with 1,155,988.75 m^3/year. These figures underscore the peak periods of water use throughout the year.

Table 4.11 Temporal water consumption (m3/month) in Adama city in 2023

Month	Residence	Institutions	Commercial	NGO	Religious	Community	Industry	Other
September	970651.25	127356.25	159068.5	5493	4058.75	9512	6358	1797
October	987363.25	116549.25	152954.5	4006	3616.75	11692	7188	2115
November	654252	152899	150493	2091	3239	13489	3179	379
December	544959	41125	166712	2711	4169	16451	6096	189
January	563574	43713	134891	4423	2594	13235	6446	297
February	547299	47962	121766	4570	5281	12372	4382	210
March	689045	60217	138799	4752	5461	13957	8618	346
April	620336	106649	192881	3854	3730	15054	8630	379
May	665436	78964	151114	7436	5717	13198	44275	252
June	540858	45018	129497	4188	5881	13355	6728	356
July	979589.25	126618.25	154400.5	3237	3582.75	10369	7120	2716
August	922345.25	65767.25	143934.5	3109	6101.75	5739	7344	1648
Total	8,685,708	1,012,838	1,870,120	49,870	53,432	148,423	116,364	10,686

4.3.2 Tracking and Tracing Water Consumption of Residential Sector

(i) Measuring household water consumption characteristics (liter/household/day)

Figure 4.9 shows that in Adama city, household water consumption averages 586 liters per day, while per capita consumption is 69.2 liters per day.

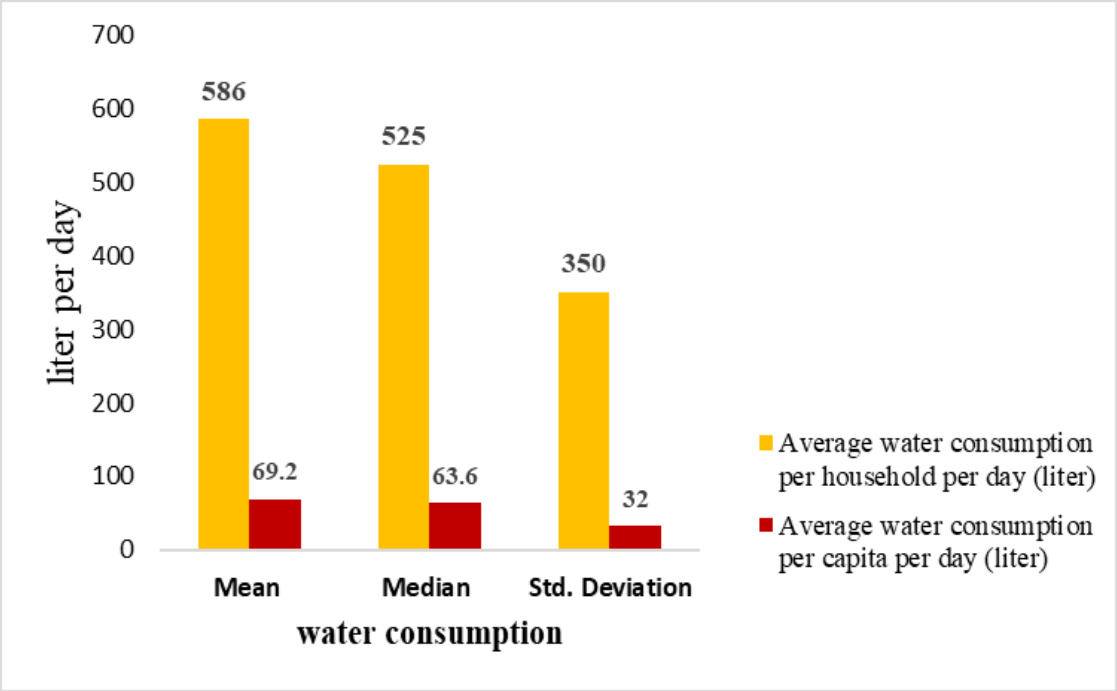

Figure 4.9 : Water consumption per household and per capita per day in Adama city

(ii) Water supply reliability per week across the sampled households

Table 4.12 reveals that 70% of households receive water at least four times in a week, while 30% get it less than three times per a week.

Table 4.12 Water supply reliability per week across the sampled households

Frequency of water supply per week	Frequency	Percent
Once a week	7	1.8
Two times a week	63	15.8
Three times a week	50	12.5
Four times a week	46	11.5
Five times a week	60	15.0
Six times a week	44	11.0
Always available but with restricted flow	130	32.5
Total	**400**	**100.0**

Figure 4.10 reveals that in the city, water supply is highly inconsistent, with 40% of areas receiving water only once a week. About 24% get water 1-2 times weekly, 18% receive it 2-3 times and 13% have access 3-4 times a week. Only 5% of the city gets water supply over five times a week.

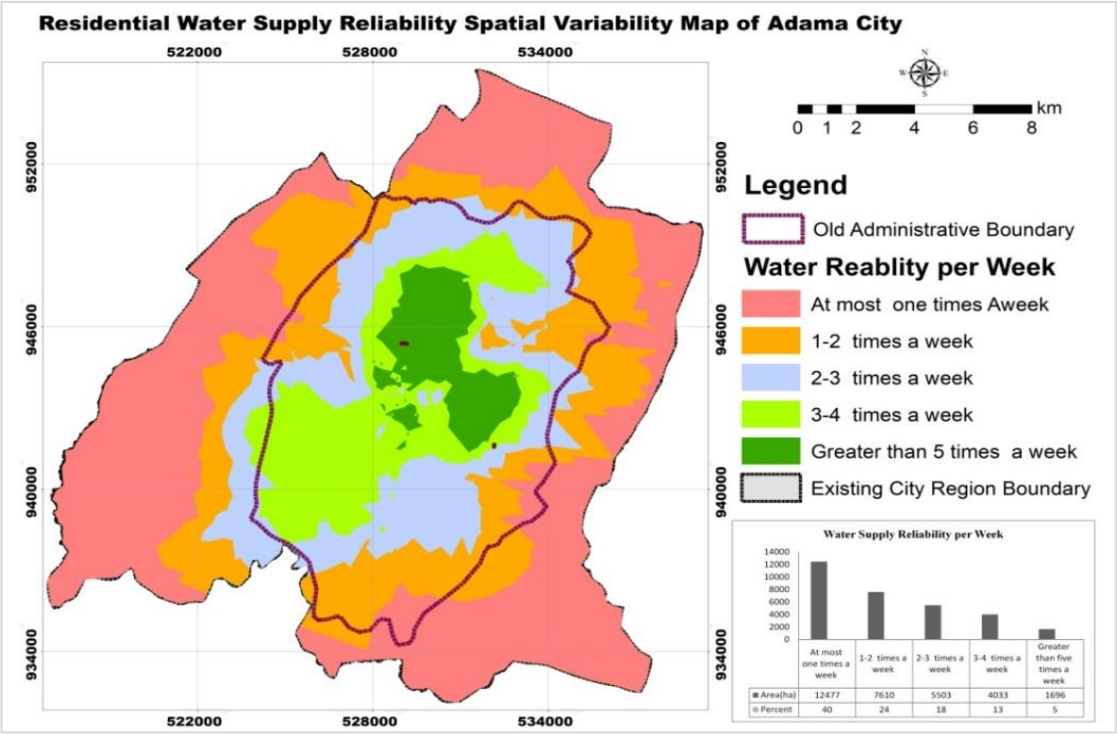

Figure 4.10: Residential water supply reliability spatial variability map of Adama city

(iii) Household-level water conservation practice

Table 4.13 revealed varying levels of engagement in water-saving practices among households in the area of in indoor and outdoor water consumption practice which mainly characterized by the following major findings.

Table 4.13 Indoor and outdoor residential water consumption practices

Retrofitting old fixtures and installing water-saving devices practices for household water conservation	**Never (%)**	**Rarely (%)**	**Occasionally (%)**	**Sometimes (%)**	**Frequently (%)**	**Usually (%)**	**Every Time (%)**
Repairing all water leaks in toilets and faucets	0.6	0.0	8.3	31.4	50.9	8.9	0.0
Inspecting dripping taps and toilets	0.6	0.0	8.0	31.6	51.0	8.8	0.0
Installing water-efficient faucets or shower heads	70.8	28.9	0.0	0.0	0.3	0.0	0.0
Installing a low-water or dual-flush toilet	71.0	29.0	0.0	0.0	0.0	0.0	0.0
Installing flow restrictor in the shower/s	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Installing water sense showerhead	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Installing water sense toilet	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Household water-saving behavior in indoor engagements							
Turning off the taps when washing face and hands	0.0	86.0	0.0	0.0	0.0	14.0	0.0
Turning off the water when brushing teeth	0.0	59.0	0.0	27.0	0.0	14.0	0.0
Turning off the shower while soaping	0.0	56.0	0.0	32.0	0.0	12.0	0.0
Taking short showers or limit showering time to 5 minutes	0.0	29.0	16.0	34.0	20.0	1.0	0.0
Turning off the tap when washing dishes	0.0	66.0	0.0	19.0	0.0	15.0	0.0
Plugging the sink when washing dishes	0.0	66.0	0.0	19.0	0.0	15.0	0.0
Reuse or recycle wastewater	0.0	1.0	46.0	1.0	51.0	1.0	0.0
Household water consumption in outdoor water conservation							
Washing a car with a bucket of water rather than a running hose	0.0	0.0	0.0	57.1	28.6	14.3	0.0
Watering early in the morning/afternoon	0.0	0.0	0.0	1.7	17.0	65.5	15.7
Watering plants when necessary and based on plant type	0.0	20.8	16.9	58.9	2.2	0.9	0.4
Use alternative water resources for outdoor services	0.0	55.6	44.1	0.0	0.3	0.0	0.0
Improve soil with organic material improves water retention	14.5	53.5	25.2	6.2	0.2	0.0	0.0

(iv) End-Use Residential Water Consumption

The result revealed that residential end-use water consumption exhibits distinct characteristics which are reflected by the following key findings:

- Average shower time is 8-10 minutes, with 11.6 liters of water per person. Showers make up 17.9% of total household water consumption.
- In toilets end use water consumption flush toilets use 12-15 liters per flush. Toilets make up for 19.2% of total water use, averaging 12.6 liters per person per day.
- Hand washing clothes accounts for 12.22% of daily water use, averaging 5.92 liters per person per day.
- In cooking on traditional stoves, primarily for drinking and cooking, consumes about 41.97% of the household water use
- Outdoor service accounts for about 8.7% of the household water consumption

4.3.3 Tracking and Tracing Water Consumption of Non Residential Sector

4.3.3.1 Commercial Water Consumption Characteristics

(i) Hotel water consumption and conservation practice

(a) Hotel water consumption characteristics

Table 4.14 indicates that the higher-ranked hotels show greater water consumption with an average of 25,974.02 liters daily, compared to medium 14,080.46 liters and normal hotels 3,881.56 liters per day. Daily water usage per room also increases with hotel rank, topping at 125.75 liters for ranked hotels, 115.85 for medium and 63.98 liters for normal hotels. Despite higher consumption, higher-ranked hotels maintain the highest occupancy rates 81.82%) compared to medium 79.69% and normal hotels 75.26%.

Table 4.14 Hotel water consumption characteristics

Hotel Rank	sample	Average daily total water consumption (liter)	Average room occupancy rate (%)	Average daily water consumption per room (liter)	Average water consumption (liter/m^2)
Normal	19	3881.56	75.26	63.98	3.76
Medium	16	14080.46	79.69	115.85	4.89
Ranked	11	25974.02	81.82	125.75	5.63
Total	**46**	**12711.9**	**78.34**	**96.79**	**4.68**

(b) Hotel end-use water consumption characteristics

Table 4.15 shows that rooms are the largest water consumers in hotels, using 29.5% that consumes 3,750 liters/day. The kitchen follows at 16.37% that consumes 2,080 liters/day, laundry at 14.54% consumes 1,848 liters/day, and landscaping at 13.46% consumes 2,916 liters/day. Air conditioning accounts for 10.05% consumes 1,278 liters/day, other services like cleaning use 15.43% consumes 1,906 liters/day and swimming pools have the smallest share at 0.65% that consumes 83 liters/day.

Table 4.15 Hotel water end-use water consumption characteristics

Hotel endues	**Percentage of total hotel water consumption (%)**	**Average Daily Water consumption(liter)**
Laundry	14.54	1, 848
Swimming pool	0.65	83
Landscape	13.46	2,916
Air conditioning	10.05	1,278
Restaurant-kitchen	16.37	2080
Rooms	29.5	3,750
Other services	15.43	1906
Total	**100**	**12,013**

(c) Hotel water conservation practice

Table 4.16 revealed the characteristics of water conservation practices in hotels. The analysis reveals the following key findings.

Table 4.16 Hotel water conservation practice

Indicator	Never (%)	Rarely (%)	Occasionally (%)	Sometimes (%)	Frequently (%)	Usually (%)	Every time (%)	Not Applicable (%)
Regularly checking for leaks in buildings proactively	0.0	28.3	32.6	39.1	0.0	0.0	0.0	0.0
Appointing facility management unit and assigning manager	0.0	39.1	0.0	37.0	23.9	0.0	0.0	0.0
Placing signs suggesting guests don't leave taps running	41.3	34.8	23.9	0.0	0.0	0.0	0.0	0.0
Establishing water consumption audit system	30.4	0.0	45.7	23.9	0.0	0.0	0.0	0.0
Encouraging guests to shower instead of bath	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Educating staff about water saving practices	47.8	30.4	21.7	0.0	0.0	0.0	0.0	0.0
Applying water for the purpose	45.7	0.0	32.6	21.7	0.0	0.0	0.0	00
Hotel toilet water conservation								
Conducting regular maintenance for toilet leaks	0.0	0.0	42.6	0.0	34.0	23.4	0.0	0.0
Installing flow restrictors to reduce tap flow	41.3	0.0	34.8	23.9	0.0	0.0	0.0	0.0
Using alternative water source for flush	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Retrofitting old toilet fixtures and lines	0.0	0.0	43.5	0.0	32.6	23.9	0.0	0.0
Reminding users not to use toilets as waste baskets	39.1	17.4	43.5	0.0	0.0	0.0	0.0	0.0
Installing self-stopping taps in toilets	47.8	0.0	52.2	0.0	0.0	0.0	0.0	0.0
Placing a sign above basins	41.3	32.6	0.0	26.1	0.0	0.0	0.0	0.0
Hotel shower water conservation								
Conducting maintenance checks for shower leaks	0.0	0.0	0.0	41.3	34.8	23.9	0.0	0.0
Installing low flow rate regulators	41.3	0.0	34.8	23.9	0.0	0.0	0.0	0.0
Installing water-efficient showerheads	41.3	0.0	0.0	34.8	23.9	0.0	0.0	0.0
Retrofitting old shower fixtures	0.0	0.0	34.8	0.0	41.3	23.9	0.0	0.0
Users taking showers less than 5 minutes	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Installing self-stopping taps in showers	37.0	28.3	19.6	15.2	0.0	0.0	0.0	0.0
We conduct regular maintenance checks for leaks for shower fixtures	41.3	23.9	19.6	15.2	0.0	0.0	0.0	0.0

Hotel water conservation in gardening	Never (%)	Rarely (%)	Occasionally (%)	Sometimes (%)	Frequently (%)	Usually (%)	Every time (%)	Not Applicable (%)
Planting indigenous plants suited to rainfall	0.0	0.0	41.3	39.1	19.6	0.0	0.0	0.0
Preparing drought-resistant plants	0.0	41.3	58.7	0.0	0.0	0.0	0.0	0.0
Grouping plants by water needs (hydro-zoning)	0.0	37.0	37.0	26.1	0.0	0.0	0.0	0.0
Improving soil with organic material	0.0	76.1	23.9	0.0	0.0	0.0	0.0	0.0
Reclaiming rainwater	0.0	80.4	19.6	0.0	0.0	0.0	0.0	0.0
Watering at night/morning	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Using drip irrigation	73.9	26.1	0.0	0.0	0.0	0.0	0.0	0.0
Water conservation in sanitary duties								
Cleaners aware not to waste water	0.0	0.0	0.0	43.5	32.6	23.9	0.0	0.0
Cleaners' clean surfaces without water	0.0	56.5	43.5	0.0	0.0	0.0	0.0	0.0
Cleaners use mops instead of hoses	0.0	0.0	0.0	0.0	63.0	37.0	0.0	0.0
Cleaners use alternative water	0.0	58.7	41.3	0.0	0.0	0.0	0.0	0.0
Cleaners use buckets to save water	0.0	0.0	0.0	0.0	89.1	10.9	0.0	0.0
Cleaners reduce chemicals	0.0	0.0	0.0	0.0	60.9	39.1	0.0	0.0
Cleaners are commonly informed how to reduce water use where possible	0.0	0.0	67.4	32.6	0.0	0.0	0.0	0.0
Water saving awareness and education								
Training for water efficiency	82.6	17.4	0.0	0.0	0.0	0.0	0.0	0.0
Suggestion boxes for water-saving	82.6	17.4	0.0	0.0	0.0	0.0	0.0	0.0
Posting water-saving signs	47.8	52.2	0.0	0.0	0.0	0.0	0.0	0.0
Informing about water saving	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Providing water-efficient appliances	82.6	17.4	0.0	0.0	0.0	0.0	0.0	0.0
Encouraging water-saving habits	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Offering incentives for water-saving	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(ii) Pension water consumption and conservation practice

(a) **Pension water consumption characteristics**

Figure 4.11 revealed that on average, a pension uses 4,368.71 liters of water daily, with usage ranging from 1,114 to 14,857 liters per day.

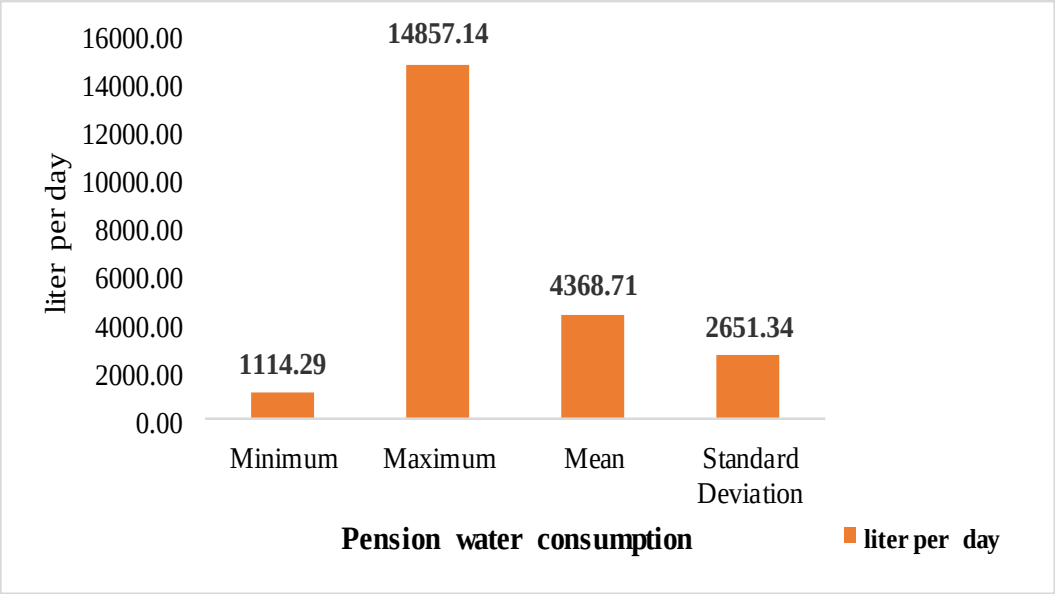

Figure 4.11 : Daily water consumption metrics of pensions(liter/day)

(b) **Pension end use water consumption characteristics**

The analysis result reveals that rooms in pensions are the largest consumers of water, making up 27% of the total usage with an average daily consumption of 76.31 liters per room. For each square meter of floor area, pensions consume an average of 4.9 liters of water per day. Commercial laundry machines, which process between 12.5 to 200 kilograms of laundry, use 20 to 28 liters of water per kilogram, resulting in a total of 5,400 liters per load. In pensions, washing towels and linens for visitor hygiene averages 22.05 liters of water per kilogram daily. The water consumption of laundry was estimated using the type, number of closes, and their corresponding weights.

(c) **Pension water conservation practices across**

Table 4.17 indicated that water conservation practices in pensions exhibit certain patterns, with several practices are either never or rarely implemented.

Table 4.17 Water conservation practice at pension

Pension water conservation practice at building or block level	Never	Rarely	Occasionally	Sometimes	Frequently	Usually
Checking regularly for leaks in buildings	0.0	0.0	59.5	31.0	7.1	0.0
Establishing facility management unit and assigning water manager	0.0	71.4	28.6	0.0	0.0	0.0
Placing a sign above basins to not leave tap running	71.4	28.6	0.0	0.0	0.0	0.0
Establishing water consumption auditing and monitoring system	0.0	100.0	0.0	0.0	0.0	0.0
Encouraging guests to shower instead of bath	0.0	0.0	78.6	14.3	7.1	0.0
Educating staff on water consumption practices	59.5	35.7	4.8	0.0	0.0	0.0
Applying water for its purpose	0.0	0.0	100.0	0.0	0.0	0.0
Water conservation practice at pension toilet						
Conducting regular maintenance checks for leaks in toilets	0.0	0.0	21.4	64.3	14.3	0.0
Installing flow restrictors to reduce tap flow	21.4	78.6	0.0	0.0	0.0	0.0
Using alternative water for flush	0.0	100.0	0.0	0.0	0.0	0.0
Retrofitting old toilet fixtures and lines	0.0	0.0	40.5	45.2	14.3	0.0
Reminding users not to use toilets as waste baskets	0.0	33.3	66.7	0.0	0.0	0.0
Installing self-stopping/sensor hand-basin taps in toilets	40.5	59.5	0.0	0.0	0.0	0.0
Water conservation practice at pension shower						
Conducting regular maintenance checks for leaks in shower fixtures	0.0	0.0	16.7	64.3	19.0	0.0
Installing low flow rate regulators	16.7	83.3	0.0	0.0	0.0	0.0
Installing water-efficient showerheads	16.7	83.3	0.0	0.0	0.0	0.0
Retrofitting old shower fixtures and lines	0.0	0.0	11.9	69.0	19.0	0.0
Setting shower usage to 5 minutes	59.5	40.5	0.0	0.0	0.0	0.0
Installing self-stopping/sensor hand-basin taps in showers	100.0	0.0	0.0	0.0	0.0	0.0
Placing a sign above basins to not leave shower running	0.0	100.0	0.0	0.0	0.0	0.0
Water conservation awareness creation practice at pension						
Cleaners reduce chemicals during cleaning	0.0	0.0	0.0	0.0	66.7	33.3
Providing training on water efficiency	45.2	54.8	0.0	0.0	0.0	0.0
Providing suggestion boxes for water consumption feedback	100.0	0.0	0.0	0.0	0.0	0.0
Posting water saving signs	45.2	54.8	0.0	0.0	0.0	0.0
Informing or instructing about water saving	0.0	42.9	57.1	0.0	0.0	0.0
Providing water-efficient appliances and systems	0.0	52.4	47.6	0.0	0.0	0.0
Encouraging employees to adopt water-saving practices	0.0	0.0	47.6	52.4	0.0	0.0
Offering incentives for water-saving efforts	100.0	0.0	0.0	0.0	0.0	0.0

(iii) Restaurant water consumption and conservation practice

(a) Restaurant water consumption characteristics

Table 18 reveals that the average daily water consumption of a restaurant is 1,334.33 liters, ranging from 666.67 to 4,166.67 liters per day.

(b) Restaurant end use water consumption

Table 4.18 reveals that in restaurant kitchens, the average daily water consumption is 633.39 liters. Meal preparation accounts for 47.5% of this water usage. Domestic water consumption in restaurant accounts for 34.6% of this water usage. On average, daily domestic water consumption in restaurants is 467.01 liters.

Table 4. 18 Restaurant end use water consumption

Type of Consumption	Share of water consumption (%)	Minimum (liter/day)	Maximum (liter/day)	Mean (liter/day)	Std. Deviation (liter/day)
Kitchen water consumption	47.5	240.00	1200.00	633.39	318.54
Domestic water consumption (urinals, hand washing and faucets)	34.6	233.33	1458.33	467.01	271.18
Landscape water consumption	3.2%	20.00	125.00	40.03	23.25
Miscellaneous consumptions (cleaning, heating, and cooling)	14.7%	40.00	1383.33	198.85	244.53

Table 4.19 Water conservation practice at restaurants

Restaurant water conservation practice at building or block level	Never (%)	Rarely (%)	Occasionally (%)	Sometimes (%)	Frequently (%)	Usually (%)
Checking regularly for leaks in the buildings proactively	0.0	0.0	39.1	60.9	0.0	0.0
Establishing facility management unit and assigning water facility manager	85.2	14.8	0.0	0.0	0.0	0.0
Placing a sign above basins suggesting that guests don't leave the tap running	38.3	61.7	0.0	0.0	0.0	0.0
Establishing water consumption audit and planning system	81.7	18.3	0.0	0.0	0.0	0.0
Serving water to guests that ask for it	0.0	59.1	40.9	0.0	0.0	0.0
Educating staff about water consumption in indoor and outdoor uses	27.0	73.0	0.0	0.0	0.0	0.0
Applying water for the purpose	0.0	43.5	56.5	0.0	0.0	0.0
Water conservation practice at restaurant toilet						
Conducting regular maintenance checks for leaks in toilets	0.0	0.0	7.0	67.0	26.1	0.0
Installing flow restrictors to reduce tap flow	85.2	14.8	0.0	0.0	0.0	0.0
Using recycled water to pour-flush	0.0	100.0	0.0	0.0	0.0	0.0
Retrofitting old toilet fixtures and lines	0.0	0.0	13.0	63.5	23.5	0.0
Reminding users not to use toilets as basket waste	0.0	28.7	71.3	0.0	0.0	0.0
Installing hand-basin taps in toilet that are self-stopping type/sensors	28.7	71.3	0.0	0.0	0.0	0.0
Placing a sign above basins suggesting that guests don't leave the tap running in service areas	44.3	55.7	0.0	0.0	0.0	0.0
Water conservation practice at restaurant hand washes						
Conducting regular maintenance checks for leaks in hand wash areas	0.0	0.0	0.0	0.0	73.9	26.1
Installing flow restrictors to reduce water flow	90.4	9.6	0.0	0.0	0.0	0.0
Installing sensors in hand wash areas	100.0	0.0	0.0	0.0	0.0	0.0
Retrofitting old hand wash fixtures	0.0	0.0	0.0	73.0	27.0	0.0
Checking tanker overflow	0.0	0.0	41.7	58.3	0.0	0.0
Customers turn off the tap while scrubbing	0.0	0.0	31.3	68.7	0.0	0.0
Placing a sign above basins suggesting that guests don't leave the tap running in hand washes	87.8	12.2	0.0	0.0	0.0	0.0
Water conservation awareness creation at restaurant						
Providing training to increase awareness of water efficiency practices	21.7	78.3	0.0	0.0	0.0	0.0
Providing suggestion boxes to collect suggestions about water consumption	100.0	0.0	0.0	0.0	0.0	0.0
Posting water saving signs	100.0	0.0	0.0	0.0	0.0	0.0
Informing or instructing about water-saving	0.0	41.7	58.3	0.0	0.0	0.0
Providing or supplying water-efficient appliances and systems	98.3	1.7	0.0	0.0	0.0	0.0
Encouraging employees to adopt water-saving practices	0.0	100.0	0.0	0.0	0.0	0.0
Offering incentives for water-saving efforts	100.0	0.0	0.0	0.0	0.0	0.0

iv) Cafe Water consumption and conservation practice

(a) Café water consumption characteristics

Figure 4.12 reveals that the average daily water consumption of a cafe is 269.5 liters, ranging from 166.67 to 733 liters.

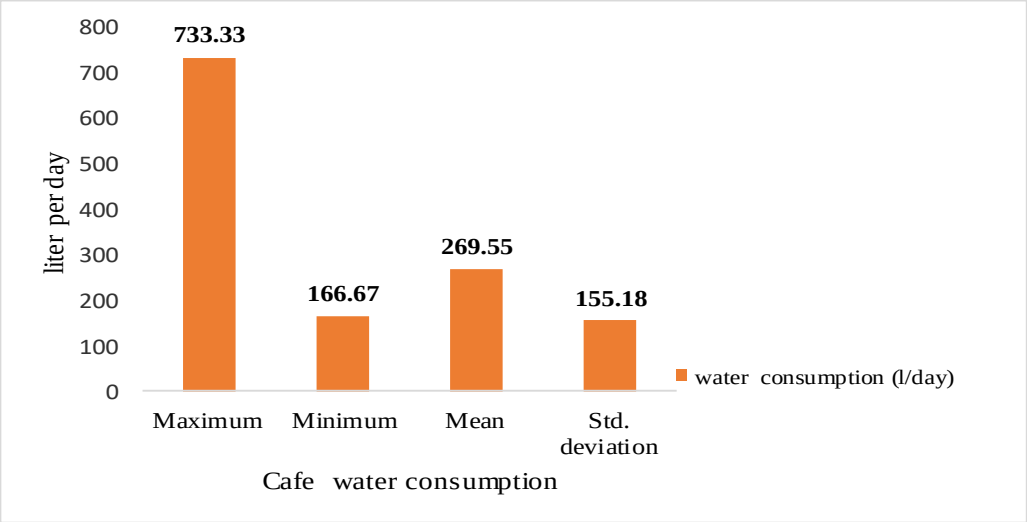

Figure 4.12 : Average daily total water consumption of cafes

(b) Café end use water consumption

Table 4.20 shows the distribution of water usage in cafes which includes kitchen purposes account for 132.3 liters per day or 49.7%, domestic needs use 97.85 liters per day or 36.3%, and cleaning and landscape watering consume 37.74 liters per day or 14%.

Table 4.20 Café end use water consumption characteristics

Type of consumption	**Share of consumption (%)**	**Average daily water consumption(l/day)**
Water consumption for kitchen purpose	49.7	132.31
Water consumption for domestic purpose (urinals, hand washing faucets, and toilets)	36.3	97.85
Others (ground cleaning and watering landscapes)	14	37.74

Table 4.21 Water conservation practices at café

Cafe water conservation practice at building or block level	Never (%)	Rarely (%)	Occasionally (%)	Sometimes (%)	Frequently (%)	Usually (%)	Every time (%)
Checking regularly for leaks in the buildings	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Establishing facility management unit and assigning water facility manager	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Placing a sign above basins suggesting guests don't leave the tap running while shaving/brushing	0.0	44.2	55.8	0.0	0.0	0.0	0.0
Establishing water consumption audit and planning system	0.0	44.2	55.8	0.0	0.0	0.0	0.0
Serving water to guests that ask for it	0.0	62.5	37.5	0.0	0.0	0.0	0.0
Educating staff about water saving	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Applying water for the purpose	94.2	5.8	0.0	0.0	0.0	0.0	0.0
Water conservation practice at cafe toilet							
Conducting regular maintenance checks for leaks in toilets	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Installing flow restrictors to reduce tap flow	93.3	6.7	0.0	0.0	0.0	0.0	0.0
Using recycled water to pour-flush	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Retrofitting old toilet fixtures	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Reminding users not to use toilets as waste baskets	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Installing self-stopping/sensor taps in toilets	91.3	8.7	0.0	0.0	0.0	0.0	0.0
Placing a sign above basins suggesting that guests don't leave the tap running in service area	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Water conservation practice at café hand wash							
Conducting regular maintenance checks for leaks in hand wash	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Installing flow restrictors to reduce water flow in hand wash areas	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Installing sensors in hand wash areas	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Retrofitting old hand wash fixtures and lines	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Checking tanker overflow	0.0	0.0	32.7	67.3	0.0	0.0	0.0
Customers turn off the tap while they scrub	0.0	32.7	67.3	0.0	0.0	0.0	0.0
Placing a sign above basins suggesting that guests don't leave the tap running in hand washes	93.2	6.8	0.0	0.0	0.0	0.0	0.0
Water conservation awareness creation in cafes							
Providing training to increase awareness of water efficiency practices	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Providing suggestion boxes to collect suggestions about water consumption	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Posting water saving signs	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Informing or instructing about water saving	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Providing or supplying water-efficient appliances and systems	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Encouraging employees to adopt water-saving practices	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Offering incentives for water-saving efforts	100.0	0.0	0.0	0.0	0.0	0.0	0.0

(iv) Commercial car wash water consumption and conservation practice

(a) Commercial car wash water consumption characteristics

The analysis result reveals that on average, each car wash station cleans 15 vehicles daily, with water usage varying based on vehicle size, dirt level, and washing method. Table 4.22 shows three methods were identified such as manual washing with bucket, sponge and brush; bucket and hose and power wash. Manual washing tends to waste more water compared to hose and power wash systems, impacting overall water efficiency at car wash stations. Larger vehicles like heavy trucks and public buses are rarely washed at stations and often cleaned in rivers, complicating water use estimates. Key informants suggest buses and trucks use 160-180 liters per wash manually and 100-120 liters with a power wash.

Table 4.22 Vehicle washing methods and water volumes used for washing

Types of vehicles	Washing methods		
	Bucket only	Bucket and hose	Power wash
Bajaj	20-25	15-20	10-15
Automobile	40-60	30-40	20-30
Pickup	60-80	40-60	30-40
Minibus	60-80	40-70	40-60
Bus	140-160	120-140	80-120
Tracks	160-180	140-160	100-120

Table 4.23 Commercial car wash water conservation practices

Equipment operation and maintenance for water conservation in in car wash stations	**Never (%)**	**Rarely (%)**	**Occasionally (%)**	**Sometimes (%)**	**Frequently (%)**	**Usually (%)**	**Every Time (%)**
Checking for water leaks regularly and repair them immediately as they occur	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Upgrading to rotary or turbo nozzles instead of flat, fan nozzles	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Replacing spray nozzles regularly	3.8	0.0	96.2	0.0	0.0	0.0	0.0
Replacing brass or plastic nozzles with low-flow stainless steel	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Maintaining all equipment to original or improved specifications for water usage	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Regularly checking sanitary lines for leaks, and fix leaks immediately	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Nozzle and hose monitory for water conservation practice in car wash stations							
Checking the alignment of nozzles	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Clothing the hose while washing	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Adjusting nozzle tip size and pressure to reduce its flow	100.0	0.0	0.0	0.0	0.0	0.0	0.0
All hoses and faucets have automatic shutoff valves	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Using nozzle protection for hand-held	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Considering collecting rainwater on the roof to use in washing phase	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Use stainless steel or hard ceramic nozzles to maintain flow and pressure	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Environmental protection and water conservation practice in car wash stations							
Sweep impervious areas instead of washing	0.0	3.7	96.3	0.0	0.0	0.0	0.0
Ensure accurate dilution ratios for detergents	0.0	3.7	96.3	0.0	0.0	0.0	0.0
Clean bays or driveways with high-pressure, low-volume water systems	0.0	3.7	96.3	0.0	0.0	0.0	0.0
Installing a water reclaim system	0.0	88.9	11.1	0.0	0.0	0.0	0.0
Staff training to inspect and maintain water systems	0.0	88.9	11.1	0.0	0.0	0.0	0.0
Preventing runoff and promoting green landscaping	0.0	100.0	0.0	0.0	0.0	0.0	0.0

4.3.3.2 Public service institutions water consumption characteristics

(i) Education sector water consumption and conservation practice

(a) Education sector water consumption characteristics

Table 4.24 shows the daily water consumption for various institutions as follows including elementary schools use 4,717.95 liters, secondary schools use 4,347.83 liters, TVET institutions use 25,641.03 liters, boarding schools use 23,411.37 liters, and universities use 1,480,000 liters. Additionally, the table indicates the average daily water consumption per student across these institutions in which TVET students use 3 liters, secondary school students use 1.75 liters, primary school students use 2.65 liters, and boarding school students use 5 liters.

Table 4.24 Education sector water consumption characteristics

Level of the education center	Daily water consumption metrics(l//institution/day)		Daily water consumption metrics (L/student/day	
	Mean	Std. Deviation	Mean	Std. Deviation
Elementary school	4717.95	4045.40	2.26	1.67
Secondary school	4347.83	3280.10	1.75	1.29
TVET	25641.03	0.00	3.00	0.00.
Boarding school	23411.37	0.00	5.00	0.00.
University	1,480,000	0.00	4.00	0.00

(b) Education sector end use water consumption characteristics

Table 4.25 indicates that water usage is distributed 40% for domestic purposes (drinking, cleaning and personal hygiene), 35% for landscaping, 6% for meal preparation, and 19% for horticulture and other uses.

Table 4.25 End use water consumption characteristics of educational institutions

Water consumption by end use (Liter/day)	Minimum	Maximum	Mean	Percent
Domestic (toilet, drinking, cleaning and personal hygiene)	192.31	10256.41	2445.4	40
Landscaping	168.27	8974.36	2139.74	35
Launch /kitchen activities)	28.85	1538.46	366.81	6
Other activities like Horticulture	24.04	1282.05	305.68	19

(c) Education institution water conservation practices

Table 4.26 revealed the water conservation practices in education sector.

Table 4. 26 Water conservation practice at education sector

Building level operation and awareness creation for water conservation in education institutions	Never (%)	Rarely (%)	Occasionally (%)	Sometimes (%)	Frequently (%)	Usually (%)
Checking regularly for leaks in the buildings	0.0	0.0	53.8	46.2	0.0	0.0
Establishing facility management unit and assigning water manager	0.0	100.0	0.0	0.0	0.0	0.0
Placing a sign above basins suggesting that students don't leave the tap running	100.0	0.0	0.0	0.0	0.0	0.0
Encouraging water consumption audit and planning	0.0	100.0	0.0	0.0	0.0	0.0
Serving water to students that ask for it	0.0	0.0	0.0	46.2	53.8	0.0
Educating staff on proper water consumption in indoor and outdoor water consumption practices	0.0	53.8	46.2	0.0	0.0	0.0
Applying water for the purpose	0.0	0.0	100.0	0.0	0.0	0.0
School toilet water conservation practices						
Conducting regular maintenance checks for leaks in toilets	0.0	0.0	100.0	0.0	0.0	0.0
Installing flow restrictors to reduce tap flow	100.0	0.0	0.0	0.0	0.0	0.0
Using alternative water to pour-flush	100.0	0.0	0.0	0.0	0.0	0.0
Retrofitting old toilet fixtures and lines	0.0	0.0	57.7	42.3	0.0	0.0
Reminding users not to use toilets as basket waste	0.0	0.0	46.2	53.8	0.0	0.0
Installing hand-basin taps in toilets that are self-stopping type/sensors	100.0	0.0	0.0	0.0	0.0	0.0
Placing a sign above basins suggesting that students don't leave the tap running in rooms	100.0	0.0	0.0	0.0	0.0	0.0
Water conservation practice at school landscapes						
Planting indigenous plants which are more likely to be naturally adapted to thrive with the amount of rainfall	0.0	0.0	100.0	0.0	0.0	0.0
Preparing plant types, which do not need much water	0.0	100.0	0.0	0.0	0.0	0.0
Grouping similar plant types according to their water requirements (hydro-zoning)	0.0	100.0	0.0	0.0	0.0	0.0
Improving soil condition with organic material improves water retention	0.0	100.0	0.0	0.0	0.0	0.0
Reclaiming water from rainwater or grey water	0.0	0.0	100.0	0.0	0.0	0.0
Watering during night and morning to avoid evaporation and losses	0.0	0.0	0.0	4.0	96.0	0.0
Using drip irrigation wherever possible	0.0	100.0	0.0	0.0	0.0	0.0
Water saving education practices in educational institutions						
Providing training to increase awareness of water saving practices	100.0	0.0	0.0	0.0	0.0	0.0
Providing suggestion boxes to collect suggestions	100.0	0.0	0.0	0.0	0.0	0.0
Posting water saving signs	100.0	0.0	0.0	0.0	0.0	0.0
Informing or instructing about water saving	100.0	0.0	0.0	0.0	0.0	0.0
Providing or supplying water-efficient appliances and systems	0.0	0.0	100.0	0.0	0.0	0.0
Encouraging employees and students to adopt water-saving habits	0.0	100.0	0.0	0.0	0.0	0.0
Offering incentives for water-saving efforts	100.0	0.0	0.0	0.0	0.0	0.0

(ii) Health sector water consumption and conservation practice

(a) Health sector water consumption characteristics

Table 4.27 reveals that hospitals consume an average of 376,811.59 liters of water daily, while health centers use 3,479.17 liters per day.

Table 4. 27 Daily water consumption metrics of health institutions

Daily water consumption metrics(L/day)	Mean	Std. Deviation
Heath center	3,479.17	1361.13
Hospital	376,811.59	0.00

(b) Health sector end use water consumption characteristics

Table 4.28 indicates that the primary categories of end-use water consumption in health institutions are kitchen, landscape, domestic, medical, laundry, and cooling and heating.

Table 4.28 End uses of water in hospitals and health centers

Type of health institutions		Kitchen/ Cafeteria (l/day)	Landscape (l/day)	Domestic (l/day)	Medical (l/day)	Laundry (l/day)	Cooling and heating (l/day)	Others (l/day)
Heath Center	Mean	347.92	2435.42	1217.71	521.875	243.54	626.25	278.33
Hospital	Mean	37681.15	263768.12	131884.1	56521.7	26376.8	67826.08	30144.9

(c) Health institution water conservation practices

Table 4.29 reveals the water conservation practices in health sector.

Table 4.29 Water conservation practices at health institutions

Building level operation and awareness creation for water conservation in health institutions	Never (%)	Rarely (%)	Occasionally (%)	Sometimes (%)	Frequently (%)
Checking regularly for leaks in buildings	0.0	0.0	88.9	11.1	0.0
Establishing a facility management	0.0	88.9	0.0	0.0	11.1
Placing signs above basins to inform water saving	0.0	88.9	0.0	0.0	11.1
Conducting water consumption audit	0.0	100.0	0.0	0.0	0.0
Serving water to visitors that ask for it	0.0	0.0	100.0	0.0	0.0
Educating staff on proper water consumption	0.0	88.9	11.1	0.0	0.0
Health toilet water conservation practices					
Conducting regular checks for leaks in toilets	0.0	100.00	0.0	0.0	0.0
Installing flow restrictors to reduce tap flow	88.9	0.0	11.1	0.0	0.0
Using recycled water to pour-flush	88.9	11.1	0.0	0.0	0.0
Retrofitting old toilet fixtures and lines	0.0	0.0	100.0	0.0	0.0
Reminding users not to use toilets as waste baskets	88.9	0.0	11.1	0.0	0.0
Installing self-stopping taps/sensors in toilets	88.9	11.1	0.0	0.0	0.0
Health shower water conservation practices					
Conducting regular checks for leaks in shower	0.0	0.0	88.9	11.1	0.0
Installing low flow rate regulators	88.9	0.0	11.1	0.0	0.0
Installing water-efficient showerheads	100.0	0.0	0.0	0.0	0.0
Retrofitting old shower fixtures and lines	0.0	0.0	88.9	11.1	0.0
Setting shower flow to up to or less than 5 minutes	100.0	0.0	0.0	0.0	0.0
Installing self-stopping taps/sensors in showers	88.9	0.0	11.1	0.0	0.0
Placing signs above basins in shower to save water	88.9	0.0	11.1	0.0	0.0
Health landscape water conservation practices					
Planting indigenous plants adapted to local rainfall	0.0	0.0	88.9	11.1	0.0
Selecting plant types that don’t need much water	0.0	88.9	11.1	0.0	0.0
Grouping similar plant types to hydro-zoning	0.0	88.9	0.0	11.1	0.0
Improving soil condition with organic material	0.0	88.9	11.1	0.0	0.0
Reclaiming water from rainwater	0.0	88.9	11.1	0.0	0.0
Watering during night/morning	0.0	0.0	0.0	0.0	100.0
Using drip irrigation wherever possible	88.9	11.1	0.0	0.0	0.0
Awareness creation in health institutions					
Providing training to increase awareness	100.0	0.0	0.0	0.0	0.0
Providing suggestion boxes to collect	100.0	0.0	0.0	0.0	0.0
Posting water-saving signs	88.9	0.0	11.1	0.0	0.0
Informing or instructing about water saving	88.9	0.0	11.1	0.0	0.0
Providing water-efficient appliances and systems	88.9	0.0	11.1	0.0	0.0
Encouraging employees to adopt water-saving	88.9	0.0	11.1	0.0	0.0
Offering incentives for water-saving efforts	100.0	0.0	0.0	0.0	0.0

4.3.3.3 Religious institutions water consumption characteristics

(a) Religious institution water consumption characteristics

Table 4.30 reveals the sacred significance of water in the religions institutions where it symbolized as purification and is integral to rituals such as baptism in churches and ablution (wudu) in mosques. On average, churches use 2768.86 liters of water daily while mosques use 2,267.65 liters.

Table 4.30 water consumption characteristics in religious institutions

Religious institution	Average daily consumption (l/day)	Religious water end use consumption			
		End Use/Function	Minimum (L/day)	Maximum (L/day)	Mean (L/day)
Mosque	2267.65	Toilet and shower	86.96	296.30	136.08
		Landscape	72.46	246.91	113.38
		Ground cleaning	43.48	148.15	68.03
		Ablution (Wudu) ritual	975.00	3900.00	1813.96
		Unseen/washing and purifying dead body	86.96	296.30	136.06
Church	2768.86	Non ritual	816.67	6481.48	1886.40
		Ritual	350.00	2777.78	808.46
		Infant baptism (L/infant)	3.00	5.00	4.00
		Water for residents/monastics (L/c/day)	65.00	75.00	70.00

(b) Religious institution water end use consumption characteristics

Table 4.30 highlights water usage in mosques and churches. In mosques, ablution (wudu) accounts for over 80% of water use, with the rest used for restrooms, cleaning, and other purposes. In churches, 70% of water is for rituals such as blessings, baptisms, and healing (averaging 808 liters daily), while 30% (1,886.4 liters daily) supports cleaning, landscaping, and monks' consumption (70 liters per person). Baby baptisms require 3-5 liters each.

(c) Religious institution water conservation practices

Table 4.31 and Table 4.32 reveals water conservation characteristics in mosques and in churches.

Table 4.31 water conservation practices at mosques

Building level operation and awareness creation for water conservation in mosques	**Never (%)**	**Rarely (%)**	**Occasionally (%)**	**Sometimes (%)**	**Frequently (%)**	**Usually (%)**
Checking regularly for leaks in the buildings proactively	0.0	0.0	0.0	0.0	100.0	0.0
Establishing facility assigning water facility manager	0.0	100.00	0.0	0.0	0.0	0.0
Placing a sign above basins to show water saving	100.0	0.0	0.0	0.0	0.0	0.0
Encouraging water consumption audit system	0.0	0.0	100.0	0.0	0.0	0.0
Serve water to visitors that ask for it	0.0	0.0	0.0	0.0	0.0	100.0
Educating believers on proper water saving	0.0	0.0	0.0	0.0	0.0	100.0
Applying water for the purpose	0.0	0.0	0.0	0.0	100.0	0.0
Water saving practice in toilets in mosques						
Conducting maintenance checks for leaks in toilets	0.0	0.0	0.0	25.0	75.0	0.0
Installing flow restrictors to reduce tap flow	21.4	57.1	21.4	0.0	0.0	0.0
Using recycled water to pour-flush	0.0	0.0	0.0	39.3	60.7	0.0
Retrofitting old toilet fixtures and lines	0.0	0.0	0.0	25.0	75.0	0.0
Reminding users not to use toilets as basket waste	0.0	0.0	25.0	75.0	0.0	0.0
Installing hand-basin taps that are self-stopping type/sensors	32.1	67.9	0.0	0.0	0.0	0.0
Water saving practice in hand washes in mosques						
Placing a sign above basins suggesting followers don't leave the tap running in the service area	67.9	32.1	0.0	0.0	0.0	0.0
Conducting maintenance checks for leaks in hand wash	0.0	0.0	7.1	0.0	92.9	0.0
Installing flow restrictors to reduce flow in hand wash	0.0	67.9	32.1	0.0	0.0	0.0
Installing sensors in hand wash area	78.6	21.4	0.0	0.0	0.0	0.0
Retrofitting old hand wash fixtures and lines	0.0	0.0	0.0	100.0	0.0	0.0
Followers turn off the tap while they scrub	0.0	0.0	0.0	0.0	0.0	100.0
Checking tanker overflow	0.0	0.0	14.3	85.7	0.0	0.0
Water saving awareness creation mosques						
Religious leaders teach their followers saving water	0.0	0.0	0.0	0.0	0.0	100.0
Mosques are ideal places to spread water-saving	0.0	0.0	0.0	0.0	0.0	100.0
Followers and leaders know water is an important resource that secures survival and must be protected	0.0	0.0	0.0	0.0	0.0	100.0
Cooperation with religious and local authorities to save water in local governance	0.0	100.0	0.0	0.0	0.0	0.0
Followers and leaders support alternative water harvesting and behavioral change in saving water during rituals	0.0	75.0	25.0	0.0	0.0	0.0
Religious leaders are aware of water-saving technologies	0.0	100.0	0.0	0.0	0.0	0.0
The value of water is referred to in religious texts	0.0	0.0	0.0	0.0	0.0	100.00

Table 4.32 Water conservation practices at churches

Building level operation and awareness creation for water conservation in churches	**Never (%)**	**Rarely (%)**	**Occasionally (%)**	**Sometimes (%)**	**Frequently (%)**	**Usually (%)**	**Every time (%)**
Checking regularly for leaks in the buildings proactively	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Establishing facility management unit and water facility	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Placing a sign above basins suggesting water saving	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Encouraging water consumption audit and planning	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Serving water to visitors that ask for it	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Educating staff on proper water saving	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Water saving practice in toilets in churches							
Conducting regular maintenance checks for leaks in toilets	0.0	0.0	0.0	80.8	19.2	0.0	0.0
Installing flow restrictors to reduce tap flow	19.2	61.5	19.2	0.0	0.0	0.0	0.0
Using recycled water to pour-flush	0.0	0.0	0.0	80.8	19.2	0.0	0.0
Retrofitting old toilet fixtures and lines	0.0	0.0	0.0	80.8	19.2	0.0	0.0
Reminding users not to use toilets as basket waste	0.0	0.0	80.8	19.2	0.0	0.0	0.0
Installing hand-basin taps in toilets that are self-stopping	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Placing a sign above basins suggesting that guests don't leave the tap running in toilet rooms	80.8	19.2	0.0	0.0	0.0	0.0	0.0
Water saving practice in landscaping in churches							
Planting indigenous plants which are more likely to be naturally adapted to thrive with the amount of rainfall	0.0	0.0	0.0	0.0	0.0	100.0	0.0
Preparing plant types that use less water	0.0	0.0	0.0	0.0	0.0	100.0	0.0
Grouping similar plants according to their water requirements	0.0	0.0	0.0	0.0	0.0	100.0	0.0
Improving soil condition that improves water retention	0.0	0.0	0.0	0.0	0.0	100.0	0.0
Reclaiming water from rainwater or grey water	0.0	0.0	0.0	80.8	19.2	0.0	0.0
Watering during night and morning to avoid evaporation	0.0	0.0	0.0	0.0	0.0	100.0	0.0
Using drip irrigation	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Water saving awareness creation churches							
Religious leaders teach their followers about water saving	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Churches are the ideal place to spread water saving awareness	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Followers and leaders know water is an important resource	0.0	0.0	0.0	0.0	0.0	100.0	0.0
There is cooperation with religious and local authorities	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Followers and leaders support alternative water harvesting	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Religious leaders are aware of water-saving technologies	0.0	0.0	100.0	0.0	0.0	0.0	0.0
The value of water is referred to in religious texts	0.0	0.0	0.0	0.0	0.0	0.0	100.0

4.3.3.4 Tracking and Tracing Industrial Water Consumption Characteristics

(a) Industrial water consumption characteristics

Table 4.33 reveals that the textile industry is a major consumer, using 100-200 liters per kilogram produced. The metal processing sector follows, with a water demand of 5-50 liters per kilogram.

Table 4.33 Water consumption of various industries per product

Type of industry	**Water required for a unit of production in a liter**
Textile Manufacturing:	100 -200 l/kg
Food Processing	1 -5 l/kg
Beverage Processing	2 - 4 l/ liter of soft drink
Paper and Pulp Manufacturing	10 to 20 m3/ ton of paper produced.
Chemical Production	2 -10 l/kg
Metal Processing	5 - 50 l/kg
Construction Materials	150- 200 l/m^3 of concrete

(b) Water conservation practices in industrial sector

Table 4. 34 revealed differences in water conservation practices in industrial sector. Key findings are summarized as table below.

Table 4.34 Water conservation practices in industrial sector

Building level operation and awareness creation for water conservation in industry	**Never (%)**	**Rarely (%)**	**Occasionally (%)**	**Sometimes (%)**	**Frequently (%)**
Checking regularly for leaks in the buildings proactively	0.0	0.0	41.3	34.8	23.9
Establishing facility management and assigning water manager	0.0	0.0	0.0	39.1	61.9
Placing a sign above basins suggesting for water saving	0.0	41.3	58.7	0.0	0.0
Encouraging water consumption audit and planning system	0.0	41.3	37.0	21.7	0.0
Monitoring cooling systems and towers	0.0	0.0	0.0	76.1	23.9
Educating staff about water saving	0.0	28.3	41.3	30.4	0.0
Applying water for the purpose	0.0	0.0	58.7	41.3	0.0
Water saving practice in toilets industry					
Conducting regular maintenance checks for leaks in toilets	0.0	0.0	40.4	36.2	23.4
Installing flow restrictors to reduce tap flow	41.3	34.8	23.9	0.0	0.0
Using alternative water source to pour-flush	0.0	100.0	0.0	0.0	0.0
Retrofitting old toilet fixtures and lines	0.0	0.0	43.5	34.8	21.7
Reminding users not to use toilets as basket waste	39.1	17.4	43.5	0.0	0.0
Installing hand-basin taps in toilets that are self-stopping	82.6	17.4	0.0	0.0	0.0
Placing a sign above basins suggesting water saving	41.3	39.1	17.4	2.2	0.0
Water saving practice in shower industry					
Conducting regular maintenance checks for leaks for shower	0.0	0.0	37.0	39.1	23.9
Installing low flow rate regulators	37.0	32.6	30.4	0.0	0.0
Installing water-efficient showerheads	41.3	0.0	39.1	19.6	0.0
Retrofitting old shower fixtures and lines	0.0	0.0	34.8	30.4	34.8
Users take shower up to or to less than 5 minutes	0.0	100.0	0.0	0.0	0.0
Installing hand-basin taps in shower that are self-stopping	82.6	6.5	10.9	0.0	0.0
Placing a sign above basins suggesting that guests don’t leave the shower running or unclosed during unused period	63.0	21.7	15.2	0.0	0.0
Water saving practice in landscaping in in industry					
Planting indigenous plants	0.0	0.0	32.6	19.6	47.9
Preparing plant types which do not need much water	0.0	41.3	45.7	13.0	0.0
Grouping similar plant types as per their water hydro-zoning	0.0	37.0	26.1	37.0	0.0
Improving soil condition to improve water retention	0.0	76.1	6.5	17.4	0.0
Reclaiming water from rainwater	0.0	80.4	4.3	15.2	0.0
Watering during the night and morning to avoid evaporation	0.0	0.0	0.0	0.0	90
Using drip irrigation wherever possible	73.9	17.4	8.7	0.0	0.0
Water saving awareness creation industry					
Providing training to increase awareness of water saving	82.6	17.4	-	-	-
Providing suggestion boxes to collect suggestions about water saving	82.6	17.4	-	-	-
Posting water saving signs	47.8	52.2	-	-	-
Informing or instructing about water saving	0.0	100.0	-	-	-
Providing or supplying water-efficient appliances and systems	100.00	0.0	0.0	0	0.0

4.4 Quantifying Water Security Performance of Adama City Through the Lens of Urban Water Metabolism

4.4.1 Quantifying Water Mass Balance Using Natural and Anthropogenic Water Flows

Tables 4.35 and 4.36 indicate that the total inflow of water is estimated at 290.51 million cubic meters while the total outflow is 206.86 million cubic meters.

Table 4.35 Inputs water flow of Adama city for the years in 2022/2023

Inputs water flow	**Unit**	**Quantity**	**Data sources**
Precipitation	M^3 /year	$262.75*10^6$	Ethiopian Metrology Agency
Centralized water			
Centralized surface water (Cs) (from Awash River)	M^3 /year	$15.48*10^6$	Adama City Water Supply and Sewerage Service Enterprise (2022/23)
Centralized groundwater water wells	M^3 /year	$1.088*10^6$	
Decentralized groundwater (Dg)			
Industrial Park boreholes	M^3 /year	$7.5*10^6$	Industrial Park water supply and sanitation head office manager
Other industries	M^3 /year	$1.3*10^6$	
Hotel boreholes	M^3 /year	$0.018*10^6$	Hotel managers (key informants)
Subtotal		**$8.82*10^6$**	
Decentralized surface water (Ds)			
Water supply for urban greenery	M^3 /year	$0.459*10^6$	Adama City beatification and greenery experts (key informants)
Recycled water (Rw)			
Industrial Park	M^3 /year	$0.756*10^6$	Adama Industrial Park water supply and sanitation experts
Household water recycling	M^3 /year	$0.164*10^6$	Sample household survey
Adama science and technology university	M^3 /year	$0.478*10^6$	Adama science and technology university
Subtotal		**$1.4*10^6$**	
Decentralized rainwater (Dr)			
Household-level roof water harvesting	M^3 /year	$0.287*10^6$	Sample household survey by
Industries	M^3 /year	$0.17*10^6$	From key informant interview
Subtotal	M^3 /year	**$0.45*10^6$**	
Grand Total	**M^3 /year**	**$290.51*10^6$**	

Table 4.36 Output water flow of Adama city for the years 2022/2023

Inputs water flow	Unit	Quantity	Data sources
Evapotranspiration (ET)	M^3 /year	64.14 *10^6	Empirical estimation
Wastewater flow (W)	M^3 /year	9.49*10^6	Calculated from the water consumption data
Surface runoff (Rs)	M^3 /year	72.62*10^6	Calculated using the SCS-CN runoff Estimation method
Groundwater Infiltration(G)	M^3 /year	57.71*106	Empirical estimation
System loss	M^3 /year	2.9*10^6	Adama City Water Supply and Sewerage Service Enterprise
Grand total	**M^3 /year**	**206.86*106**	

4.4.2 Weight of Importance for Urban Water Security Performance Indicators

The indicators for drinking water and human well-being, ecosystem water security, climate change and water-related hazards and socioeconomic perspectives were adopted from Aboelnga et al., (2019). Their respective weights are presented below.

(i) The pairwise comparison matrix and calculated weight for household water security

Table 4.37 presents the importance weights for the drinking water and human well-being indicator in Adama city with water availability receiving the highest weight (29%) and water quality the lowest (3%). The consistency ratio (CR) of 9.87% confirms within the acceptable 10% threshold.

Table 4.37 The pairwise comparison matrix and weight for the drinking water and well-being.

Indicators	Availability	Quality	Reliability	Accessibility for water	Adequacy and equity	Dependency	Diversity	Consumption	Accessibility for sanitation	Wastewater quality	Weight
Availability	1.00	2.00	5.00	5.00	5.00	3.00	3.00	7.00	5.00	4.00	29%
Quality	1/2	1.00	2.00	2.00	2.00	3.00	3.00	7.00	4.00	2.00	15%
Reliability	1/5	1/2	1.00	3.00	3.00	3.00	3.00	5.00	4.00	2.00	14%
Accessibility for water	1/5	1/2	1/3	1.00	2.00	2.00	3.00	3.00	2.00	2.00	9%
Adequacy and equity	1/5	1/2	1/3	1/2	1.00	2.00	2.00	3.00	2.00	2.00	8%
Dependency	1/3	1/3	1/3	1/2	1/2	1.00	2.00	3.00	2.00	2.00	7%
Diversity	1/3	1/3	1/3	1/3	1/2	1/2	1.00	2.00	2.00	2.00	6%
Consumption	1/7	1/7	1/5	1/3	1/3	1/3	1/2	1.00	2.00	2.00	5%
Accessibility for sanitation	1/5	1/4	1/4	1/2	1/2	1/2	1/2	1/2	1.00	2.00	4%
Waste water quality	1/4	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1.00	3%
Total	**3.36**	**6.06**	**10.28**	**13.67**	**15.33**	**15.83**	**18.50**	**32.00**	**24.50**	**21.00**	**100%**

(ii) The pairwise comparison matrix and calculated weight for ecosystem water security

Table 4.38 shows the indicator weights for Adama city's ecosystem water security, ranging from pollution levels (31%) to green roofing (8%). The consistency ratio (CR) of 9.74% confirms the evaluation's reliability within the 10% threshold.

Table 4.38 The pairwise comparison matrix for ecosystem water security perspective

Indicators	**state of pollution**	**Proportion of bodies of water with good ambient water**	**effectiveness of storm network and wastewater**	**Green surfaces**	**Change in the Ecosystem**	**Green roofing**	**Weight**
State of pollution	1.00	2.00	3.00	2.00	2.00	2.00	31%
Proportion of Bodies of Water with Good Ambient Water	1/2	1.00	2.00	3.00	2.00	2.00	23%
effectiveness of storm network and wastewater	1/3	1/2	1.00	3.00	3.00	2.00	19%
Green surfaces	1/3	1/3	1/3	1.00	2.00	3.00	10%
Change in the extent of water related ecosystems over time	1/2	1/2	1/3	1/2	1.00	2.00	9%
green roofing	1/2	1/2	1/2	1/3	1/2	1.00	8%
Total	3.17	4.83	7.17	9.83	10.50	12.00	100%

(iii) The pairwise comparison matrix and calculated weight for climate change and water hazards

Indicators	Precipitation	Flood-prone areas	Number of floods	Public health	Temperature	Greenhouse Gas	Weight
Precipitation	1.00	1.00	3.00	3.00	2.00	4.00	28%
Flood-prone areas	1.00	1.00	3.00	3.00	2.00	3.00	25%
Number of floods	1/3	1/3	1.00	3.00	2.00	3.00	18%
Public health	1/3	1/3	1/3	1.00	2.00	3.00	13%
Temperature	1/2	1/2	1/3	1/2	1.00	2.00	10%
Greenhouse gas	1/4	1/3	1/3	1/3	1/2	1.00	06%
Total	3.42	3.50	8.17	10.83	9.50	16.00	100%

Table 4.39 shows the importance weights for climate change and water-related hazards indicators, with precipitation ranked highest at 28% and greenhouse gases lowest at 6%. A consistency ratio (CR) of 9.55% confirms reliability within the 10% threshold.

Table 4.39 The pairwise comparison matrix for climate change and water-related hazards

(iv) The pairwise comparison matrix and weight for socioeconomic water security

Table 4.40 presents the socioeconomic perspective indicator weights, with budget allocation ranked highest at 25% and cost recovery at 9%. The consistency ratio (CR) of 9.86%, below the 10% threshold ensures reliability.

Table 4.40 The pairwise comparison matrix for socioeconomic perspective

Indicators	Budget directed to WSS	illegal users	Customer's complaints	Operation and maintenance cost recovery	Water tariff	Affordability	Water energy consumption	Wastewater tariff	waste water energy consumption	Weight
Budget directed to water and wastewater	1.00	2	2.00	5.00	3.00	5.00	5.00	4.00	2.00	25%
illegal users	1/2	1.00	2.00	3.00	3.00	3.00	3.00	6.00	4.00	20%
Customer's complaints	1/2	1/2	1.00	3.00	3.00	3.00	3.00	6.00	2.00	16%
Operation and maintenance recovery	1/5	1/3	1/3	1.00	2.00	2.00	2.00	4.00	2.00	9%
Water tariff	1/3	1/3	1/3	1/2	1.00	2.00	2.00	2.00	2.00	8%
Affordability	1/5	1/3	1/3	1/2	1/2	1.00	2.00	2.00	2.00	7%
Water energy consumption	1/5	1/3	1/3	1/2	0.50	1/2	1.00	2.00	2.00	6%
Wastewater tariff	1/4	1/6	1/6	1/4	1/2	1/2	1/2	1.00	2.00	4%
Wastewater energy consumption	1/2	1/4	1/2	1/2	1/2	1/2	1/2	1/2	1.00	5%
Total	3.68	5.25	7.00	15.75	14.00	17.50	19.00	27.50	19.00	100%

4.4.3 Grading the Urban Water Security Level of Adama City From Each Indicators

(i) Grading urban water security from a household clean water supply perspective

Table 4.41 presents the current values (indicators' quantities) and scores (scaled from 1 to 5, detailed in Appendix V) for the drinking water and human well-being. By applying the Integrated Urban Water Security Index (IUWSI), Adama's urban water security grade for the drinking water and human well-being is 1.

Table 4.41 Values, scores, and weights of the drinking of water and human well-being

Indicators	Variables	Unit	Value	Score	Weight
Availability of water	Freshwater per capita	m^3/capital/year	161	1	29%
Variety of water and energy sources	Ratio of reused wastewater to total wastewater produced	%	6.4	1	6%
	Percentage contribution of alternative water sources	%	6.7	2	
	Percentage contribution of alternative energy sources	%	0	1	
Consumption	Daily per capita billed water consumption	l/capital/day	69	3	5%
Reliability	Unbilled water or water lost in distribution	%	20	2	14%
	Percentage of households with metered water consumption	%	76	3	
	Efficiency of energy use within the network	%	40	1	
Water quality	Percentage of drinking water samples meeting WHO and local standards	%	60	1	15%
	Percentage of wastewater treatment plant samples meeting WHO and local quality standards	%	60	1	3%
Accessibility	Percentage of the population accessing safely managed drinking water services	%	78	3	9%
	Percentage of the population with access to safely managed sanitation services	%	19.7	1	4%
Adequacy and Equity	Average compliance with minimum service standards for supply time	hr/ day	16	2	8%
Ratio of water bodies' dependency	Percentage of water imported from transboundary or external sources	%	90	1	7%

(ii) Grading urban water security from an ecosystem perspective

Table 4.42 presents the current values (indicators' quantities) and scores (scaled from 1 to 5, detailed in Appendix V) for the ecosystem indicators. By applying the Integrated Urban Water Security Index (IUWSI), Adama's urban water security grade for ecosystem was 1.98.

Table 4.42 Values, scores, and weights of the ecosystem indicators

Indicators	Variable	Unit	Value	score	Weigh
State of pollution	safely treated wastewater flows	%	6.5	1	31%
Bodies of water with good ambient water quality	water samples meeting WHO and local quality standards.	%	70	2	23%
Over time change in water-related ecosystem extent	Over time change in water-related ecosystem extent	% change/year	0.22	5	9%
Green roofing	Share of green roofing compared to total roof surface area.	%	0.0	1	8%
Green surface	Green surface area as a percentage of total surface area.	%	60.85	5	10%
Effectiveness of storm and wastewater network	Sewer blockages per kilometer per year.		300	1	19%

(iii) Grading water security from climate change and water-related hazards perspective

Table 4.43 presents the current values (indicators' quantities) and scores (scaled from 1 to 5, detailed in Appendix V) the urban water security of Adama city from climate change and water-related hazards perspective. By applying the integrated urban water security index (IUWSI) the grade of urban water security from climate change and water-related hazards perspective of Adama city was found to be 3.35.

Table 4.43 Values, scores, and relative weights of the climate change and water-related hazards perspective

Indicators	Variable	Unit	Value	Score	Weight
Greenhouse Gas	Urban water supply and wastewater contribute to greenhouse gas emissions.	kg CO2/m3	0.153	3	6%
Public health (water-borne diseases)	Number of incidents of potable water contamination	Number/year per 100,000 people	43.7	1	13%
Number of floods	Flood-related deaths over three years	Number/three years per 100,000 people	0	5	18%
Flood zones	Ratio of flood-prone area to total surface area	%	24.71%	1	25%
Precipitation	Yearly average rainfall	mm/year	825	5	28%
Temperature	Yearly average temperature	Degrees Celsius	20	5	10%

(iv) Grading urban water security from socioeconomic perspective

Table 4.44 presents the current values (indicators' quantities) and scores (scaled from 1 to 5, detailed in Appendix V) the urban water security of Adama city from socioeconomic perspective. By applying the integrated urban water security index (IUWSI) the grade of urban water security from socioeconomic perspective of Adama city was found to be 2.35.

Table 4.44 Values, scores, and relative weights of the socioeconomic indicators

Indicators	Variable	Unit	value	score	weight
Water energy use	Energy consumption per unit for urban water supply	kwh/m3	12	1	7%
Wastewater energy use	Average energy use per cubic meter for wastewater treatment	kwh/m3	0.8	2	5%
Water charge	Water tariff for 15 m³	$/m3	1.65	4	8%
Sanitation charge	Wastewater charge for 15 m³	$/m3	0	1	4%
Affordability	Total annual operating revenues per capita relative to national GNI		0.67	2	6%
Budget allocation for water and wastewater services	national budget allocated to WWS	%	10 %	2	25%
Cost recovery for operation and maintenance	Operating expenditure to operating revenue	%	90	5	9%
Illegal uses	Number of illegal users	Number/year/10,000 subscribers	116	3	20%
Customer’s complaints	No. of total complaints (leakage, no water, blockage)	Number/year/10,000 subscribers	1395	1	16%

(v) Measuring city level urban water security using cumulative index (IUWSI)

Table 4.45 presents the cumulative city-level score of the Integrated Urban Water Security Index (IUWSI) derived from the combined results of individual Urban Water Security Index (UWSI) calculations. The weights for individual urban water security components were determined in aggregate revealing that drinking water and human well-being had the highest importance at 58%, followed by socioeconomic factors at 24%. Climate change and water-related hazards accounted for 7%, and ecosystem health held a weight of 11%. The consistency ratio (CR) was calculated to be 9.45%. The calculation result from the IUWSI reveals that the city level urban water security was found to be 1.95.

Table 4. 45 Cumulative single index (IUWSI)

Indicator	drinking of water and human well-being	socioeconomic	ecosystem	climate change and water-related hazards	weight
Drinking of water and human well-	1.00	5.00	5.00	5.00	58%
Socioeconomic	1/5	1.00	3.00	5.00	24%
Ecosystem	1/5	1/3	1.00	2.00	11%
Climate change and water-related hazards	1/5	1/5	1/2	1.00	7%
Total	1.54	6.53	9.50	13.00	100%

4.5 Characterizing Water Consumption By Using Spatial and Non-Spatial Water Consumption Determinants

4.5.1 Water Consumption Characteristics and Urban Settlement Pattern

(i) Water consumption characteristics in central , intermediate, and peripheral neighborhood settlements

The One-Way ANOVA test confirmed that there is significant difference in average daily household water consumption among the central, intermediate and periphery neighborhoods, with a p-value of 0.001 indicating statistical significance. The Tukey HSD test also confirmed that water consumption difference between central, intermediate and periphery neighborhood settlements was statistically significant. Table 4.46 shows that the intermediate settlement has the highest mean consumption at 739 liters per day, followed by the central area at 568 liters per day and the periphery at 402 liters per day. The result reveals that generally water consumption increases from center to intermediate and decreases towards periphery neighborhoods with certain exceptions. The result is in line with the alternative hypothesis (H1) that suggests the water consumption shows significance difference as distance increase from the center to intermediate and to periphery of the city (Water consumption generally increases from the center to intermediate areas with some exceptions, and then declines toward the periphery).

Table 4.46 Water consumption per household and per capita per day across central, intermediate, and peripheral neighborhood settlements

Consumption	Central		Intermediate		Periphery	
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Average consumption per household per day (liter)	568	358	739	283	402	251
Average consumption per capita per day (liter)	79	32	76	26	48	29

(ii) Water consumption characteristics in formal and informal housing settlements

The Independent t-Test confirmed that there is significant difference in the average daily household water consumption between the formal and informal parcels with a p-value of 0.001 indicating statistical significance. The Tukey HSD test also confirmed that the water consumption difference between formal and informal parcels was statistically significant. Figure 4.13 also asserts that formal parcels consume 2.4 times more water than informal ones.

This result is in line with the alternative hypothesis (H1) that suggests the water consumption shows significance difference with in the formal and informal housing ownership.

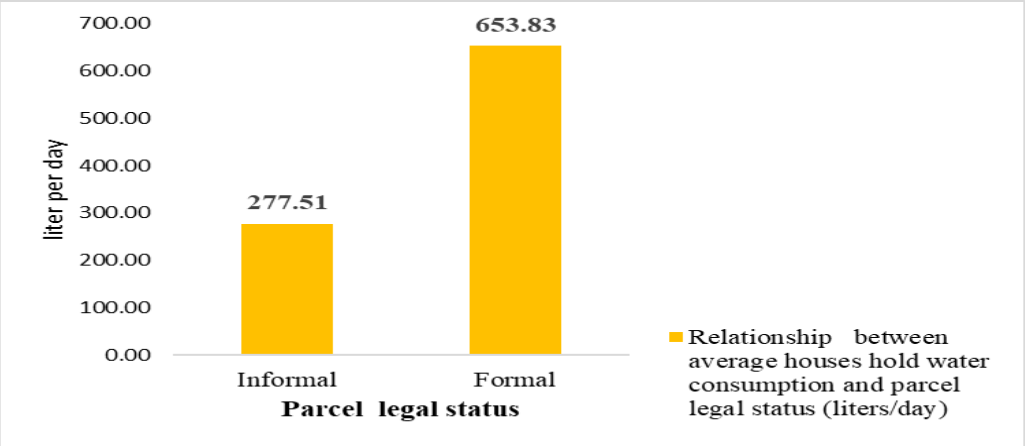

Figure 4.13 Relationship between average household water consumption and parcel legal status

(iii) Water consumption characteristics in different housing conditions

The One-Way ANOVA test confirmed significant differences in average daily household water consumption across varying housing conditions very good, good, fair and bad with a p-value of 0.001, indicating statistical significance. As shown in Figure 4.14 higher-quality houses were found to use three times more water than lower-quality. The result is in line with the alternative hypothesis (H1) that suggested the water consumption shows significance difference with the housing condition.

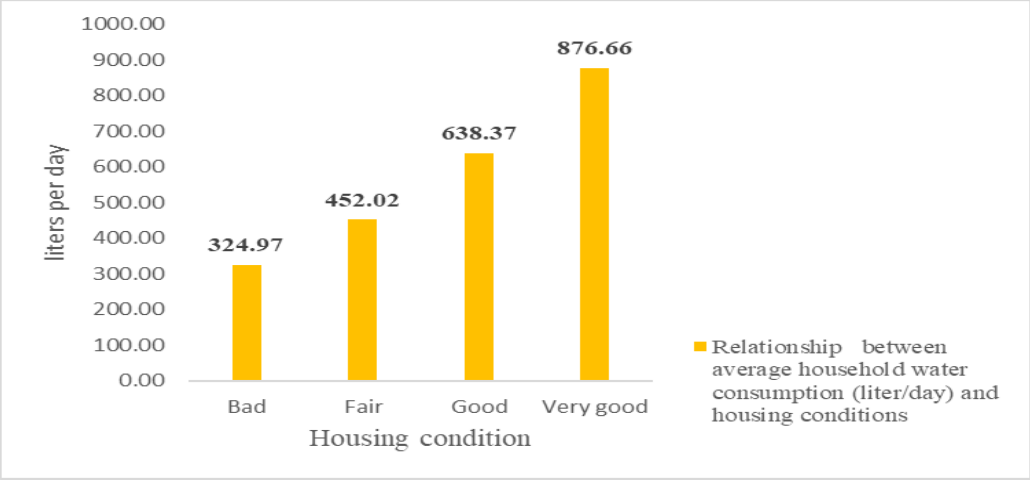

Figure 4.14: Average household water consumption and in line with housing condition

4.5.2 Identifying Water Consumption Determinants and Developing Water Consumption Spatial Pattern Using the Random Forest Machine Learning Techniques

(i) Raster spatial data of the spatial and non-spatial water consumption determinants

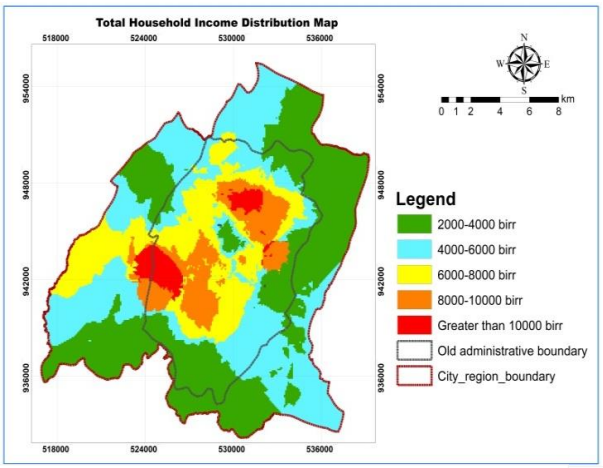

Figure 4. 15 :Total household income distribution map

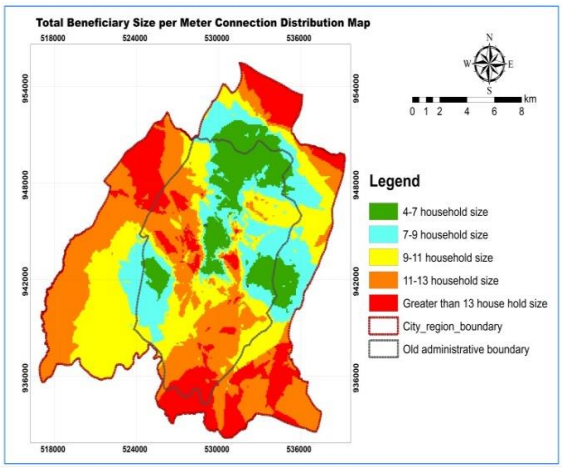

Figure 4.16: Total beneficiary per a meter connection map

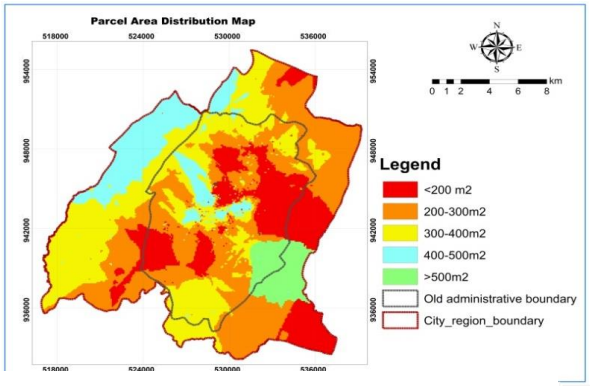

Figure 4.17 : Parcel area distribution

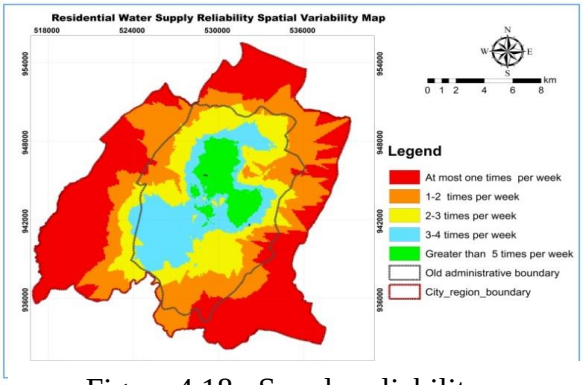

Figure 4.18 : Supply reliability map

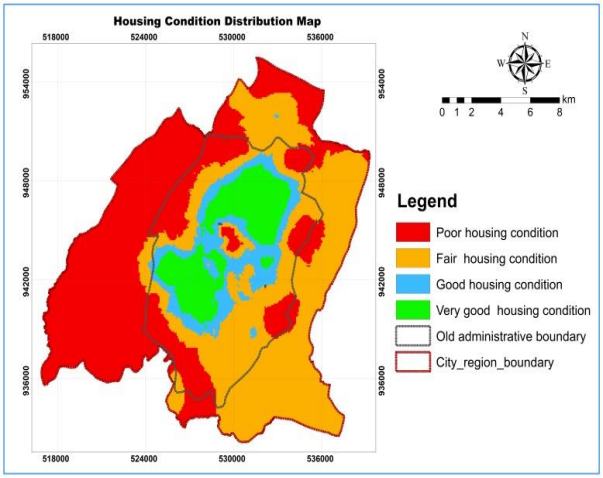

Figure 4.19 : Housing condition distribution map

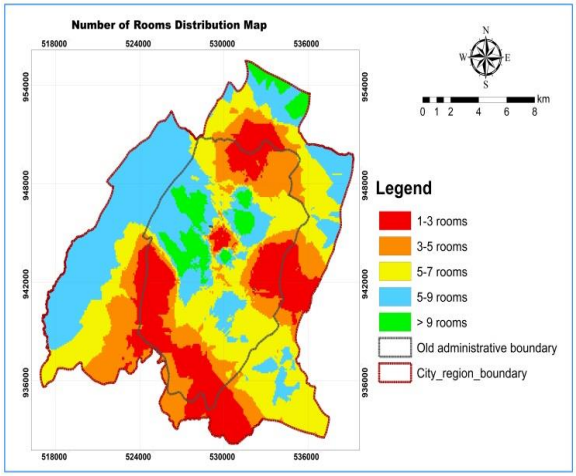

Figure 4.20 : Number of rooms map

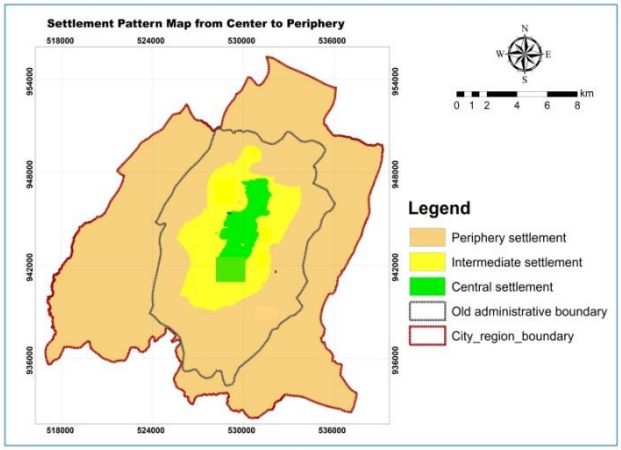

Figure 4.21 : Central, intermediate and

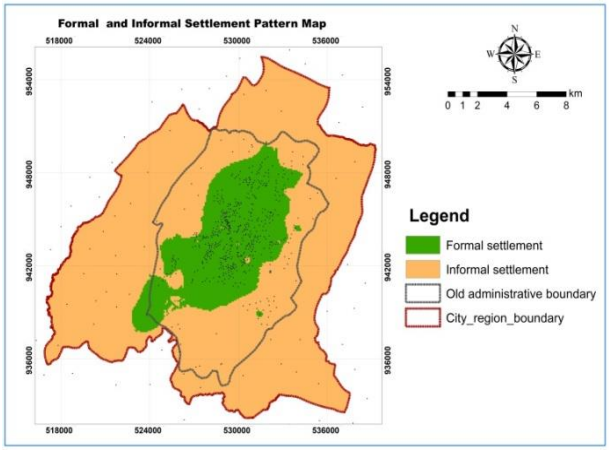

Figure 4. 22 : Formal and informal settlement

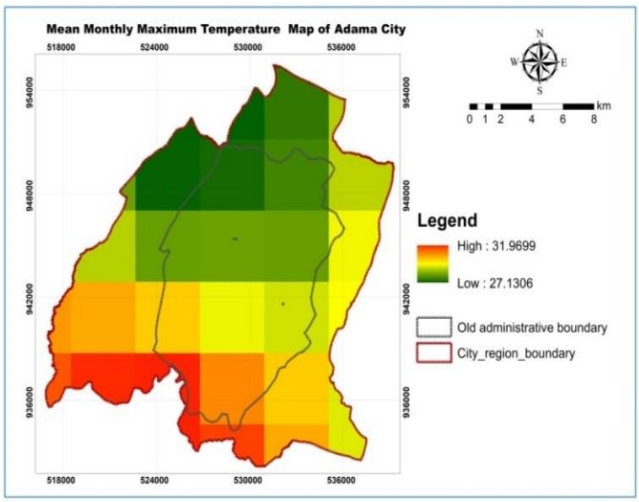

Figure 4.23 : Mean monthly maximum temperature

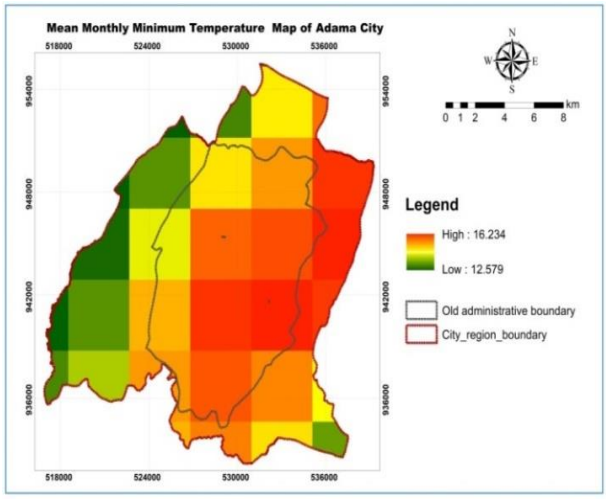

Figure 4.24 : Mean monthly minimum temperature

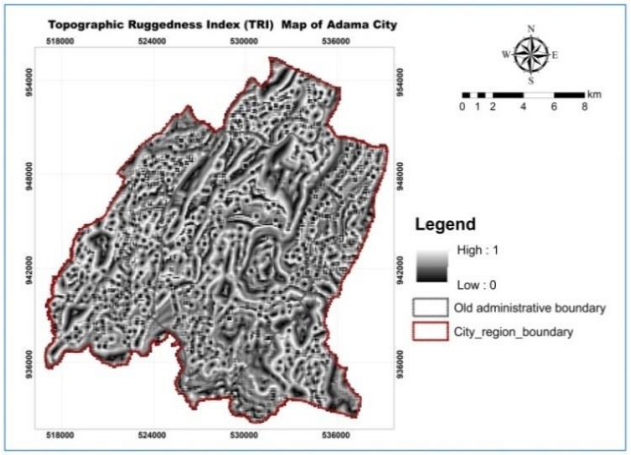

Figure 4.25 : TRI map of Adama City

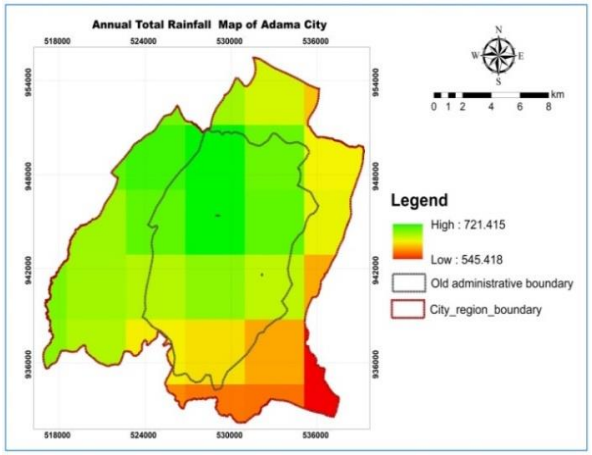

Figure 4.26 : Total annual rainfall map

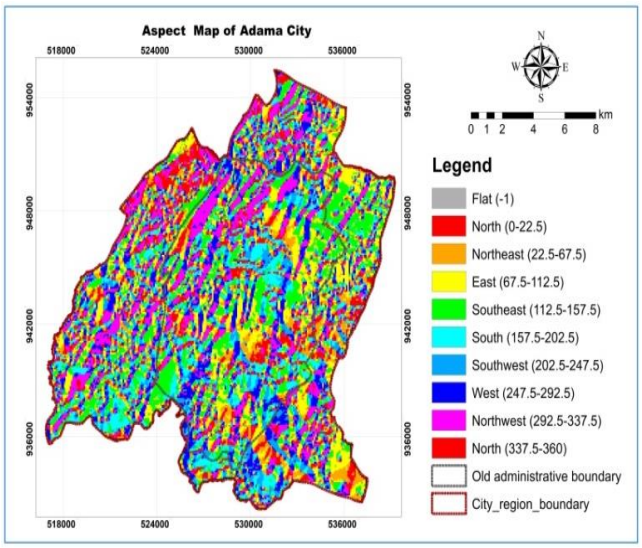

Figure 4.27: Aspect map of Adama

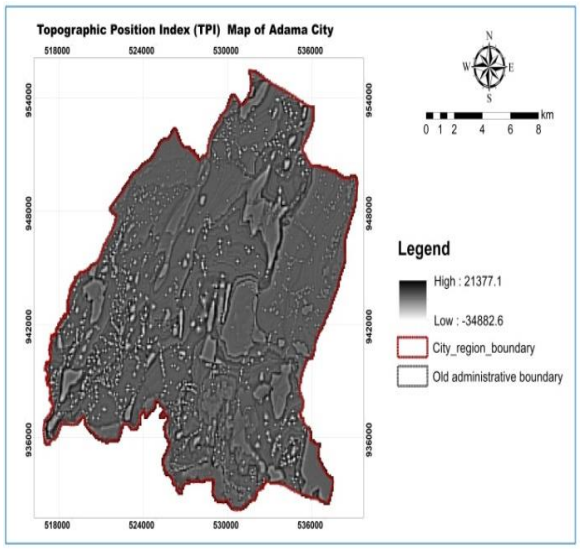

Figure 4.28: TPI map of Adama City

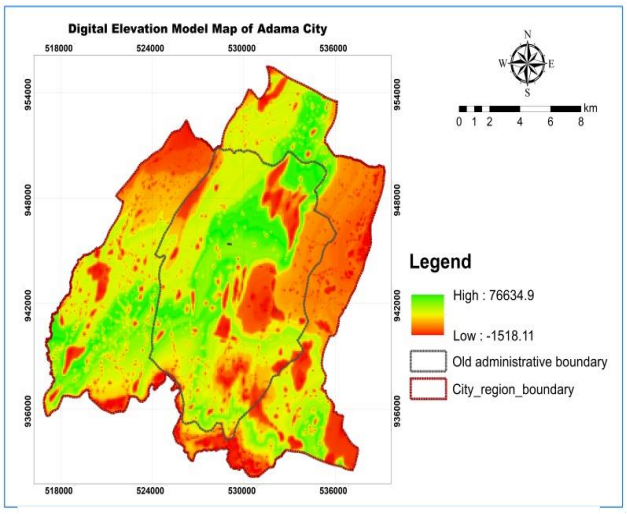

Figure 4.29: DEM map of Adama city

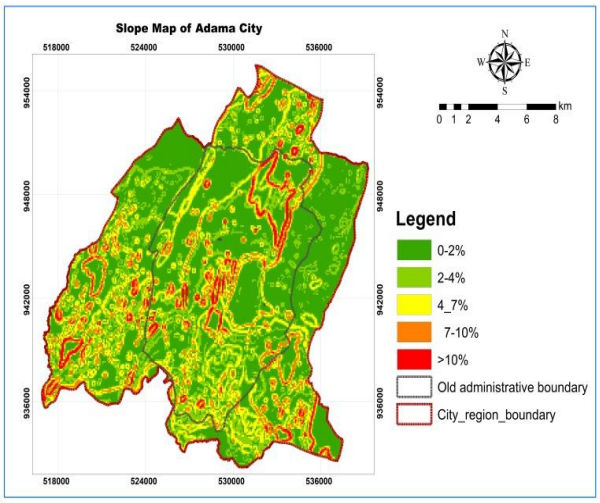

Figure 4. 30: Slope map of Adama city

(ii) Results from model training

Table 4.47 reveals that the model training achieved an R^2 value of 77.4%, indicating that these independent variables can predict daily household water consumption with 77.4% accuracy. The study also used 10-fold cross-validation, repeated 5 times, to validate the predictions by dividing the dataset into 10 subgroups, each serving as the validation set in turn.

Table 4. 47. Model Train Result

400 samples

16 predictors

Pre-processing: scaled (19), centered (19)

Resampling: Cross-Validated (10-fold, repeated 5 times)

Summary of sample sizes: 368, 369, 367, 365, 366, 368…

Resampling results across tuning parameters:

mtry	min. node. size	RMSE (liter)	R squared	MAE (liter)
1	20	253.0211	0.5863452	187.0763
1	30	254.8815	0.5802180	188.8105
3	20	201.9555	0.6922547	140.8809
3	30	206.3987	0.6799379	144.8156
5	20	185.6864	0.7330260	127.8779
5	30	190.2526	0.7211520	132.1991
7	20	176.3966	0.7550056	121.3599
7	30	182.4313	0.7401859	126.3876
9	20	171.8452	0.7646027	117.9047
9	30	178.1024	0.7488656	123.3120
11	20	168.2627	0.7720581	115.6154
11	30	174.7499	0.7558457	121.0202
13	**20**	**166.6818**	**0.7742122**	**114.2791**
13	30	173.2456	0.7577750	119.8080

Tuning parameter 'splitrule' was held constant at a value of maxstat RMSE was used to select the optimal model using the smallest value. The final values used for the model were mtry = 13, splitrule = maxstat and min. node. size =

(iii) Independent features (variables) and their importance

Table 4.48 reveals that among socioeconomic features, household size score 100 and income score 27.72 are the most influential factors in predicting daily water consumption. Housing quality also plays a significant role, with very good housing scoring 29.24, good housing 10.3, and fair housing 3.2, while poor housing is not significant. The number of rooms ranks fourth in importance with a score of 26.7. Parcel area has a notable importance score of 13.14, while roof area has no impact. Parcel legal status, formal parcels are significant predictors with a score of 18.15, while informal parcels are not.

The location of the household also affects water consumption predictions with intermediate settlements scoring 10.47, central settlements 0.9615, and periphery settlements 0, indicating that intermediate settlements, likely with higher housing quality, are better predictors. Water service continuity, specifically households receiving water more than three times a week, significantly impacts water consumption predictions with a weight of 11.41. Climatic features also influence water usage, with average annual minimum temperature being the most influential predictor with weight 10.6 followed by average annual maximum temperature with weight 6.3 and annual rainfall total weight 4.06. This is unexpected in Adama, where water consumption typically rises during the rainy season due to increased river volume and stable water access while dry seasons see constraints impacting consumption. Topographic features were also examined, with aspect scoring the highest at 5.5, indicating substantial influence. TPI, TRI, and DEM scored 1.7, 0.14 and 3.2, respectively.

Table 4.48 Variable importance scale

	Overall scale
Total house hold size	100.0000
Very good housing condition	29.2418
Total household income (monthly)	27.7228
Number of rooms	26.6620
Formal housing ownership	18.1504
Parcel Area	13.1409
Households that receive water more Frequently than three times per week	11.4178
Monthly mean minimum temperature	10.5959
Intermediate settlement (Location2)	10.4794
Good housing condition	10.2551
Monthly mean maximum temperature	6.2405
Aspect	5.4620
Total annual rainfall	4.0662
Digital elevation model (Dem)	3.1795
Fair housing condition	3.1569
Topographic Position Index (TPI)	1.7441
Central settlement (Location3)	0.9615
Topographic Ruggedness Index (TRI)	0.1460
Slope	0.001

(iv) Results from model testing

Table 4.49 reveals that the model testing result was found to be R^2 score of 77%.

Table 4.49. Model testing result

ME	-0.23
MAE (liter)	110.79
MSE ($litre^2$)	23071.59
RMSE (liter)	151.89
NRMSE %	48.60
PBIAS %	0.00
RSR	0.49
rSD	0.77
NSE	0.76
mNSE	0.57
rNSE	0.75
d	0.92
md	0.75
rd	0.92
cp	0.82
r	0.88
R2	**0.77**
bR2	0.72
KGE	0.74
VE	0.82

(v) Residential water consumption spatial distribution pattern of Adama city

Figure 4.31 illustrates the spatial distribution of water consumption in Adama city, influenced by spatial and non-spatial determinants. Table 4.50 highlights variations in household water usage across different settlement patterns. The raster surface map shows that 31% of urban areas consume 239–354 liters per day, 38% consume 354–433 liters per day, 13% use 585–791 liters per day and 5% exceed 791 liters per day.

Table 4.50. Spatial distribution of household water consumption pattern of Adama city

House hold water consumption (l/day)	Area	Area coverage	Percent
239- 354	58	9250.72	31
354- 433	98	11399.38	38
433-585	77	4038.19	13
585- 791	58	3614.14	12
> 791	24	1927.34	6

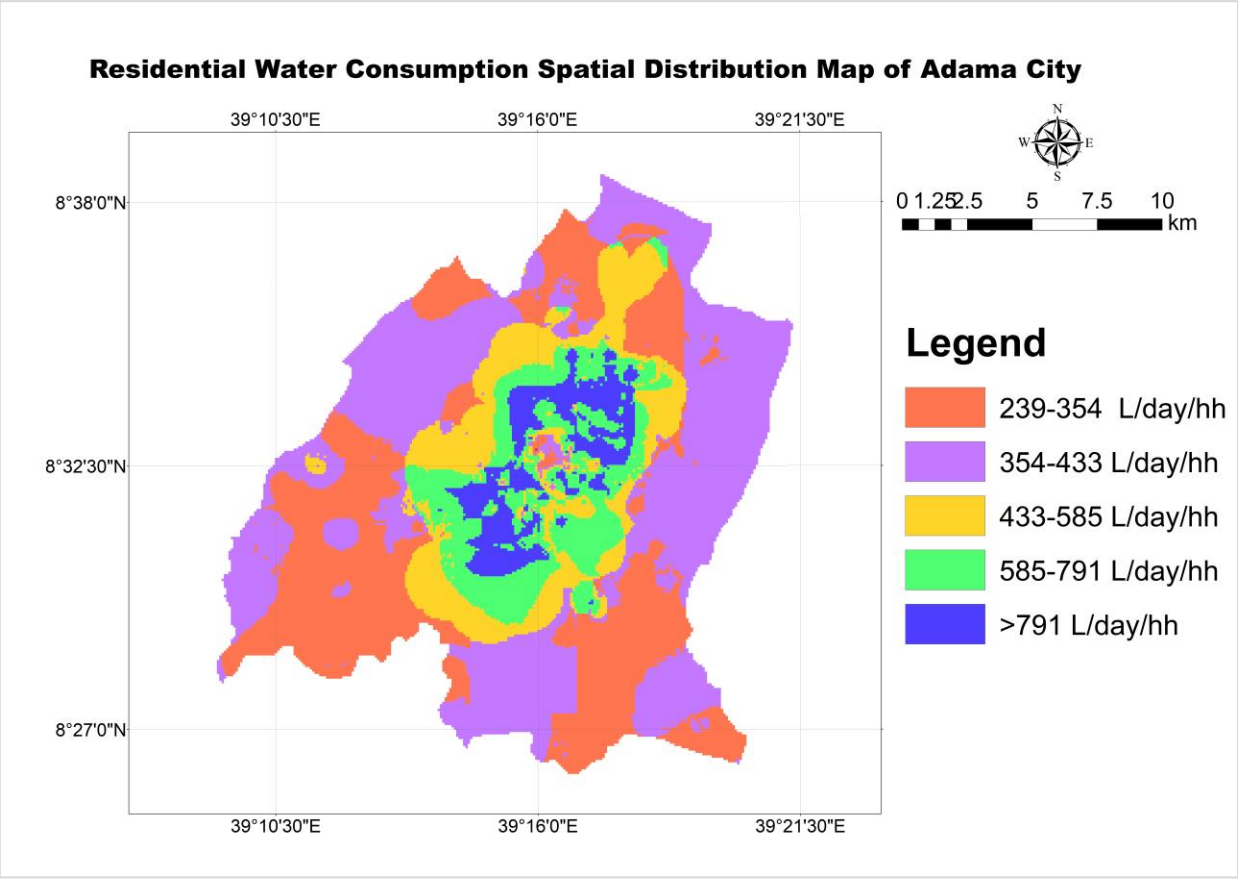

Figure 4. 31 Residential water consumption spatial distribution map of Adama city in 2023

4.5.3. Characterizing Urban Water Metabolic Performance of Adama City

The water metabolism performance of Adama city was assessed using indicators from Renouf et al. (2017) and Kenway et al. (2011) with findings summarized in Tables 4.51 and Table 4.52 reveals a population density of 13,685.5 people/km², classifying Adama as a very high-density urban center (Rosenberg, 2019). This density drives increasing annual water demand, with water use intensity at 86,261 m³/km².

Table 4.51 Population and water use intensity

Indicator	**Unit**	**Estimated values**	
Population density (people/km2)	Population/area	Pop/A	13, 685.5
Intensity of water use (m3/km2)	Total water use/area	(C + D)/A	86, 261

Adama city's water supply totals 27.26 million m³ annually with 16.6 million m³ (61.3%) from centralized systems and 10.66 million m³ (39.7%) from decentralized sources. Decentralized water including surface and groundwater plays a vital role in sustaining urban green spaces, industries and serving as a backup during main supply disruptions.

Table 4.52 Centralized supply replaceability/ supply substitution of alternative sources of water including loss in the system for the years 2022–2023

% of potential replaceability/substitution of centralized water supply						
% of total C/(C+D) *100	Rainwater (P/C*100)	Runoff (RS/ C*100)	Wastewater (W/ C*100)	System loss Cufw/C*100)	Wastewater and rainwater (W+P/C*100)	All Alternative supplies (W+P+Rs)/ C*100
61.3	1582.8	437.5	1452.3	17.5	1707.4	2,145

Table 4.53 shows that precipitation could meet 973% of the city's water needs, runoff 268.8%, wastewater 34.56%, and reducing system losses 10.55%, demonstrating their potential to fully replace the centralized and decentralized water supply.

Table 4.53 Total use replaceability/supply substitution of alternative sources of water including loss in the system for the years 2022–2023

% of potential replaceability/substitution of both centralized and decentralized water supply				
Rainwater P/(C+D) *100	Runoff water Rs/(C+D) *100	Wastewater W/(C+D) *100	System loss Cufw/C+d*100)	Wastewater and rainwater (W+P)/ (C+D) *100
973	**268.8**	**34.56**	**10.55**	**1574.02**

CHAPTER FIVE

DISCUSSIONS

5.1 Adama City's Water Stress Designation Within Ethiopia's Spatial Water Stress Classification Map

5.1.1 Spatial Distribution of Water Stress and the Designation of Adama City

The Falkenmark index shows Ethiopia's water availability at 1,109 m^3 per person, indicating water stress, as it falls below the 1,700 m^3 per person per year. Similarly, the Sustainable Water Partnership (SWP) (2021) also classifies Ethiopia as water-stressed, with 1,162 m^3 per person annually. The Falkenmark index result reveals that several Ethiopian basins face severe water scarcity. The Awash, Mereb, Rift Valley, Wabishebele, Danakil, Ogaden, and Aysha basins receive less than 500 m^3 per capita annually, indicating absolute water scarcity. Genale Dawa, Omo-Gibe, and Tekeze basins are categorized as water-scarce, offering 500–1,000 m^3 per capita annually. The Abay basin faces water stress, with 1,000–1,700 m^3 per capita annually, while the Baro-Akobo basin remains unaffected by water stress. Similarly, according to FAO (2016), all Ethiopian river basins except the Nile face water shortages. Sustainable Water Partnership (SWP) (2021) highlights the Awash Basin where Adama city is located as particularly water-stressed. The WorldBank (2020) notes that the Wabi Shebele River basin, despite its large area, is water-scarce due to low annual flow. According to Awulachew et al., (2007) three of the 12 major river basins, the Ogaden, Aysaha, and Danakil, are designated dry basins. Adane et al., (2021) also confirmed that water stress in Ethiopia is increasing from time to time.

The result from the Falkenmark index indicated that 38.15% of Ethiopian urban centers are in absolute water scarcity areas, 37.71% are in water scarcity areas, 18.64% are located in water-stressed areas and only 5.5% are in non-water-stressed areas. Adama city is located in the water stressed area of Ethiopia. In the same vein Zablon (2021) reports that six of Ethiopia's ten capital urban areas are located in high or extremely high-water stress areas. The Ethiopian Panel on Climate Change (2015) also states that climate change, urbanization, and urban centers expansion are worsening water stress in the country. This indicates that water stress is increasing in urban areas, necessitating a re-evaluation of structural and local plans to incorporate water-sensitive city principles. These principles aim to make urban areas self-sufficient within their boundaries by adopting alternative water harvesting strategies.

5.1.2 Adama City's Geographic Position within Ethiopia's Water Risk Zones

Adama city is located in a moderate to high groundwater potential zone, reflecting a broader pattern in Ethiopia, where 77% of the total population and 79.65% of the urban population live in such areas. However, 23% of the population, 20.35% of the urban population and 33% of urban centers (369 in total) are in low groundwater potential zones. Studies on Ethiopia's groundwater potential report varying figures from 2.6 billion cubic meters (FDRE-MWR, 2002) to 40 billion cubic meters (Mengistu et al., 2019) shows an uncertain yet significant quantity (Melesse et al., 2013). Groundwater occurrence is influenced by rainfall variability, topography, climate and geology (Ayalew, 2018). Groundwater is the main water source in low-income nations (Carrard et al., 2019), but unplanned ground water extraction is intensifying ground water stress (Mengistu et al., 2021). Six of Ethiopia's ten capital cities face high water stress, with groundwater levels supplying urban centers are declining rapidly (Zablon, 2021). Scholars Sharp (2010), Göbel et al., (2007), Kriech and Osborn, (2022) also reported that urbanization exacerbates groundwater depletion through increased extraction and impervious surfaces that limit infiltration and redirecting water as runoff. The spatial analysis reveals that urban settlement planning in Adama city and across Ethiopia has largely overlooked the protection of current and future groundwater potential through water-sensitive urban planning.

Adama receives an average annual rainfall of 721 mm. Whereas results from the spatial analysis of the distribution of urban centers relative to annual rainfall patterns, revealing that 28.15% are located in areas with less than 100 mm annually, 43.52% in areas with 100-200 mm, and 28.33% in areas with over 2300 mm. Melesse et al., (2013) noted that mean annual rainfall in Ethiopia's southeast, east, and northeast is as low as 200 mm, affecting dry basins like Afar-Danakil, Aysha, and Ogaden. Consequently, urban areas with less than 200 mm of annual rainfall experience water stress. Similarly, Ayalew (2018) and Fazzini et al., (2015) reported that Ethiopia's diverse rainfall patterns, from semi-arid deserts to humid southwest regions. This implies that urban areas that are located in southwest regions are commonly subjected to water stress.

The overlay spatial analysis of Ethiopia's flood-prone areas and distribution of urban centers identified that Adama is in a moderate flood zone . Meanwhile, 27% of the urban centers are located in major flooding areas, 28% in moderate, 17% in minor, and 28% in the safest areas. While no comparable studies exist, Ethiopia ranks 34th out of 162 for flood risk (World Bank,

2019). Similarly, WBG Climate Change Knowledge Portal (CCKP) (2020) underlined that natural disasters like flooding and drought, along with uneven topography result in a highly affected communities. Additionally, the World Bank (2010) reported that in Ethiopia climate change-induced floods are damaging urban infrastructure, including roads and bridges. This suggests that disaster management policies and strategies are crucial in every urban center to effectively withstand shocks caused by flooding.

5.2 Tracking and Tracing Water Consumption from Source To Endues

5.2.1. Tracking and Tracing Water Consumption at City Level

Adama city's water supply heavily depends on a centralized surface water system from the Awash River which accounts for 60% of its water demands. This reliance on a single source, coupled with seasonal variability and overlooked alternatives like rainwater harvesting and recycling, raises concerns about sustainability. Groundwater, once a primary source, is no longer now viable due to over-extraction and quality degradation. Similarly, previous lessons warn that a "business-as-usual" approach is inadequate and urban centers must diversify internal water resources to address urban water insecurity (UN-Water ,2021; Renouf et al.,2017 and UNESCO, 2010). In the same vein, DH-Consult (2018) warned that Adama faces a potential water crisis if the Awash River supply fails, due to its reliance on a single source and lack of alternative solutions like rainwater harvesting and recycling. The Adama Stuctural Plan Report (2020) also reported that water shortages affect livelihoods, sanitation and business operations. Studies by Fransiscus et al., (2023) and der Bruggen et al., (2010) noted that depending on one water source is unsustainable for rapidly growing urban populations. Adama city faces significant water stress due to over-reliance on a single source and lack of water-sensitive planning. The "one system and one source" approach, combined with neglecting water sensitive interventions worsens the issue. Similarly, Renouf et al., (2017) and Kennedy et al., (2011) reported that the absence of diversified water-sensitive interventions leads to an unsustainable water supply.

Over 30 years, Adama’s population grew 15-fold, water production tripled, and consumption doubled, yet 20% of water is unaccounted for due to leaks, faulty meters and illegal connections. The Awash River has a daily capacity of 43,000 cubic meters, but 9%-10% is lost during transmission, leaving only 40,663 cubic meters available. With 20% non-revenue water and 38% unmet demand. Non-revenue water in developing countries ranges from 20% to 60%

(Karadirek and Aydin, 2022 ; Covas et al., 2008) and supply-demand gaps are comparable to Delhi (20%-30%) and Nairobi (35%) (Depinder and Umra, 2024 ; Subhojit Goswami, 2018). the city's water-use index is 0.62. Urban areas with a water-use index below 0.7 are deemed "extremely water deficient" (Chen ,2019). The spatial analysis shows that Adama's water network covers just 45% of the master plan area, with problems like aging pipes, leaks, and unauthorized connections contributing to both "economic" and "physical" water scarcity. This highlights inadequate infrastructure and insufficient water supply as dual challenges. UN-Water (2021) defines "economic water scarcity" as a result of infrastructure issues and "physical water scarcity" due to supply shortages.

Adama city is in the "Water Supply City" stage of urban water management focusing on centralized water systems from surface water dams and neglecting alternative water sources. Adama's reliance on surface water without efforts to diversify through internal water-sensitive practices limits self-resilience. This aligns with the linear "take-make-use-dispose" model prevalent in developing countries. Similarly, researchers like Bahri (2015) and Jiménez and Asano (2008) note that water consumption in developing countries often follows a "linear model" neglecting recycling and reusing, which conflicts with water-sensitive principles that view cities as "water supply catchments." In the same vein, Kennedy et al., (2011) and Musango et al., (2017) noted that the linear approach treats resources unsustainably unlike the circular model which promotes a "take-make-use-remake" strategy for efficient water resource use.

5.2.2. Tracking and Tracing Residential and Non-Residential Water Consumption

(i) Tracking and tracing residential water consumption and conservation practices

Residential areas in Adama city account for 73% of water use, with households averaging 586 liters daily and 69.2 liters per capita below WHO's 100 liter and the national 80liter per capita standards. Household water use peaks in intermediate areas (739 liters/day), followed by city centers (568 liters) and the periphery (402 liters). This implies that household water uses peaks in intermediate areas and declines toward the periphery, while supply reliability drops from the center outward due to better infrastructure in central zones. Stoker et al.,(2019) reported that neighborhood water use varies with location and infrastructure.

Households commonly repair leaks but show low adoption of water-saving technologies like efficient faucets, showerheads, and dual-flush toilets, indicating limited use of water-sensitive

practices. Carolina et al., (2021) and Basak et al., (2020) reported that retrofitting such technologies can significantly reduce water use. Efficient indoor fixtures save 9%-12%, while high-efficiency replacements cut usage by 35%-50% (Inman and Jeffrey 2014). Outdoor conservation efforts, like using alternative water sources or enhancing soil retention, remain uncommon despite Raul's (2024)findings that improved soil reduces plant water needs.

(ii) Tracking and tracing commercial water consumption and conservation practices

Ranked hotels in Adama use 25,974 liters/day, medium hotels 14,080 liters, and normal hotels 3,882 liters, with rooms accounting for 29.5% of total water use. Room water usage ranges from 63-125.97 liters/day. However, researchers report varying daily water use per hotel room. Klaus Reichardt (2017) cited 400-800 liters, the Sustainable Hospitality Alliance (2020) cited 400-1600 liters, and Alhudaithi et al.,(2022) reported an average of 981 liters. Manuela Capra (2023) notes annual water use per room can range from 60,000 to 220,000 liters. Adama's hotel water consumption breakdown includes 29.5% for rooms, 16.37% for kitchens, 14.54% for laundry, 0.65% for pools, 13.46% for gardens, and 10.5% for air conditioning. Hoeever, the U.S. Environmental Protection Agency(EPA) (2009) reported that 30% rooms, 14% kitchen, 16% laundry, 1% pool, 16% landscape, 11% cooling, 12% other. Manuela (2023) reports 37% rooms, 21% kitchen, 12% laundry, 2% pool, 17% bathroom, 4% steam, 7% other.

Hotel water conservation practices are rarely implemented, with limited leak checks, lack of water managers, and no signs encouraging water-saving. Audits and staff training are neglected, and technological solutions like flow restrictors and water-efficient fixtures are mostly ignored. Similarly, research findings indicates that the absence of water-saving appliances can lead to significant water losses from toilets, showers and hand washing (Constantinoiu, 2022). Dripping taps alone can waste up to 200 liters of water daily (Webplace, 2018), while a leaking toilet can waste between 800 and 1,000 liters each day (Water Science School, 2019). Showers longer than 10 minutes can result in a loss of 17 liters of water (Constellation, 2016).

Pensions consume an average of 4,368.71 liters of water daily ranging from 1,114 to 14,857 with variations based on location, size, and guest behavior. Room usage accounts for 27%, averaging 76.31 liters per room, and laundry uses 22.05 liters per kilogram of towels/linens. Water conservation practices are largely absent, with no facility management, water audits, or staff education, and rarely using water-saving technologies like flow restrictors or self-stopping

taps. This highlights a significant gap in water conservation in pensions, as agreed by researchers (Lee et al., 2018; Pensiri et al., 2016 ; Alhudaithi et al., 2022).

Restaurant water consumption averages 1,334.33 liters per day ranging from 666.67 to 4,166.67 liters with kitchen usage at 47.5%, domestic (urinals and handwashing) at 35%, landscaping at 3%, and other tasks at 14.9%. According to the U.S. Environmental Protection Agency(EPA) (2009) in developed countries like the USA, a typical restaurant uses 22,620 liters of water per day. The U.S. Environmental Protection Agency(EPA) (2012) also reported that 54% of the water in restaurants is consumed by the kitchen, 31% by the domestic restroom and 4% by landscape

A café's average daily water consumption is 269.5 liters, varying from 166.67 to 733 liters based on factors like location, size, and customer behavior. Kitchen use accounts for 49.7%, domestic purposes 36.3%, and the remaining 14% for cleaning and landscaping. Research shows cafes can consume up to 22,620 liters daily (Powerhouse Dynamics, 2024). Additionally, Baristaguild (2016) noted that the average daily water consumption in cafes ranges 2,400 to 4,000 liters. Water conservation practices are lacking, with no facility management, audits, or staff training. Measures such as flow restrictors, self-stopping taps, and water-saving signs are rarely used, reflecting poor implementation of conservation efforts.

Water usage in car wash stations varies significantly by vehicle type and washing method. Estimates show manual washing of buses and trucks uses 160-180 liters, while power washing uses 100-120 liters. It was also found that water requirements for washing different types of vehicles are Bajaj 10-25 liters, automobiles 20-60 liters, pickups 40-80 liters, minibuses 40-80 liters, buses 80-160 liters, and trucks 100-180 liters. Water-saving measures are largely neglected, with few stations adopting low-flow nozzles, leak checks or water-recycling systems. Practices like hose management and rainwater collection are seldom implemented. In this context, however, researchers reported that water conservation practices in car washes are crucial. For example, PSD Codax (2024) noted that car washes employing recycling methods can reduce freshwater consumption by up to 80-90%. Additionally, the EPA(water Sense) (2012) reported that installing low-flow nozzles and limiting water consumption are important and impactful conservation practices.

(iii) Tracking and tracing public service water consumption and conservation practices

Average daily water consumption varies across educational institutions such as 4,718 liters for elementary schools, 4,348 liters for secondary schools, 25,641 liters for TVETs, 23,411 liters for boarding schools, and 1,480,000 liters for universities. Water use per student is relatively low in Adama city (2.26 liters in elementary, 1.75 liters in secondary, 3 liters in TVETs, 5 liters in boarding, 4 liters in universities) compared to other studies. Meanwhile, various studies report differing results on student water consumption. Farina et al., (2011) reported an average of 8.5 liters per student per day, while Morote et al., (2020) reported 7.34 liters. Nunes et al., (2019) found that regular public schools use a minimum of 9.5 liters per student, extended period schools use 10 liters, and technical schools use 12 liters per student per day. This implies that compared to these studies, student water consumption in Adama city is relatively low Domestic use (drinking, cleaning and hygiene) accounts for 40% of consumption, landscaping 35%, meal prep 6%, and other needs 19%. The U.S. Environmental Protection Agency (EPA)(2012) reports slightly different allocations in that 45% for domestic use, 28% for landscaping, and 7% for kitchen use. Water conservation efforts are minimal, with basic actions like leak checks, self-stopping taps, and water-saving signs rarely implemented.

The results indicate that hospitals consume an average of 376,811.59 liters of water daily, while health centers use an average of 3,479.17 liters per day. Water consumption in healthcare facilities is often reported per bed. According to Central Ground Water Authority (2016), hospitals with more than 100 beds can consume about 450 liters per bed per day, totaling approximately 45,000 liters per day per hospital. Health centers with fewer than 100 beds typically consume about 350 liters per bed, amounting to less than 35,000 liters per day.

In health institutions, water usage is typically categorized into kitchen/café, laundries, medical equipment, cooling/heating, landscape, and domestic uses (toilets, showers and urinals). Health centers use 347.92 liters per day in kitchens, while hospitals use 37,681.15 liters. Landscape water usage is 2,435.42 liters per day in health centers and 263,768.12 liters in hospitals. Domestic use in health centers is 1,217.71 liters per day while hospitals use 131, 884.01liters. Medical purposes consume 521.875 liters per day in health centers and 56,521.7 liters in hospitals. Laundry purposes consume 243.54 liters per day in health centers and 26,376.8liters in hospitals. Reports like Practice green helath (2020) indicates that the average daily water consumption in hospitals is in between 160 to 1400 liters per patient per day .The result reveals

that water conservation practices in health institutions are largely inadequate, with many crucial measures either rarely or never implemented. Regular leak checks in building water lines are occasionally performed, but checks for leaks in toilets are seldom conducted. Establishing facility management for water conservation is uncommon, and there is minimal adoption of flow regulators in showers and toilets. Additionally, no training is provided to raise awareness about water-saving practices, and there are no suggestion boxes or signs promoting water conservation efforts. This indicates that water conservation practices in health institutions are at a very low level.

It was found that water is symbolically important in many global religions and is used in rituals for cleansing, purification, and baptism. This study finds that churches use an average of 2,694.87 liters daily, while mosques use 2,267.65 liters. The higher consumption in churches is due to activities like cleaning, faith-healing practices, monastic housing, landscaping, and baptism rituals. In churches, water serves dual purposes such as ritualistic and non-ritualistic. Ritualistically, water holds sacred significance and is blessed by a priest in Christianity for activities such as sin-cleansing, healing, blessing the sick, and baptism. Non-ritualistically, water is used for general cleanliness, landscaping, restroom facilities, and supplying monks with water. The result indicates a 70:30 ratios between ritual and non-ritual water usage in churches. Ritual water uses averages 808 liters per day, while non-ritual use averages 1,886.40 liters per day. Baptisms typically require three to five liters of water each, and monks use an average of 70 liters of water per person per day. Meanwhile, other research findings often do not specify the average daily water consumption at each service type in churches.

It was also found that in mosques, over 80% of water is consumed during the ablution (wudu) ritual, which involves washing hands, face, arms, head, ears, and feet. Other significant water uses include restrooms and showers (5%), landscaping, general cleaning, and occasional needs like washing the deceased before burial (6%). Research suggests that in certain contexts with efficient water-saving practices, one liter of water may serve for ablution purposes per individual, depending on local conditions and the frequency of ablutions performed throughout the day (Prayerinislam, 2024)

The result also revealed that water conservation practices in religious institutions show a mix of shortcomings and strengths. While the establishment of facility management and assignment of water managers are rarely practiced, and the installation of flow restrictors, self-stopping or

sensor taps in toilets, and hand wash areas are generally not implemented, there are consistent efforts to educate followers on water-saving. Signs promoting water conservation are seldom used, and advanced measures like sensors in hand wash areas are not commonly adopted. However, religious teachings play a positive role, with leaders consistently educating followers on water-saving, emphasizing the importance of water in religious texts, and fostering a strong recognition of water's value for survival. While specific studies are not always provided, research suggests that water conservation practices in religious institutions are generally strong, guided by religious teachings on the sacred and careful use of water (IGC, 2024; GIZ, 2016). This implies that religious institutions could serve as key stakeholders in developing city-wide water-saving strategies, contributing significantly to a water-sensitive community.

(iv) Tracking and tracing industrial water consumption characteristics

The result from the key informants shows that water consumption varies across industries for example textile manufacturing uses 100-200 liters per kilogram, food processing uses 1-5 liters per kilogram, beverage processing uses 2-4 liters per liter of soft drink, paper and pulp manufacturing uses 10-20 cubic meters per ton of paper, chemical production uses 2-10 liters per kilogram, metal processing uses 5-50 liters per kilogram, and construction materials use 150-200 liters per cubic meter of concrete. Researchers also indicate that water consumption per product is standardized and adheres to production stage guidelines. For example, Apure (2023) and Aquafit4use (2010) report consistent water quantity consumption for each unit product.

Water conservation practices in industries are largely neglected, with minimal use of audits, staff education, and basic measures like flow restrictors and self-stopping taps. Alternative water sources and efficient fixtures in toilets and showers are rarely implemented, and awareness training is seldom provided. Although specific studies are not provided, several studies highlight the importance of water conservation in industries for sustainable freshwater management. Agana et al., (2013) emphasize that integrated water management and harvesting reduce industries' impact on freshwater resources. Gradhoc (2024) notes that water-saving practices in the food industry not only reduce freshwater extraction but also lower costs and support the realization of ISO 14001 environment protection agenda.

5.3 Quantifying Water Security Performance of Adama City

(i) Quantifying water mass balance using natural and anthropogenic water flows

In urban water mass balance estimation, the storage change (ΔS) can be positive or negative (Oudin et al., 2018). The results show a total water inflow of 290.51 million cubic meters, with outflow at 206.86 million cubic meters, leading to a positive storage change of approximately 83.65 million m^3 annually. According to Renouf et al. (2017) and Kenway et al. (2011), a positive change occurs when water inflow surpasses outflow in urban systems. Reba et al. (2018) also emphasize that while ideally inputs should equal outputs, discrepancies in storage change may arise from calculation errors, assumed runoff coefficients and data inaccuracies.

(ii) Grading the urban water security level of Adama city from each indictor's perspective

The Urban Water Security Index for Adama city's drinking water and human well-being is 1.6. According to Zeitoun et al., (2016), the drinking water and human well-being dimension scores between 1.5-2.5, indicating that current policies and measures are insufficient, with major concerns in water availability, quality and diversity. The city's practices are not aligned with the "city as water supply catchments" principle, which advocates for self-sufficiency through alternative water sources within urban boundaries. The principle of "city as water supply catchments" emphasizes that urban areas can be self-sufficient by generating alternative water sources within their internal boundaries (Wong and Brown, 2009).

From an ecosystem perspective, Adama's the Urban Water Security Index score is 1.98, highlighting challenges like inadequate wastewater treatment, lack of green infrastructure and frequent sewer blockages. The city is not aligned with the "cities providing ecosystem services" principle, which promotes urban ecology through green infrastructure and public participation. According to Wong and Brown (2009), urban areas can actively support and enhance urban ecology by protecting water bodies and wetlands, integrating green infrastructure like green roofs and rain gardens, enacting water-conscious planning regulations, and encouraging public participation, cities can contribute to ecosystem health and biodiverse.

Regarding climate change and water-related hazards, Adama's Urban Water Security Index score of 3.35 falls in the "reasonable" category (2.5–3.5), indicating basic water security are ensured but a need for flood protection strategies in flood-prone areas. From a socioeconomic perspective, the score is 2.35, reflecting insufficient interventions. Issues like water energy

consumption, budget allocation, customer complaints and tariffs affect the city's water security. Adama has not yet built a water-sensitive community, as practices such as water recycling and roof harvesting are not implemented. Wong and Brown (2009) suggested that communities are said to be water sensitive, if there are practices of using alternative water sources like recycling and roof water harvesting methods.

(iii) Grading the urban water security level of Adama city from the overall integrated cumulative urban water security index (IUWSI) perspective

Based on the weighted independent water security indexes, the overall integrated urban water security index (IUWSI) was estimated to measure city wide urban water security grade. The weights for individual urban water security components were determined in aggregate, revealing that drinking water and human well-being had the highest importance at 58%, followed by socioeconomic factors at 24%. Climate change and water-related hazards accounted for 7%, and ecosystem health held a weight of 11%. The consistency ratio (CR) was 9.45%, well below the 10% threshold, ensuring reliable weighting and expert judgment matrix (Saaty, 2008). In a similar study, Aboelnga et al. (2020) reported comparable findings, with a cumulative weight of 66% assigned to drinking water and human well-being indicators, 17% to ecosystem indicators, 10.6% to climate change and water-related hazards, and 10.4% to socioeconomic factors.

The calculation result from the commulative integrated urban water security index measurment reveals that the city level urban water security was found to be 1.95. According to Zeitoun et al., (2016), this places it within the 1.5-2.5 range, indicating the current intervention practices for water security are inadequate, highlighting significant concerns across all dimensions of water security. This implies that key water-sensitive interventions such as low-impact development practices, promoting green and blue infrastructure, rainwater harvesting, treating wastewater for non-potable uses, using water-saving technologies, integrating parks and wetlands, and minimizing impermeable pavements are currently limited in water-sensitive implementation practices in the city water management practices.

5.4 Characterizing Residential Water Consumption Using Spatial and Non-Spatial Water Consumption Determinants

5.4.1 Water Consumption Characteristics and Urban Settlement Pattern

The result reveals that the intermediate settlement has the highest mean consumption at 739 liters per day, followed by the central area at 568 liters per day and the periphery at 402 liters per day. This implies that household water consumption peaks in intermediate neighborhoods and declines toward the periphery. Thus, water consumption generally increases from the city center to intermediate areas and decreases toward the outskirts with some exceptions. This shows that the water consumption shows significance difference as distance increase from the center to intermediate and to periphery of the city. This trend is due to denser slums and lower-income residents in the core, wealthier families in better homes in the intermediate zone, and inadequate water infrastructure in peripheral areas. Similarly, Stoker et al., (2019) also reported that water consumption disparities in urban neighborhoods result from differences in infrastructure, water supply reliability, housing quality and conservation practices

The result reveals a significant correlation between water consumption and housing quality, with high-quality houses using three times more water than low-quality ones. This implies that the water consumption shows significance difference with the housing condition. This result is consistent with findings from Millock and Nauges (2010) and Cavanagh, et al.,, (2002) who also observed increased water consumption with improvements in building quality and outdoor facilities. The result also reveals that formal residential plots, with better access to clean water and stronger connections to the water system, consume 2.4 times more water than informal ones. This result implies that the water consumption shows significance difference with in the formal and informal housing ownership. This is due to the poorer infrastructure and lower water supply reliability in periphery areas where informal houses are often located. This result aligns with Atkins et al., (2021) found that formal parcels consume more water compared to informal ones.

5.4.2 Independent Features Selection and Generating Water Consumption Raster Map Using Random Forest Technique

(i) Model training

The model training summary shows an R^2 value of 77.4%, indicating that the independent variables predict 77.4% of the average daily household water consumption. According to Fernando (2024) R-squared value of "1" (one) means the independent variables fully explain the variability in the dependent variable, while a value of "0" (zero) means they do not explain any variability. Maklin (2019) and Deepak (2019) note that, although there is no consensus on a minimum acceptable R-squared value 50% and higher values indicate stronger models.

(ii) Selected variables for predicting dependent variable (household water consumption)

Not all features contribute equally to the water consumption (Poornima and Boyapati, 2021). By analyzing importance scores, this study identified key variables while excluding irrelevant ones. Household size (score value 100) and income (score value 27.72) are the most significant socioeconomic predictors of daily water consumption. Previous studies like Bich-Ngoc et al., (2022), Bolton et al., (2017) and Ouyang et al.,(2014) confirm the impact of household size, while others Hussien et al., (2016), Corbella and Pujol, (2009) and Dalhuisen et al., (2003) reported the positive relationship between income and water use.

Housing quality, categorized as very good (score value 29.24), good (score value 10.3), fair (score value 3.2) and poor (score value 0) also influences water consumption, with poor housing showing no impact, consistent with Álvaro-et al.,(2016). Similarly, the number of rooms (score value 26.7) significantly affects water consumption, aligning with Millock and Nauges (2010) and Cavanagh et al., (2002). While the parcel area (score value 13.14) impacts consumption due to activities like gardening. According to Rondinel and Sarmiento (2020), larger parcel areas correlate with increased household water consumption due to more outdoor activities like gardening and horticulture.

The study revealed that formal legal parcels (score value 18.15) significantly influence water use, while informal parcels do not. This aligns with Atkins et al., (2021) and SaharAttia (2015) who found that formal parcels generally consume more water than informal. Locational factors show intermediate settlements (score value 10.47) show water usage better than central (score value 0.9615) and peripheral (score value 0) areas. This implies that intermediate settlements, likely due to higher-quality housing consume more water. Conversely, central areas, associated

with lower living standards, exhibit the lowest household water consumption. Stoker et al.,(2019) observed that neighborhood water consumption varies based on access to adequate water supply opportunities.

Water service reliability (score value 11.42) also plays a critical role in water consumption trend. Purshouse et al., (2017) also found that water supply reliability strongly influences consumption levels. Climatic factors include average annual minimum temperature (score value 10.6), maximum temperature (score value 6.3) and rainfall (score value 4.06) as significant predictors for water consumption. In Adama city, water usage increases during the rainy season due to fewer restrictions, stable water pressure, sufficient supply, and increased river volumes. Conversely, during the dry season, water supply is rationed and less reliable. Research by Dobbin et al., (2023), Gato-Trinidad et al., (2007) and Syme et al., (2004) indicates that water consumption significantly increases during high-temperature seasons for both indoor and outdoor activities.

The result reveals that topographic features impact water consumption, with aspect scoring 5.5, Digital Elevation Model (DEM) scoring 3.2, Topographic Position Index (TPI) scoring 1.7, and Topographic Roughness Index (TRI) scoring 0.14. Hazeltine (2003) noted that the distribution of water supply networks and reservoir placement are influenced by topography. Similarly, research by You et al., (2019) and Wang et al., (2018) indicates that households on steep slopes and elevated areas store water due to unreliable supply and pressure issues, resulting in minimal water consumption.

(iii) Model testing and developing water consumption surface raster map

After training, the model's performance was found with an R^2 score of 77%. This implies that the water consumption prediction model is able to explain the household water consumption characteristics . Studies show that the rise of big data in hydrology has led to increased use of machine learning to analyze the relationship between humans and water resources (Xu and Liang, 2021). Smolak et al., (2020) found the Random Forest (RF) algorithm highly effective for predicting water consumption. The application of machine learning, especially Random Forest, in software applications has been steadily increasing (Patil et al., 2022 ; Kalashak, 2021 and Poornima and Boyapati, 2021). The predicted raster water consumption map can help to visualize water consumption pattern and disparities so that urban planners, water resource

managers and policy makers can make informed strategic decision in relation to water sensitive interventions. Besides, by understanding the features or variables, scenario planning can be developed by the expected changes in the variables. Similarly, Poornima and Boyapati (2021) noted that water consumption prediction map can be used by urban planners and water resource managers to make evidence based decision on water allocation and infrastructure development.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Ethiopia is experiencing increasing urban water stress driven by rapid urbanization, climate change and inadequate water management. The uneven distribution of water stress across the country is due to the imbalance between withdrawals and availability, further exacerbated by population growth, sectoral water demands and urban expansion. Many urban areas, including Adama, are situated in areas of high-water stress with low groundwater potential, flood risks, and limited rainfall. Urban-focused, water-sensitive approaches and policies for managing water insecurity remain underdeveloped, emphasizing the urgent need for a paradigm shift toward water-sensitive urban planning.

Adama city is experiencing significant physical and economic water scarcity with 38% of the demand unmet and a Water Supply and Demand Balance Index (SDBI) of 0.62. The per capita water consumption stands at 69.2 liters which is below both the national average and the WHO standard. In the last 30 years, the population grew 15 times while water production tripled. Despite these efforts, 20% of water is lost due to wastage and the water supply network covers only 45% of the city. Adama's water supply issues arise from high demand, inefficiencies, inadequate infrastructure, and limited water-sensitive solutions, leading to inconsistent distribution and restricted access in many areas. The study concluded that tracking and tracing urban water flow from source to end-use is crucial for understanding water consumption and transformation in urban areas and for identifying improvement targets and water-sensitive intervention strategies.

Adama city's water management follows a linear "take-make-use-dispose" model with minimal recycling and deviating from circular metabolism. The city's water supply system, classified as a "Water Supply City," relies on a centralized source for 60% of its water prioritizing supply expansion over sustainable alternatives. Key water conservation practices, such as leak checks, water audits and efficient appliances are rarely implemented. Technological solutions and behavioral changes, like shorter showers and proper toilet use are uncommon, indicating a lack of water-sensitive practices and community engagement.

The results indicates that Adama city's water supply is insufficient to support its socioeconomic activities. The city's Urban Water Security Index (IUWSI) stands at 1.95, indicating a lack of comprehensive water-centric policies and strategies to achieve water security across drinking water, ecosystems, water-related hazards and socioeconomic factors. Additionally, the city's water management fails to integrate water-sensitive principles, missing opportunities to view the urban landscape as a water supply catchment that could generate alternative sources. Moreover, Adama falls short in enhancing urban ecology by failing to protect water bodies, integrate green infrastructure and promote water-conscious ecosystem planning.

The study also concluded that applying machine learning, especially the Random Forest (RF) algorithm is a growing field that addresses limitations of linear water consumption prediction models. Random Forest (RF) integrates both spatial and non-spatial determinants of water consumption and helps to generate predictive raster maps. These maps help urban planners and policymakers to visualize consumption patterns and disparities, facilitating informed decisions on water-sensitive interventions and infrastructure developments. Additionally, analyzing the change of variables or features can support to develop future scenario for water sensitive intervention planning.

In conclusion, the principle "you can't manage what you can't measure" goes with the need for urban water metabolism study from the eye of water sensitive city principles. In developing countries like Ethiopia, there's a gap in integrating water management with urban planning. This study calls for a new paradigm that aligns with water-sensitive principles and urban metabolism science. Implementing water-sensitive urban planning that is supported by strong legal frameworks, community engagements and technology will improve water security and ensure long-term sustainability. The next section explores measures to address increasing water stress and urban insecurity at city and national level.

6.2 Recommendations

Water is a precious yet limited resource and paradoxically, it is often consumed and managed with negligence. Current activities and approaches lack a water-centric focus. Addressing the growing issue of water scarcity requires aligning planning policies, practices, legal frameworks, community awareness and technologies with urban water-sensitive principles. Therefore, this study recommends the following water-sensitive strategies tailored for both local and national level interventions.

(i) Proposed water sensitive intervention approaches for Adama city

- **Diversifying and integrating alternative water sources**

The first water-sensitive intervention involves improving water conservation at home. This includes installing water-efficient fixtures, retrofitting old ones and adopting habits like turning off faucets when not in use and taking quick showers. Outdoors, strategies include planting drought-tolerant plants, reusing water for gardening and watering landscapes during cooler hours to reduce evaporation. The second strategy focuses on ensuring a reliable water supply by expanding and diversifying sources including centralized surface and subsurface supplies, rainwater harvesting and wastewater recycling. The third strategy addresses growing water competition in urban areas like Adama, advocating for a fit-for-purpose approach to balance sectoral needs. The fourth strategy emphasizes transitioning to a water-sensitive city with flexible combined systems combining centralized and decentralized solutions to enhance community water access.

- **Understanding the seasonality of the Awash River and the need to explore alternative water sources**

Concerns about the Awash River as Adama's water supply arise from two main factors. First, its seasonal variability due to fluctuating rainfall and runoff, which causes inconsistent flow, and secondly, the city's heavy reliance on this single source. This dependence, combined with limited alternative sources, jeopardizes long-term water supply sustainability. As DH-Consult (2018) warns, any disruption to the Awash River would significantly worsen the city's water supply issues. In the future, the city needs an integrated water supply system that combines both surface and groundwater sources, incorporating both centralized and decentralized approaches. This system should be guided by water conservation strategies and supported by efficient water-

saving technologies. The city needs water harvesting strategy for emergency this can be realize by implanting water for the purpose water resource planning and management.

- **Promoting city level water sensitive urban spatial planning and design**

This approach emphasizes integrated land use decision-making to achieve sustainable, water-sensitive urban development. It focuses on strategies such as water-conscious infrastructure, green spaces, low-impact urban agriculture and the preservation of wetlands and groundwater zones. Harmonizing spatial planning with water-sensitive urban design is crucial, incorporating measures like alternative water harvesting, infiltration structures and permeable surfaces. Aligning land use policies with a water-sensitive vision promotes green infrastructure such as rain gardens and urban forests while safeguarding ecosystems. Water-centric zoning supports balanced development, integrates green and blue infrastructure and conserves vital water resources.

- **Rethinking the city as "water supply catchment" through integrated city region water-sensitive planning**

Urban areas can enhance self-sufficiency by developing alternative water sources within their boundaries by reducing reliance on external supplies. Adopting a water-sensitive approach, based on the "water supply catchment" principle, involves diversifying sources like surface water, groundwater, rainwater, stormwater runoff and recycled wastewater. This fosters circular water metabolism and minimizes dependence on external resources.

- **Promoting circular urban water metabolism at city level**

Adama's linear "take-make-use-dispose" water consumption model and reliance on centralized systems classify it as a "Water Supply City," revealing a missed opportunity for a more resilient, circular urban water metabolism approach. Hence, the city administration must shift its strategy towards promoting alternative water harvesting methods to address this gap and enhance sustainability using circular urban water metabolism.

- **Building water-sensitive communities through public awareness and education**

The findings highlight a significant gap in community-level water conservation practices, underscoring the urgent need for greater citizen awareness and education. Building water-sensitive communities is crucial for cultivating a conservation-oriented culture. To foster a

water-sensitive community, implementing key city-level programs is essential. These include launching city-wide water-saving campaigns, introducing signage that promotes water conservation in institutions and public spaces, partnering with religious organizations that advocate for water-saving practices to educate their followers, celebrating “water day” in educational institutions and engaging the community in planning and executing water-related initiatives such as stormwater management and rainwater harvesting projects.

- **Installing water-sensitive technologies for water intensive beneficiaries**

Urban areas often experience high per capita water consumption across residential and non-residential sectors. To promote water conservation, efficient technologies such as fixing leaks, installing low-flow fixtures, dual-flush toilets and WaterSense-labeled products along with regular leak inspections should be prioritized. Smart landscape watering systems can further optimize water use. Rainwater harvesting offers an effective solution, incorporating low-cost roof collection systems for non-potable uses and underground reservoirs for long-term storage. High consumption establishments like hotels, restaurants and pensions should implement water-efficient appliances such as low-flow showerheads, toilets and faucets with sensor-based fixtures mandatory in water-intensive operations. Additionally, periodic maintenance of water infrastructure including leak repairs and system rehabilitation is crucial for ensuring water quality and minimizing wastage. Adopting greywater systems, rain barrels, drought-tolerant landscaping with native plants and water-efficient irrigation can significantly enhance urban water management and sustainability.

- **Initiating water-sensitive legal frameworks**

Effective water management requires implementing and enforcing water-centric legal frameworks at regional, municipal and neighborhood levels. These frameworks should include standards for water-efficient appliances, stormwater regulations like permeable pavements and rain gardens and policies to foster water conservation and urban resilience. Existing water laws must be enforced and updated to align with water-sensitive city principles. Minimum standards for constructing water harvesting structures should be established at all levels, including residential and non-residential areas. Protecting urban catchments such as wetlands, watersheds, and buffer zones should also be prioritized. Legal frameworks should clarify resource allocation, usage rights and responsibilities, particularly for groundwater. Finally, promoting the

use of water-saving technologies requires developing and enforcing clear guidelines to regulate and monitor water conservation practices effectively.

(ii) Proposed water sensitive policy intervention approaches at national level

- **Integrating groundwater development with water sensitive land use planning**

In developing countries, urban expansion and rising water demand, combined with unregulated spatial planning jeopardize groundwater sustainability. To counter this, development plans must integrate groundwater management with spatial planning. In areas with active groundwater use, implementing pollution protection and rehabilitation measures is crucial. The following actions are essential:

- Developing and implementing groundwater management plans at national , regional and city region levels.
- Developing groundwater management on an integrated approach, including surface water, conservation, water quality and reuse strategies.
- Promoting water-wise groundwater utilization across all sectors, including agriculture, industry and residential use.

- **Revising basin master plans and optimizing river basin planning and water allocation**

Integrated basin-scale master plans are crucial for managing water stress. A responsive master plan is essential for effectively addressing growing water demands. Key considerations for a water-sensitive basin master plan include:

- Focusing on drought-prone and water-stressed basins.
- Promoting watershed management practices to enhance water and soil conservation.
- Developing and enforcing legislation for sustainable water resource management.

- **Linking 'top-down' and 'bottom-up' approaches of water management practices**

An effective integrated water management approach needs a comprehensive top-down policy paired with bottom-up and indigenous practices. Success hinges on expanding local knowledge and implementing nature-based solutions at the community level.

- **Building resilient urban centers through water-sensitive city framework**

Urbanization demands sustainable water strategies that align with growth. Shifting from unsustainable "supply-side" management to "demand-side" approaches is vital, focusing on

efficiency, minimizing losses, fostering water-sensitive communities and adopting water-saving technologies.

6.3 Future Research Direction

Periodic assessment and monitoring of urban water stress and security are crucial, given their dynamic nature. This research emphasizes the importance of regular studies to analyze urban metabolism trends and provide critical insights for evidence-based decision-making. Future research should expand to include additional case studies and adopt longitudinal analyses of urban water metabolism to deepen understanding of changes in water consumption patterns across Ethiopian urban areas. Furthermore, as this study focuses solely on residential water usage, future investigations should also model non-residential water consumption to comprehensively capture the complexities of urban water use in the context of Ethiopia's rapid urbanization. This research is limited to water, overlooking the interconnectedness of urban water systems with other urban systems, such as energy and waste. A holistic approach is required for a more comprehensive analysis and future research will explore these interconnected aspects. Additionally, future research will aim to communicate the importance of integrating urban metabolism and water sensitivity to policymakers, enabling its incorporation into urban development policy toolkit.

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Appendixes

Supplementary/Appendices/

Appendix I: Questioner survey for tracking and tracing city-wide water consumption characteristics

1.1 Questioner survey for tracking and tracing household water consumption characteristics

Dear Participants,

This study is part of my Ph.D. in Urban and Regional Planning at the Ethiopian Institute of Architecture, Building Construction, and City Development, Addis Ababa University. It aims to gather data on household water consumption in Adama city, focusing on tracking and tracing water consumption from the source to end uses. The questionnaire will take 10 to 15 minutes, and your honest responses are crucial to the study's success. Participation is voluntary and you can ask any unclear idea at any time. All information will be kept confidential and analyzed secretly. Thank you for your cooperation.

Section I : Basic information

Please answer the following questions as they pertain to you.

1) Id number----------meter Id ----------geographic location----------
2) Sex of household head a. male b. female
3) Name of the household head----------
4) Total household size ----------
5) Total household size of renters (if any) ----------
6) How many of your family are under age of a. 0- 14 years ----- b. 15-59 years ----- c. 60+ --
7) Marital status a. married b. single c. separated d. divorce e. widowed
8) Highest educational attainment of the household head

a. Illiterate b. read and write c. primary (1-8) d. secondary school (9-12)
e. certificate/diploma f. degree g. masters h. PhD

9) Main occupation of the head of the household

a. Government b. NGO c. private d. self-employed e. unemployed f. retires

10) Income of the household by his/her major sources

a. salary (birr)----------b. business income (birr) ----------c. remittance (birr)---------- d. rental income (birr)----------e. pension(birr)--------- f. other ---------

11) Total income in birr per month ----------

Section II: Neighborhood characteristics of the respondents

1) Location of parcel a. central b. intermediate c. periphery
2) Age of the main building----------
3) Housing topology a. detached villa b. attached duplex c. attached row house d. condominium e. apartment f. other traditional buildings
4) Tenure a. owner occupied b. rented from kebele c. rented from RHA d. rented from private e. Other (specify) ----------
5) Legal status a. formal b. informal
6) Housing condition a. very good b. good c. fair d. bad
7) Number of rooms excluding toilet & bathroom----------
8) Area of the parcel(m^2)
9) Roof area (m^2) ----------
10) Building height (m)----------

Section III: water source types, availability, continuity and accessibility of municipal water supply characteristics (drinking water and human well-being water security related issues)

1) Household's main source of drinking water (multiple choices is possible)

a. piped water into dwelling b. piped water to yard c. public tap d. spring e. rainwater f. tanker truck g. surface water (river, dam and pond)

2) Average water bill payment per month per Kiremt, Tsheday, Bega and Meher --------
3) How often do you get water from the pipe? a. once a week b. twice a week c. three times a week d. four times a week e. five times a week f. six times a week g. every day
4) What reasons do you think for discontinuity of the supply?

a. topography of the area b. poor service quality c. pressure problem

d. restriction due to lack of adequate water quantity e lack of water network expansion

5) Which one of the supplementary water sources you use commonly? a. spring b. surface water (river, pond and lake) c. well d. Other specify ----------
6) If yes for # 5, estimated supplementary quantity of water per month (20-liter jerican)
7) Do you buy water from water vendors/ tanker-truck/? a. yes b. no
8) If yes, for #7 how much water you collect from truck per week (20 Liters jerican)----
9) Do you collect rain water? a. yes b. no
10) If yes, for # 9 how much water you get from rain water per month/year(liter)
If yes for +# 9 for what purpose do you use a. consumption b. hygiene c. outdoor service
11) Do you recycle water? a. yes b. no
12) If yes, for # 12 how much water you get from recycle water per month/year(liter) ---
13) If yes for #12 for what purpose do you use ? a. for toilet sanitation b. for yard cleaning c. compost making d. combination of ---and ----
15) Is the water supplied from your main source usually acceptable?

a. yes, acceptable b. no unacceptable taste c. no unacceptable color d. no unacceptable smell e. no contains materials f. no other reason (specify)----------

Section IV: Water consumption at end use appliances

1) Do you have a garden/green plantation/ at home? a. yes b. no
2) Do you have shower? a. yes b. no
3) If yes for # 2 the type of shower is ----------

a. bath tub-private b. bath tub-shared c. shower private d. shower-shared e. bath tub & shower-shared f. bath tub & shower- private

4) Number of showers per week a. 0 b. 1 to 2 c. 3 to 5 d. 6 to 10
5) Length of shower time (minute) a. less than 5 b. 6 to 8 c. 10 to 15 d. > 15
6) Do you have toilet ? a. yes b. no
7) If yes # 6 the specify the number of toilets ----------
8) If yes for # 6 the type of toilet is ----------

a. flush toilet- private b. flush toilet- shared c. pit-private d. pit shared e. specify (if other)

9) Type of cloth washing a. machine b. traditional
10) Average meal prepared per household per a week ----------

Section V: Water conservation practices

Dear respondent, please indicate your frequency of practicing water conservation using the seven-point Likert scale below. Select the number that best represents how often you engage in water conservation activities: 1. Never, 2. Rarely, 3. Occasionally, 4. Sometimes, 5. Frequently, 6. Usually 7. Every time and not applicable 00

Table.1 Household water consumption measurement using Likert scale

s.n	Water saving behaviors	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Every time	Not applicable
I	**Installation and retrofitting of water-saving technologies**								
1.1	Repairing all water leaks in toilets and faucets	1	2	3	4	5	6	7	00
1.2	Inspecting dripping taps and toilets	1	2	3	4	5	6	7	00
1.3	Installing water-efficient faucets or shower heads	1	2	3	4	5	6	7	00
1.4	Installing a low-water or dual-flush toilet	1	2	3	4	5	6	7	00
1.5	Installing flow restrictor in the shower/s	1	2	3	4	5	6	7	00
1.6	Installing water sense showerhead	1	2	3	4	5	6	7	00
1.7	Installing water sense toilet	1	2	3	4	5	6	7	00
II	**Indoor water conservation behavior**								
2.1	Turn off the water when shaving and washing your face and hands	1	2	3	4	5	6	7	00
2.2	Turn off the water when brushing your teeth	1	2	3	4	5	6	7	00
2.3	Turn off the shower while soaping	1	2	3	4	5	6	7	00
2.4	Take short showers or limit showering time to 5 minutes								00
2.5	Turn off the tap when washing dishes	1	2	3	4	5	6	7	00
2.6	Plug the sink when washing dishes	1	2	3	4	5	6	7	00
2.7	Track water consumption based on the bill	1	2	3	4	5	6	7	00
III	**Outdoor water conservation behavior**								
3.1	Washing a car with a bucket of water rather than a running hose	1	2	3	4	5	6	7	00
3.2	Watering early in the morning/afternoon	1	2	3	4	5	6	7	00
3.3	Watering plants when necessary and based on plant type	1	2	3	4	5	6	7	00
3.4	Use alternative water resources	1	2	3	4	5	6	7	00
IV	**General awareness in water sensitive water management and planning**								
4.1	We discuss about the importance and benefits of water saving	1	2	3	4	5	6	7	00
4.2	We have intentions to install water efficient devices	1	2	3	4	5	6	7	00
4.3	Local government give awareness seminar about the importance and benefits of water saving	1	2	3	4	5	6	7	00
4.4	We are aware of water centric regulations in the city	1	2	3	4	5	6	7	00

1.2 Questioner survey for tracking and tracing commercial water consumption characteristics

1.2.1 Hotels, pensions, restaurants and cafes

Dear participants,

This study is part of my Ph.D. in Urban and Regional Planning at the Ethiopian Institute of Architecture, Building Construction, and City Development, Addis Ababa University. It aims to gather data on commercial services water consumption in Adama city, focusing on tracking water consumption from the source to end uses. The questionnaire will take 10 to 15 minutes, and your honest responses are crucial to the study's success. Participation is voluntary, and you can ask any unclear idea at any time. All information will be kept confidential and analyzed secretly. Thank you for your cooperation.

Section I. Basic information for commercial services (hotel, pension and café)

1) Meter Id----------
2) Name of hotel /pension/café/ ----------
3) Rank----------
4) Geographic location ----------
5) Neighborhood location a. central b. intermediate c. periphery
6) Number of rooms----------
7) Number of beds ----------
8) Total parcel area ----------
9) Total roof area ----------
10) Number of beds ----------
11) Number of staffs----------
12) Average number of visitors per day/ month----------
13) Average occupation of the bed per day/month -------
14) Average monthly bill payment----------

Section II. Types of centralized and decentralized water sources

Table 2. Type of commercial services' water supply sources

s.no	Type of source	source type		quantity (liter)
		yes	no	
1	Piped water supply			
2	Protected well (own well)			
3	Protected spring			
4	Rainwater harvesting			
5	Unprotected well			
6	Unprotected spring			
7	Tanker-truck or cart			
8	Surface water			

Section III. Water availability, reliability and accessibility

1) How many days per week piped water supplied on average?
 a. one times a week b. two times a week c. three times a week d. four times a week
 e. five times a week f. six times a week g. everyday h. not all
2) What reasons do you think for discontinuity of the supply?
 a. topography b. poor service quality c. pressure problem or limited supply source
 d. restriction due to lack of adequate water quantity e. lack of water network
 f. any combination of the listed problems ----------
3) Does your hotel/pension/ café/ has a storage tank? a. yes b. no
4) If yes for # 3 how many liters does the storage tank hold in liters----------?
5) What problems or challenges do you observed in your water tanker?
 a. water over flow from the tanker b. leakage c. lack of water due to pressure d. other-----
6) Do you collect rain water? a. yes b. no
7) If yes for # 6, how much water you get from rain water? per month/day/year (liter) ---
8) If yes for # 6 for, what purpose do you use it? a. consumption b. hygiene c. amenity d. the combination of ----------and----------
9) Do you recycle water? a. yes b. no
10) If yes, for # 9 how much water you get from recycled water? per month/day/ (liter)--
11) If yes for # 9 for what purpose do you use it?
 a. consumption b. hygiene c. amenity d. combination of ----------and-----
12) Do you have your own well? a. yes b. no
13) If yes, for # 12 how much water you get from well water? per month/day/ (liter)-----
14) Do you have garden area a. yes
 b. no
15) Do you have agricultural area a. yes
 b. no
16) Do you wash your car inside your compound a yes b. no
17) Is the water supplied from your main source usually acceptable?
 a. yes, acceptable b. no unacceptable taste c. no unacceptable color d. no unacceptable smell e. no contains materials f. no other reason (specify)----------

Section IV. Water consumption at water end use appliances

1) Number of toilets----------
2) Type of toilets ----------
3) Average flushing per day ----------
4) Number of showers----------
5) Type of showers----------
6) Average shower time in minute per guest----------
7) Number of hand washes----------
8) Average number of hand wash per day per guest----------
9) Type of hand washes----------
10) Average cloth washing per week----------
11) Number of urine closet----------
12) Type of the urine closet----------
13) The number of meals served per day----------
14) Type of washing machine ----------
15) Availability of swimming pools and spas (area)----------

Section V: Water conservation practices

Dear respondents, please indicate your frequency of practicing water conservation using the seven-point Likert scale below. Select the number that best represents how often you engage in water conservation activities: 1. Never, 2. Rarely, 3. Occasionally, 4. Sometimes, 5. Frequently, 6. Usually 7. Every time and not applicable 00

Table 3. Commercial water consumption measurement using Likert scale

s.n	Indicators	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Every time
I	Building level operation and awareness creation for commercial water conservation							
1.1	We regularly check for leaks in the buildings proactively	1	2	3	4	5	6	7
1.2	We have facility management unit and we assign water facility manager	1	2	3	4	5	6	7
1.3	We place a sign above basins suggesting that guests don't leave the tap running while shaving or brushing teeth	1	2	3	4	5	6	7
1.4	we have water consumption audit and planning system	1	2	3	4	5	6	7
1.5	Encourage guests to shower instead of bath	1	2	3	4	5	6	7
1.6	Educate staff about water saving in indoor and outdoor water consumption practices	1	2	3	4	5	6	7
1.7	We apply water for the purpose	1	2	3	4	5	6	7
II	Toilets							
2.1	We conduct regular maintenance checks for leaks in toilets	1	2	3	4	5	6	7
2.2	We install flow restrictors to reduce tap flow	1	2	3	4	5	6	7
2.3	We use alternative water source to pour-flush	1	2	3	4	5	6	7
2.4	We retrofit old toilet fixtures and lines	1	2	3	4	5	6	7
2.5	We remind users not to use toilets as basket waste	1	2	3	4	5	6	7
2.6	We install hand-basin taps in toilet that are self-stopping type/sensors/	1	2	3	4	5	6	7
2.7	We place a sign above basins suggesting that guests don't leave the tap running in toilets	1	2	3	4	5	6	7
III	Showers							
3.1	We conduct regular maintenance checks for leaks for shower fixtures	1	2	3	4	5	6	7
3.2	We install low flow rate regulators	1	2	3	4	5	6	7
3.3	We install water-efficient showerheads	1	2	3	4	5	6	7
3.4	We retrofit old shower fixtures and lines	1	2	3	4	5	6	7
3.5	We install hand-basin taps in shower that are self-stopping type/sensors	1	2	3	4	5	6	7
3.6	Users take shower up to or to less than 5	1	2	3	4	5	6	7

	minutes							
3.7	We place a sign above basins suggesting that guests don't leave the shower running or un closed during un used period	1	2	3	4	5	6	7
IV	Hand washes and Faucets							
4.1	We repair leaks and plumbing problems in hand wash							
4.2	We install flow control fixtures on all faucets	1	2	3	4	5	6	7
4.3	Reservoirs and taps used at our institutions have water loss minimizing (low-flow sensor)	1	2	3	4	5	6	7
4.4	We check for leaks and dripping taps, and encourage to report them	1	2	3	4	5	6	7
4.5	We check taps and ensure they are not left running when not in use at night or during ceremony	1	2	3	4	5	6	7
4.6	We supervise and monitor our water tankers for overflow	1	2	3	4	5	6	7
4.7	We place signs on equipment on how to use/save/	1	2	3	4	5	6	7
V	Kitchens / Cafeterias/							
5.1	We use automatic dishwasher only for full loads.	1	2	3	4	5	6	7
5.2	We use automatic washing machine only for full loads.	1	2	3	4	5	6	7
5.3	We repair leaky faucets, pipes, and plumbing fixtures	1	2	3	4	5	6	7
5.4	We install an automatic shutoff so water does not run when waste disposal is not in use	1	2	3	4	5	6	7
5.5	We avoid running tap water to cool it off for drinking	1	2	3	4	5	6	7
5.6	We don't let the faucet run while we clean	1	2	3	4	5	6	7
5.7	We place signs on equipment on how to save							
VI	Ground cleaning and compound sanitation							
6.1	Cleaners are aware of not to leave taps running or use excessive water	1	2	3	4	5	6	7
6.2	Cleaners clean hard surface without water							
6.3	Cleaners use mop than hose							
6.4	Cleaners use alternative water	1	2	3	4	5	6	7
6.5	Cleaners keep a bucket in bathroom	1	2	3	4	5	6	7
6.6	Cleaners reduce chemicals during cleanings	1	2	3	4	5	6	7
6.7	Cleaners are commonly informed how to reduce water use where possible							
VII	Garden & irrigation							
7.1	We plant indigenous plants which are more likely to be naturally adapted to thrive with the amount of rainfall in the local area	1	2	3	4	5	6	7
7.2	We prepare plant types, during landscape planning, which do not need much water	1	2	3	4	5	6	7
7.3	We group similar plant types according to their	1	2	3	4	5	6	7

	water requirements (hydro-zoning)							
7.4	We improve soil condition with organic material to improve water retention	1	2	3	4	5	6	7
7.5	We reclaimed water from a rainwater	1	2	3	4	5	6	7
7.6	We water during the night and morning to avoid evaporation and loses	1	2	3	4	5	6	7
7.7	We use drip irrigation wherever possible	1	2	3	4	5	6	7
VIII	Swimming Pools and spas							
8.1	We backwash pool filters only when necessary	1	2	3	4	5	6	7
8.2	We cover pools and spas when not in use	1	2	3	4	5	6	7
8.3	We lower the pool's water level	1	2	3	4	5	6	7
8.4	We check for leaking pipes, valves and joiners.	1	2	3	4	5	6	7
8.5	We check for cracks or gaps in the bond beam	1	2	3	4	5	6	7
8.6	We drain pool or spa only when necessary	1	2	3	4	5	6	7
8.7	We shut off fountains and waterfalls	1	2	3	4	5	6	7
IX	Laundries							
9.1	We run full loads	1	2	3	4	5	6	7
9.2	We evaluate wash cycles and detergent / chemical formulations for maximum efficiency	1	2	3	4	5	6	7
9.3	We check for leaks	1	2	3	4	5	6	7
9.4	We choose the correct load size	1	2	3	4	5	6	7
9.5	We use hot water reuse systems and other water conserving technology where feasible	1	2	3	4	5	6	7

X	**Water saving educations / awareness/**							
10.1	We provide training to increase awareness of water efficiency practices and procedures.	1	2	3	4	5	6	7
10.2	We provide suggestion boxes to collect suggestions about water consumption	1	2	3	4	5	6	7
10.3	We post water saving signs	1	2	3	4	5	6	7
10.4	We inform or instruct about water saving	1	2	3	4	5	6	7
10.5	We provide or supply water-efficient appliances and systems	1	2	3	4	5	6	7
10.6	We encourage employees to adopt water-saving habits	1	2	3	4	5	6	7
10.7	We offer incentives for water-saving efforts							

1.2.2 Questioner Survey for Tracking and Tracing Cara Wash Water Consumption Characteristics

Dear participants,

These questions aim to gather information about water usage in car washes in Adama City. We seek to understand the entire process, from water sourcing to final use, as well as attitudes and experiences with water conservation. Your honest and thoughtful responses are crucial for this study, so accuracy and consistency are highly valued!

Section I. Basic information for commercial services (car washes)

1) Owner of the car wash
   a. government b. private c. Ngo d. community e. unions
2) Geographic location of the car wash ----------
3) Type of the car wash ----------
4) Average number of vehicles/cars/ served per day ----------
5) Average water consumption per month ----------

Section II. Types of centralized and decentralized water sources for car washes

Table 4. Type water supply sources for carwashes

s.no	Type of source	source type		quantity (liter)
		yes	no	
1	Piped water supply			
2	Protected well (own well)			
3	Protected spring			
4	Rainwater harvesting			
5	Unprotected well			
6	Tanker-truck or cart			
7	Surface water			

Section III. Water availability, reliability and accessibility

Table 5 Vehicle washing methods and water volumes used for each type of washing

Types of vehicles	Washing methods		
	bucket only (liter)	bucket and hose (liter)	power wash (liter)
Bajaj			
Automobile			
Pickup			
Minibus			
Bus			
Tracks			

1) How many days per week piped water supplied on average?

b. one times a week b. two times a week c. three times a week d. four times a week

e. five times a week f. six times g. everyday h. not all

2) What reasons do you think for discontinuity of the supply?

a. topography b. poor service quality c. pressure problem or limited supply source

d. restriction due to lack of adequate water quantity e. lack of water network expansion

f. any combination of the listed problems ----------

3) Do you collect rain water? a. yes b. no

4) If yes for # 3, how much water you get from rain water? per month/day/year (liter) ---

5) Do you recycle or reuse water? a. yes b. no

6) If yes, for # 5 how much water you get from recycled water? per month/day/ (liter)---

7) Do you have your own well? a. yes b. no

8) If yes, for # 7 how much water you get from well water? per month/day/ (liter)------

9) Do you have garden area a. yes b. no

10) Do you wash in the river a. yes b. no

Section IV. Method of washing car and its impacts

1) What method of washing car do you use
   a) carwash from bucket with sponge and rinse off with buckets of water
   b) Carwash from bucket with sponge and rinse off with hose
   c) Carwash from bucket with sponge and rinse off with power washer
   d) Car wash using In-Bay Automatic Car Wash
2) Types of Service
   a) Full-service
   b) Exterior only
   c) Both full-Service and Exterior
3) What do you think the impact of the car wash in the city
   a) Wate generation
   b) Th use of harsh chemicals
   c) High water consumption
   d) Destruction of habitants in the river

Section V. Water conservation practices

Table. 6 Car wash water consumption measurement using Likert scale

S.N	Saving Water in Vehicle Wash Operations	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Every time
I	**Equipment operation and maintenance for water conservation in in car wash stations**							
1.1	Check for water leaks regularly and repair them immediately as they occur	1	2	3	4	5	6	7
1.2	Upgrade to rotary or turbo nozzles instead of flat, fan nozzles	1	2	3	4	5	6	7
1.3	Replace spray nozzles regularly as they wear	1	2	3	4	5	6	7
1.4	Replace brass or plastic nozzles, which erode quickly, with low-flow stainless steel or hard ceramic nozzles	1	2	3	4	5	6	7
1.5	Maintain all equipment to original or improved specifications for water usage	1	2	3	4	5	6	7
1.6	Regularly check sanitary lines for leaks, and fix leaks immediately	1	2	3	4	5	6	7
1.7	Upgrade to rotary or turbo nozzles instead of flat, fan nozzles	1	2	3	4	5	6	7
II	**Nozzle and hose monitory for water conservation practice in stations**							
2.1	Check the alignment of nozzles regularly	1	2	3	4	5	6	7
2.2	Cloth the hose while washing the car	1	2	3	4	5	6	7
2.3	Adjust nozzle tip size and pressure to reduce its flow rate	1	2	3	4	5	6	7
2.4	All hoses and faucets have automatic shutoff valves	1	2	3	4	5	6	7
2.5	Use nozzle protection for hand-held wands	1	2	3	4	5	6	7
2.6	Consider collecting rainwater on the roof to use in washing phase	1	2	3	4	5	6	7
2.7	Use stainless steel or hard ceramic nozzles to maintain flow and pressure	1	2	3	4	5	6	7
3	**Environmental protection and water conservation practice in car wash stations**							
3.1	Sweep impervious areas instead of washing							
3.2	Ensure accurate dilution ratios for detergents	1	2	3	4	5	6	7
3.3	Clean bays or driveways with high-pressure, low-volume water systems instead of hoses	1	2	3	4	5	6	7
3.4	Installing a water reclaim system							
3.5	Staff training to inspect and maintain water systems	1	2	3	4	5	6	7
3.6	Preventing runoff and promoting green landscaping.	1	2	3	4	5	6	7
3.7	Allaying water saving techniques	1	2	3	4	5	6	7

1.3 Questioner Survey for Tracking and Tracing Service Institutions Characteristics

1.3.1 Education and health sector

Dear Participants,

This study is part of my Ph.D. in Urban and Regional Planning at the Ethiopian Institute of Architecture, Building Construction, and City Development, Addis Ababa University. It aims to gather data on service institutions water consumption in Adama city, focusing on tracking and tracing water consumption from the source to end uses. The questionnaire will take 10 to 15 minutes, and your honest responses are crucial to the study's success. Participation is voluntary, and you can ask any unclear idea at any time. All information will be kept confidential and analyzed secretly. Thank you for your cooperation**.**

Section I. Basic information for service institutions (education and health sector)

1) Owner of the service institution (school/health)
2) a. government b. private c. NGO d community e. religious
3) Level of educational/health/ institution ----------
4) Geographic location education/health ----------
5) Number of staffs education/health ----------
6) Number of students regular--------- extension----------
7) Average number of patients per day in the health institution --------
8) Number of beds in the health institution----------
9) Total parcel area education/health ----------
10) Roof area education/health ----------
11) If available irrigated area (ha)----------
12) If available garden area (ha)----------
13) Average bill payment per month in education/health ----------

Section II. Types of centralized and decentralized water sources

Table 7. Type of water supply sources for institutional services

s.no	Type of source	source type		quantity (liter)
		yes	no	
1	Piped water supply			
2	Protected well (own well)			
3	Protected spring			
4	Rainwater harvesting			
5	Unprotected well			
6	Tanker-truck or cart			
7	Surface water			

Section III. Water availability, reliability and accessibility

1) How many days per week piped water supplied on average?
   c. one times a week b. two times a week c. three times a week d. four times a week
   e. five times a week f. six times g. everyday h. not all
2) What reasons do you think for discontinuity of the supply?
   a. topography b. poor service quality c. pressure problem or limited supply source
   d. restriction due to lack of adequate water quantity e. lack of water network expansion
   f. any combination of the listed problems ----------
3) Does your education/health institution has a storage tank? a. yes b. no
4) If yes for # 3 how many liters does the storage tank hold in liters----------?
5) What problems or challenges do you observed in your water tanker?
   a. water over flow from the tanker b. leakage c. lack of water due to pressure
   d. other-----
6) Do you collect rain water? a. yes b. no
7) If yes for # 6, how much water you get from rain water? per month/day/year (liter) ---
8) If yes for # 6 for, what purpose do you use it?
   a. consumption b. hygiene c. amenity d. the combination of ----------and---------
9) Do you recycle or reuse water ? a. yes b. no
10) If yes, for # 9 how much water you get from recycled water? Per month/day/ (liter)--
11) If yes for # 9 for what purpose do you use it?
    a. consumption b. hygiene c. amenity d. combination of ----------and-----
12) Do you have your own well? a. yes b. no
13) If yes, for # 12 how much water you get from well water? per month/day/ (liter)-----
14) Do you have garden area a. yes b. no
15) Do you have agricultural area a. yes b. no
16) Do you wash your car inside your compound a yes b. no
17) What is the main source for outdoor service a. pipe water b. decentralized water supply
18) Is the water supplied from your main source usually acceptable?
    a. yes, acceptable b. no unacceptable taste c. no unacceptable color d. no unacceptable smell e. no contains materials f. no other reason (specify)----------

Section IV. Water consumption at water end use appliances

1) Number of toilets----------
2) Type of toilets ----------
3) Average flushing per day ----------
4) Number of showers----------
5) Type of showers----------
6) Average shower time in minute per guest----------
7) Number of hand washes----------
8) Average number of hand wash per day per guest----------
9) Type of hand washes----------
10) Average cloth washing per week----------
11) Number of urine closet----------
12) Type of the urine closet----------
13) The number of meals served per day----------
14) Type of washing machine ----------

s.n	Indicators	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Every time
I	Building level operation and awareness creation for commercial water conservation							
1.1	We regularly check for leaks in the buildings proactively	1	2	3	4	5	6	7
1.2	We have facility management unit and we assign water facility manager	1	2	3	4	5	6	7
1.3	We place a sign above basins suggesting that students/patients/don't leave the tap running	1	2	3	4	5	6	7
1.4	we have water consumption audit and planning system	1	2	3	4	5	6	7
1.5	Encourage users to shower instead of bath	1	2	3	4	5	6	7
1.6	Educate students/patients/about water saving in indoor and outdoor water consumption practices	1	2	3	4	5	6	7
1.7	We apply water for the purpose	1	2	3	4	5	6	7
II	Toilets							
2.1	We conduct regular maintenance checks for leaks in toilets	1	2	3	4	5	6	7
2.2	We install flow restrictors to reduce tap flow	1	2	3	4	5	6	7
2.3	We use alternative water source to pour-flush	1	2	3	4	5	6	7
2.4	We retrofit old toilet fixtures and lines	1	2	3	4	5	6	7
2.5	We remind users not to use toilets as basket waste	1	2	3	4	5	6	7

2.6	We install hand-basin taps in toilet that are self-stopping type/sensors/	1	2	3	4	5	6	7
2.7	We place a sign above basins suggesting that guests don't leave the tap running in toilets	1	2	3	4	5	6	7
III	Showers							
3.1	We conduct regular maintenance checks for leaks for shower fixtures	1	2	3	4	5	6	7
3.2	We install low flow rate regulators	1	2	3	4	5	6	7
3.3	We install water-efficient showerheads	1	2	3	4	5	6	7
3.4	We retrofit old shower fixtures and lines	1	2	3	4	5	6	7
3.5	We install hand-basin taps in shower that are self-stopping type/sensors	1	2	3	4	5	6	7
3.6	Users take shower up to or to less than 5 minutes	1	2	3	4	5	6	7
3.7	We place a sign above basins suggesting that users don't leave the shower running or un closed during un used period	1	2	3	4	5	6	7
IV	Hand washes and Faucets							
4.1	We repair leaks and plumbing problems in hand wash							
4.2	We install flow control fixtures on all faucets	1	2	3	4	5	6	7
4.3	Reservoirs and taps used at our institutions have water loss minimizing (low-flow sensor)	1	2	3	4	5	6	7
4.4	We check for leaks and dripping taps, and encourage to report them	1	2	3	4	5	6	7
4.5	We check taps and ensure they are not left running when not in use at night or during ceremony	1	2	3	4	5	6	7
4.6	We supervise and monitor our water tankers for overflow	1	2	3	4	5	6	7
4.7	We place signs on equipment on how to use/save/	1	2	3	4	5	6	7

Table 8. Service institution (education and health) water consumption measurement using Likert scale

V. Ground cleaning and compound sanitation								
5.1	Cleaners are aware of not to leave taps running or use excessive water	1	2	3	4	5	6	7
5.2	Cleaners clean hard surface without water							
5.3	Cleaners use mop than hose							
5.4	Cleaners use alternative water	1	2	3	4	5	6	7
5.5	Cleaners keep a bucket in bathroom and use it to save water	1	2	3	4	5	6	7
5.6	Cleaners reduce chemicals during cleanings	1	2	3	4	5	6	7
5.7	Cleaners are commonly informed how to reduce water use where possible							
VI	**Garden & irrigation**							
6.1	We plant indigenous plants which are more likely to be naturally adapted to thrive with the amount of rainfall in the local area	1	2	3	4	5	6	7
6.2	We prepare plant types, during landscape planning, which do not need much water	1	2	3	4	5	6	7
6.3	We group similar plant types according to their water requirements (hydro-zoning)	1	2	3	4	5	6	7
6.4	We improve soil condition with organic material to improve water retention	1	2	3	4	5	6	7
6.5	We reclaimed water from a rainwater	1	2	3	4	5	6	7
6.6	We water during the night and morning to avoid evaporation and loses	1	2	3	4	5	6	7
6.7	We use drip irrigation wherever possible	1	2	3	4	5	6	7
VII	**Laundries**							
7.1	We run full loads	1	2	3	4	5	6	7
7.2	We evaluate wash cycles and detergent / chemical formulations for maximum efficiency	1	2	3	4	5	6	7
7.3	We check for leaks	1	2	3	4	5	6	7
7.4	We choose the correct load size	1	2	3	4	5	6	7
7.5	We use hot water reuse systems and other water conserving technology where feasible	1	2	3	4	5	6	7
VII	**Water saving educations / Awareness/**							
8.1	We provide training to increase awareness of water efficiency practices and procedures.	1	2	3	4	5	6	7
8.2	We provide suggestion boxes to collect suggestions about water consumption	1	2	3	4	5	6	7
8.3	We post water saving signs	1	2	3	4	5	6	7
8.4	We inform or instruct about water saving	1	2	3	4	5	6	7
8.5	We provide or supply water-efficient appliances and systems	1	2	3	4	5	6	7
8.6	We encourage employees to adopt water-saving habits	1	2	3	4	5	6	7
8.7	We offer incentives for water-saving efforts							

1.3.2 Religious institutions

Dear participants,

This study is part of my Ph.D. in Urban and Regional Planning at the Ethiopian Institute of Architecture, Building Construction, and City Development, Addis Ababa University. It aims to gather data on service institutions/religious institutions/ water consumption in Adama city, focusing on tracking and tracing water consumption from the source to end uses. The questionnaire will take 10 to 15 minutes, and your honest responses are crucial to the study's success. Participation is voluntary, and you can ask any unclear idea at any time. All information will be kept confidential and analyzed secretly. Thank you for your cooperation.

Section I. Basic information for service institutions (religious institutions)

1) Type of religious institution ----------
2) Geographic location the religious institutions ----------
3) Number of followers of the religious institutions----------
4) Total parcel area of the religious institutions ----------
5) Roof area of the religious institutions ----------
6) If available irrigated area (ha)----------
7) If available garden area (ha)----------
8) Average bill payment per month the religious institutions ----------

Section II. Types of centralized and decentralized water sources

Table 9. Type of water supply sources for religious services

s.no	Type of source	source type		quantity (liter)
		yes	no	
1	Piped water supply			
2	Protected well (own well)			
3	Protected spring			
4	Rainwater harvesting			
5	Unprotected well			
6	Unprotected spring			
7	Tanker-truck or cart			
8	Surface water			

Section III. Water Availability, Reliability and Accessibility

1) How many days per week piped water supplied on average?
d. one times a week b. two times a week c. three times a week d. four times a week
e. five times a week f. six times g. everyday h. not all
2) What reasons do you think for discontinuity of the supply?
a. topography b. poor service quality c. pressure problem or limited supply source
d. restriction due to lack of adequate water quantity e. lack of water network expansion
f. any combination of the listed problems ----------
3) Does your religious institution has a storage tank? a. yes b. no
4) If yes for # 3 how many liters does the storage tank hold in liters----------?
5) What problems or challenges do you observed in your water tanker?
a. water over flow from the tanker b. leakage c. lack of water due to pressure d. other-----
6) Do you collect rain water? a. yes b. no
7) If yes for # 6, how much water you get from rain water? per month/day/year (liter) ---
8) If yes for # 6 for, what purpose do you use it?
a. consumption b. hygiene c. amenity d. the combination of ----------and---------
9) Do you recycle or reuse ? a. yes b. no
10) If yes, for # 9 how much water you get from recycled water? per month/day/ (liter)---
11) If yes for # 9 for what purpose do you use it?
a. consumption b. hygiene c. amenity d. combination of ----------and-----
12) Do you have your own well? a. yes b. no
13) If yes, for # 12 how much water you get from well water? per month/day/ (liter)-----
14) Do you have garden area a. yes
b. no
15) Do you have agricultural area a. yes
b. no
16) Is the water supplied from your main source usually acceptable?
a. yes, acceptable b. no unacceptable taste c. no unacceptable color d. no unacceptable smell e. no contains materials f. no other reason (specify)----------

Section IV. Water consumption at water end use appliances

Table 10 water end use consumption data collection format for mosque

Mosque end uses	Estimated quantity (liter per month)
Toilet and shower (L/day)	
Landscape(L/day)	
Ground cleaning(L/day)	
Ablution (Wudu) ritual(L/day)	
Unseen/ washing and purify dead body(L/day)	

Table 11 water end use consumption data collection format for churches

Water functions in churches	Estimated quantity (liter per month)
Non ritual (L/day)	
Ritual (L/day)	
Infant baptism (L/infant)	
Water for residents/ monastics (L/c/day)	

Section V: Water conservation practices

Dear respondents, please indicate your frequency of practicing water conservation using the seven-point Likert scale below. Select the number that best represents how often you engage in water conservation activities: 1. Never, 2. Rarely, 3. Occasionally, 4. Sometimes, 5. Frequently, 6. Usually 7. Every time and not applicable 00

Table 12. Service institution (religious) water consumption measurement using Likert scale

s.n	Indicators	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Every time
I	Building level operation and awareness creation for commercial water conservation							
1.1	We regularly check for leaks in the buildings proactively	1	2	3	4	5	6	7
1.2	We have facility management unit and we assign water facility manager	1	2	3	4	5	6	7
1.3	We place a sign above basins suggesting that guests don't leave the tap running while shaving or brushing teeth	1	2	3	4	5	6	7

1.4	we have water consumption audit and planning system	1	2	3	4	5	6	7
1.5	Encourage users to shower instead of bath	1	2	3	4	5	6	7
1.6	Educate staff about water saving in indoor and outdoor water consumption practices	1	2	3	4	5	6	7
1.7	We apply water for the purpose	1	2	3	4	5	6	7
II	Toilets							
2.1	We conduct regular maintenance checks for leaks in toilets	1	2	3	4	5	6	7
2.2	We install flow restrictors to reduce tap flow	1	2	3	4	5	6	7
2.3	We use alternative water source to pour-flush	1	2	3	4	5	6	7
2.4	We retrofit old toilet fixtures and lines	1	2	3	4	5	6	7
2.5	We remind users not to use toilets as basket waste	1	2	3	4	5	6	7
2.6	We install hand-basin taps in toilet that are self-stopping type/sensors/	1	2	3	4	5	6	7
2.7	We place a sign above basins suggesting that guests don't leave the tap running in toilets	1	2	3	4	5	6	7
III	Showers							
3.1	We conduct regular maintenance checks for leaks for shower fixtures	1	2	3	4	5	6	7
3.2	We install low flow rate regulators	1	2	3	4	5	6	7
3.3	We install water-efficient showerheads	1	2	3	4	5	6	7
3.4	We retrofit old shower fixtures and lines	1	2	3	4	5	6	7
3.5	We install hand-basin taps in shower that are self-stopping type/sensors	1	2	3	4	5	6	7
3.6	Users take shower up to or to less than 5 minutes	1	2	3	4	5	6	7
3.7	We place a sign above basins suggesting that guests don't leave the shower running or un closed during un used period	1	2	3	4	5	6	7
IV	Hand washes and Faucets							
4.1	We conduct regular maintenance checks for leaks in hand wash							
4.2	We install flow restrictors to reduce water flow	1	2	3	4	5	6	7
4.3	We install sensors in hand wash area	1	2	3	4	5	6	7
4.4	We retrofit old hand wash fixtures and lines	1	2	3	4	5	6	7
4.5	Users turn off the tap while they scrub	1	2	3	4	5	6	7
4.6	We check tanker over flow	1	2	3	4	5	6	7
4.7	We place a sign above basins suggesting that guests don't leave the tap running in hand washes	1	2	3	4	5	6	7

V	**Garden & irrigation**							
5.1	We plant indigenous plants which are more likely to be naturally adapted to thrive with the amount of rainfall in the local area	1	2	3	4	5	6	7
5.2	We prepare plant types, during landscape planning, which do not need much water	1	2	3	4	5	6	7
5.3	We group similar plant types according to their water requirements (hydro-zoning)	1	2	3	4	5	6	7
5.4	We improve soil condition with organic material to improve water retention	1	2	3	4	5	6	7
5.5	We reclaimed water from a rainwater	1	2	3	4	5	6	7
5.6	We water during the night and morning to avoid evaporation and loses	1	2	3	4	5	6	7
5.7	We use drip irrigation wherever possible	1	2	3	4	5	6	7
VI	**Water saving educations / Awareness/**							
6.1	Religious leaders teach their followers about the worth of water	1	2	3	4	5	6	7
6.2	Institutions are the ideal place to spread water saving awareness	1	2	3	4	5	6	7
6.3	Followers and leaders know water is an important resource that secures survival and therefore must be protected	1	2	3	4	5	6	7
6.4	There is cooperation with religious and local authorities to save water in the local governance	1	2	3	4	5	6	7
6.5	Followers and leaders support alternative water harvesting and to bring behavioral change in saving water during ritual ceremony	1	2	3	4	5	6	7
6.6	Religion leaders are aware of water saving technologies and appliances	1	2	3	4	5	6	7
6.7	The value of water is referred in the religious text							

1.2 Questioner Survey for Tracking and Tracing Industrial Water Consumption Characteristics

Dear participants,

This study is part of my Ph.D. in Urban and Regional Planning at the Ethiopian Institute of Architecture, Building Construction, and City Development, Addis Ababa University. It aims to gather data on industrial institution water consumption in Adama city, focusing on tracking and tracing water consumption from the source to end uses. The questionnaire will take 10 to 15 minutes, and your honest responses are crucial to the study's success. Participation is voluntary, and you can ask any unclear idea at any time. All information will be kept confidential and analyzed secretly. Thank you for your cooperation

Section I. Basic information for industrial institutions

1) Owner of the industry----------
2) Geographic location----------
3) Type of the industry ----------
4) The number of staffs and average visitors per day ----------
5) Total parcel area ----------
6) Total roof area ----------
7) If available, number of residents in the institutions---------
8) Number of restrooms----------
9) Number of bathrooms----------
10) If available irrigated area (ha)----------
11) If available garden area (ha)----------
12) Monthly average bill payment ----------

Section II. Types of centralized and decentralized water sources

Table 13. Type of water supply sources for religious services

s.no	Type of source	source type		quantity (liter)
		yes	no	
1	Piped water supply			
2	Protected well (own well)			
3	Protected spring			
4	Rainwater harvesting			
5	Unprotected well			
6	Unprotected spring			
7	Tanker-truck or cart			
8	Surface water			

Section III. Water Availability, Reliability and Accessibility

1) How many days per week piped water supplied on average?
   e. one times a week b. two times a week c. three times a week d. four times a week
   e. five times a week f. six times g. everyday h. not all
2) What reasons do you think for discontinuity of the supply?
   a. topography b. poor service quality c. pressure problem or limited supply source
   d. restriction due to lack of adequate water quantity e. lack of water network expansion
   f. any combination of the listed problems ----------
3) Does your institution has a storage tank? a. yes b. no
4) If yes for # 3 how many liters does the storage tank hold in liters----------?
5) What problems or challenges do you observed in your water tanker?
   a. water over flow from the tanker b. leakage c. lack of water due to pressure d. other-----
6) Do you collect rain water? a. yes b. no
7) If yes for # 6, how much water you get from rain water? per month/day/year (liter) ---
8) If yes for # 6 for, what purpose do you use it?
   a. consumption b. hygiene c. amenity d. the combination of ----------and---------
9) Do you recycle or reuse ? a. yes b. no
10) If yes, for # 9 how much water you get from recycled water? per month/day/ (liter)---
11) If yes for # 9 for what purpose do you use it?
    a. consumption b. hygiene c. amenity d. combination of ----------and-----
12) Do you have your own well? a. yes b. no
13) If yes, for # 12 how much water you get from well water? per month/day/ (liter)----
17) Do you have garden area a. yes b. no
18) Do you have agricultural area a. yes b. no
19) Is the water supplied from your main source usually acceptable?
    a. yes, acceptable b. no unacceptable taste c. no unacceptable color d. no unacceptable smell e. no contains materials f. no other reason (specify)----------

Section IV. Water consumption at end use appliances

Table 14 water end use consumption data collection format for industries

Type of industry	Water required for a unit of production in a liter
Textile manufacturing:	
Food processing	
Beverage processing	
Paper and pulp manufacturing	
Chemical production	
Metal processing	
Construction materials	

Section V: Water conservation practices

Dear respondents, please indicate your frequency of practicing water conservation using the seven-point Likert scale below. Select the number that best represents how often you engage in water conservation activities: 1. Never, 2. Rarely, 3. Occasionally, 4. Sometimes, 5. Frequently, 6. Usually 7. Every time and not applicable 00

s.n	Indicators	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Every time
I	Building level operation and awareness creation for commercial water conservation							
1.1	We regularly check for leaks in the buildings proactively	1	2	3	4	5	6	7
1.2	We have facility management unit and we assign water facility manager	1	2	3	4	5	6	7
1.3	We place a sign above basins suggesting that guests don't leave the tap running while shaving or brushing teeth	1	2	3	4	5	6	7
1.4	we have water consumption audit and planning system	1	2	3	4	5	6	7
1.5	Encourage users to shower instead of bath	1	2	3	4	5	6	7
1.6	Educate staff about water saving in indoor and outdoor water consumption practices	1	2	3	4	5	6	7
1.7	We apply water for the purpose	1	2	3	4	5	6	7
II	Toilets							
2.1	We conduct regular maintenance checks for leaks in toilets	1	2	3	4	5	6	7
2.2	We install flow restrictors to reduce tap flow	1	2	3	4	5	6	7
2.3	We use alternative water source to pour-flush	1	2	3	4	5	6	7
2.4	We retrofit old toilet fixtures and lines	1	2	3	4	5	6	7

2.5	We remind users not to use toilets as basket waste	1	2	3	4	5	6	7
2.6	We install hand-basin taps in toilet that are self-stopping type/sensors/	1	2	3	4	5	6	7
2.7	We place a sign above basins suggesting that guests don't leave the tap running in toilets	1	2	3	4	5	6	7
III	Showers							
3.1	We conduct regular maintenance checks for leaks for shower fixtures	1	2	3	4	5	6	7
3.2	We install low flow rate regulators	1	2	3	4	5	6	7
3.3	We install water-efficient showerheads	1	2	3	4	5	6	7
3.4	We retrofit old shower fixtures and lines	1	2	3	4	5	6	7
3.5	We install hand-basin taps in shower that are self-stopping type/sensors	1	2	3	4	5	6	7
3.6	Users take shower up to or to less than 5 minutes	1	2	3	4	5	6	7
3.7	We place a sign above basins suggesting that guests don't leave the shower running or un closed during un used period	1	2	3	4	5	6	7
IV	Hand washes and faucets							
4.1	We repair leaks and plumbing problems							
4.2	We install flow control fixtures on all faucets	1	2	3	4	5	6	7
4.3	Reservoirs and taps used at our institutions have water loss minimizing (low-flow sensor)	1	2	3	4	5	6	7
4.4	We check for leaks and dripping taps, and encourage to report them	1	2	3	4	5	6	7
4.5	We check taps and ensure they are not left running when not in use at night or during ceremony	1	2	3	4	5	6	7
4.6	We supervise and monitor our water tankers for overflow	1	2	3	4	5	6	7
4.7	We place signs on equipment on how to use/save/	1	2	3	4	5	6	7

Table 15. Industrial water consumption measurement using Likert scale

V	**Kitchen and cafeteria service**							
5.1	We use automatic dishwasher only for full loads.	1	2	3	4	5	6	7
5.2	We use automatic washing machine only for full loads.	1	2	3	4	5	6	7
5.3	We repair leaky faucets, pipes, and plumbing fixtures	1	2	3	4	5	6	7
5.4	We install an automatic shutoff so water does not run when waste disposal is not in use	1	2	3	4	5	6	7
5.5	We avoid running tap water to cool it off for drinking	1	2	3	4	5	6	7
5.6	We don't let the faucet run while we clean	1	2	3	4	5	6	7
5.7	We place signs on equipment on how to use and save							
VI	**Ground cleaning and compound sanitation**							
6.1	Cleaners are aware of not to leave taps running or use excessive water	1	2	3	4	5	6	7
6.2	Cleaners clean hard surface without water							
6.3	Cleaners use mop than hose							
6.4	Cleaners use alternative water	1	2	3	4	5	6	7
6.5	Cleaners keep a bucket in bathroom and use it to save water	1	2	3	4	5	6	7
6.6	Cleaners reduce chemicals during cleanings	1	2	3	4	5	6	7
6.7	Cleaners are commonly informed how to reduce water use where possible							
VII	**Garden & irrigation**							
7.1	We plant indigenous plants which are more likely to be naturally adapted to thrive with the amount of rainfall in the local area	1	2	3	4	5	6	7
7.2	We prepare plant types, during landscape planning, which do not need much water	1	2	3	4	5	6	7
7.3	We group similar plant types according to their water requirements (hydro-zoning)	1	2	3	4	5	6	7
7.4	We improve soil condition with organic material to improve water retention	1	2	3	4	5	6	7
7.5	We reclaimed water from a rainwater	1	2	3	4	5	6	7
7.6	We water during the night and morning to avoid evaporation and loses	1	2	3	4	5	6	7
7.7	We use drip irrigation wherever possible	1	2	3	4	5	6	7
VIII	**Water saving educations / awareness/**							
8.1	We provide training to increase awareness of water efficiency practices and procedures.	1	2	3	4	5	6	7
8.2	We provide suggestion boxes to collect suggestions about water consumption	1	2	3	4	5	6	7
8.3	We post water saving signs	1	2	3	4	5	6	7
8.4	We inform or instruct about water saving	1	2	3	4	5	6	7
8.5	We provide or supply water-efficient appliances and systems	1	2	3	4	5	6	7
8.6	We encourage employees to adopt water-saving habits	1	2	3	4	5	6	7
8.7	We offer incentives for water-saving efforts							

Appendix II: Check list for measuring urban water mass balance by integrating its natural and anthropogenic flows within Adama city's water flow system

Table 16 Inputs water flow of Adama city for the years

Inputs water flow	Unit	Quantity	Data sources
Total population	Number		Adma structural plan report
Area	Km^2		Adma structural plan report
Density	Population/km^2		Calculated by the researchers
Rainfall (P)	mm /year		National Metrology Institute of Ethiopia
	M^3 /year		
Centralized water			
Centralized surface water (Cs) (from Awash River)	M^3 /year		Adama City Water Supply and Sewerage Service Enterprise (2022/23)
Centralized groundwater water (from boreholes) (Cg)	M^3 /year		
Decentralized groundwater (Dg)			
Industrial Park boreholes	M^3 /year		Industrial Park water supply and sanitation head office manager
Other industries	M^3 /year		
Hotel boreholes	M^3 /year		Hotel managers (key informants)
Subtotal			
Decentralized surface water (Ds)			
Water supply for urban greenery (from Awash)	M^3 /year		Adama City beatification and greenery experts (key informants)
Recycled water (Rw)			
Industrial Park	M^3 /year		Adama Industrial Park water supply and sanitation experts
Household water recycling	M^3 /year		Sample household survey by researchers
Adama science and technology university	M^3 /year		Adama science and technology university
Decentralized rainwater (Dr)			
Household-level roof water harvesting	M^3 /year		Sample household survey by
Industries	M3 /year		From key informant interview

Table 17 Output water flow of Adama City for the years 2022/2023

Inputs water flow	Unit	Quantity	Data sources
Evapotranspiration (ET)	M3 /year		Calculated using the Hargreaves-Samani approach
Wastewater flow (W)	M3 /year		Calculated from the water consumption profile
Surface runoff (Rs)	M3 /year		Calculated using the SCS-CN Runoff Estimation Method
Groundwater Infiltration(G)	M3 /year		Calculated using the natural water flow mass balance system
System loss	M3 /year		Adama City Water Supply and Sewerage Service Enterprise

Appendix III: Checklist for measuring urban water security performance through the lens of water metabolism

Table 18 Check list for values and scores of the drinking of water and human well-being water security data collection format

Indicators	variables	Unit	Value	Score	Weight
Water availability	Freshwater per capita	m^3/capital/year			
Diversity of water and energy sources	Reused wastewater/production of wastewater	%			
	Contribution of alternative water sources, %	%			
	Contribution of alternative energy sources, %	%			
Consumption	Billed authorized consumption per person per day	l/capital/day			
Reliability	Nonrevenue water	%			
	Metered water (percentage of households whose water consumption is metered)	%			
	Energy efficiency in the network	%			
	Commercial losses from non-revenue water	%			
Water quality	Proportion of drinking water samples meeting WHO and local standards	%			
	Proportion of samples of wastewater treatment plant meeting the world health organization WHO and locally applicable quality standards	%			
Accessibility	Proportion of population using safely managed drinking water services	%			
	Proportion of population using safely managed sanitation services	%			
Adequacy and equity	Average supply time compliance with minimum service standard	hr/ day			
Water bodies' dependency ratio	Percentage of imported water from transboundary/system input volume	%			

Table 19 Check list for values and scores of the ecosystem water security data collection format

Indicators	Variable	Unit	Value	score	Weight
State of pollution	Percentage of safely treated wastewater flows SDG6.3.1 b				
Bodies of water with good ambient water quality	Proportion of samples of water sources (surface water or groundwater) meeting WHO and locally applicable quality standards				
Change in the extent of water-related ecosystems over time	Change in the extent of water-related ecosystems over time (SDG6.6.1)				
Green roofing	Surface area of green roofing in relation to total roof surface area				
Green surface	Green surface area in relation to total surface area				
Effectiveness of storm network and wastewater network	Sewer system blockages (No. blockages/km/year)				

Table 20 Check list for values and scores of the of the climate change and water-related hazards water security data collection format

Indicators	Variable	Unit	Value	Score	Weight
Greenhous Gas (GHG)	GHG emissions from urban water supply and wastewater	kg CO2/m3			
Public health (water-borne diseases)	Number of potable water contamination incidents (diarrhoea)	Number/year per 100,000 people			
Number of floods	Number of deaths due to floods over three years	Number/three years per 100,000 people			
Flood-prone areas	Surface area of the flood-prone area versus total surface area	%			
Precipitation	Average annual precipitation	mm/year			
Temperature	Average annual temperature	Degrees Celsius			

Table 21 Check list for values and scores of the of the socioeconomic water security data collection format

Indicators	Variable	Unit	value	score	weight
Water energy consumption	Per unit energy consumption for urban water supply	kwh/m3			
Wastewater energy consumption	Average energy consumption in cubic meter wastewater treatment	kwh/m3			
Water tariff	Water tariff per 15 m3	$/m3			
Sanitation tariff	Waste water tariff per 15 m3	$/m3			
Affordability	Total annual operating revenues per population served/national GNI per capita; expressed in percentage				
Budget directed to water and wastewater services	Percentage of national budget directed to WWS	%			
Operation and maintenance cost recovery	Operating expenditure/operating revenue	%			
Illegal uses	Number of illegal uses	Number/year/10,000 subscribers			
Customer's complaints	No. of total complaints (leakage, no water, blockage)	Number/year/10,000 subscribers			

Appendix IV: Checklist for mapping and quantify the existing water sources at city region Data sources

- Adama city water supply and sanitation office
- Oromia water source bureau
- Observation / field survey/

➢ **Location, quantity of underground water sources**

Table 22 checklist for location, quantity of underground water sources

	Well water source information				
s.n	Name of the well	Type of well	Depth of well (m)	Avg depth of ground water level (m)	Average daily quantity of water drawn (liters)

Table 23 checklist for location, quantity of surface water sources

➢ **Location, quantity of surface water sources**

	Surface water source information				
s.n	Name of the source	Capacity (m3/day)	Transmition location	Reservoir location and information	Additional information

- **Checklist for water source identification and characterization**

- What are the main sources of water for the city?
- Is the city able to meet the water demand
- Do you think the city is self-reliant with in its boundary ?
- Is the water supply covering all localities of the city including all periphery areas?
- Is the city providing daily water supply with known duration to all localities?
- Is there enough supply during all seasons?
- Are water sources for municipal supply inside city boundary/ far away ?
- Are groundwater levels in the city constant (i.e. seasonal levels similar to previous years)?
- Can the city able to sustain projected demand at current supply levels for the next 10 years?
- Are water bodies protected and without instances of land-use change from "water body" to any other land-use in the city plan?
- During rainy season, does water quickly drain off from your locality
- Do you feel the city government is taking adequate steps to conserve/ protect water sources
- Would you say water sources used by this household have improved over the last ten years?
- Does the city has any water related legal frameworks?
- How do you evaluate the master plan of the city in safeguarding water bodies ?
- Is there any practices of public awareness and education in water saving in the city ?
- What are the major constraints to supply sustainable water supply in the city?

Appendix V: indicators, variables, units, and scoring systems to assess water security

Table 3.24 Indicators, variables, units and scores for drinking water and human well-being

Indicators	variables	Units	1	2	3	4	5
Availability	Freshwater availability per person	m3/capita/year	<500	500–800	800–1000	1000–1700	>1700
Variety of water and energy sources.	Reuse of wastewater and wastewater generation	%	<10	10–30	30–50	50–70	>70
	Contribution from alternative water sources in %	%	<5	5–15	15–30	30–60	>60
	Contribution of alternative energy sources as a percentage.	%	<5	5-15	15-30	30-60	>60
Consumption	Daily billed consumption per person.	L/capita/day	<20	21–50	51–90	91–100	>101
Reliability	Nonrevenue	%	>=25	25–20	20–15	15–10	10–0
	Leakage index for infrastructure.	number	=>3	3–2.5	2.5–2.0	2.0–1.5	<1.5
	households with metered water	%	0–60	61–70	71–80	81–90	91–100
	Network energy efficiency.	%	<40	40–50	50–60	60–80	>80
	Commercial losses due to non-revenue water.	%	>=25	25–20	20–15	15–10	10–0
Water quality	Drinking water samples meeting WHO and local standards.	%	0–60	61–70	71–80	81–90	91–100
	Wastewater treatment samples meeting WHO and local quality standard	%	0–60	61–70	71–80	81–90	91–100
Accessibility	Population with access to safe drinking water services.	%	0–60	61–70	71–80	81–90	91–100
	Population with access to safe sanitation services.	%	0–60	61–70	71–80	81–90	91–100
Adequacy and Equity	Average compliance with minimum service standard for supply time.	hr./day	<8	8–16	17–20	21–23	24
Dependency Ratio	input volume from imported transboundary water	%	>60	60–40	40–20	20–10	<10

Source: Aboelnga et al., (2020) , Zeitoun et al., (2016) and M. S. Babel et al., (2020)

Table 3.25 Indicators, variables, units and scores for ecosystems

Indicators	variables	Units	1	2	3	4	5
State of pollution	wastewater flows safely treated (SDG 6.3.1b).	%	0–60	61–70	71–80	81–90	91–100
water bodies with good ambient quality (SDG 6.3.2)	water source samples (surface water or groundwater) meeting WHO and local quality standards.	%	0–60	60–70	70–80	80–90	90–100
water-related ecosystems change (SDG 6.6.1).	Annual change in water quantity within these ecosystems.	% change/year	>60	60–40	40–20	20–10	<10
Green roofing	Ratio of green roof area to total roof area.	%	<5	5–15	15–30	30–60	>60
Green surfaces	Ratio of green area to total surface area.	%	<5	5–15	15–30	30–60	>60
Effectiveness of stormwater and wastewater networks.	Rate of sewer system blockages per kilometer per year.	No. blockages/km/year	>300	200–300	100–200	50–100	<50

Source: Aboelnga et al., (2020) and M. Babel et al., (2023)

Table 3.26 Indicators, variables, units and scores for climate change and water-related hazards

Indicators	variables	Units	1	2	3	4	5
Greenhouse gas emissions	Greenhouse gas emissions generated by the system	kg CO2/m3	>3.5	3.5–2.5	2.5–1.5	1.5–0.5	<0.5
Impact on public health from waterborne diseases	Incidents of potable water contamination leading to diarrhea	number/year per 100,000 people	>1000	800–500	500–100	100–30	<=30
Frequency of floods	Deaths caused by flooding in a three-year period	number/year per 100,000 people	>1000	800–500	500–100	100–30	<=30
Flood-prone areas	Ratio of flood-prone area to total surface area	%	>20	20–15	15–10	10–5	<5
Precipitation	Yearly average precipitation	mm/year	<100	100–300	300–500	500–700	>700
Temperature	Yearly average temperature	Celsius degree	>40	35–40	30–35	25–30	<25

Source: Aboelnga et al., (2020) and M. Babel et al., (2023)

Table 3.27 Indicators, variables, units and scores for socioeconomic perspectives

Indicators	variables	Units	1	2	3	4	5
Energy consumption for water per authorized consumption	Energy consumption per unit of urban water supply	kWh/m3	>4.5	4.5–3.5	3.5–2.5	2.5–1.5	1.5
Energy consumption for wastewater treatment	Average energy consumption per cubic meter of wastewater treated	kWh/m3	>1	1–0.75	0.75–0.5	0.5–25	<0.25
Water pricing structure	Tarif per 15 cubic meters of water	$/m3	<0.5	0.5–0.75	0.75–1	1–1.5	>1.5
Sanitation service pricing	Tarif per 15 cubic meters of wastewater	$/m3	<0.5	0.5–0.75	0.75–1	1–1.5	>1.5
Financial accessibility	Ratio of total annual operating revenue per population served to gross national income (GNI) per capita (%)	%	>1	0.8–1.0	0.8–0.6	0.6-0.4	<0.4
The allocation of the national budget towards water resources	the national budget allocated to water and sanitation (%)	%	<1	1–5	5–10	10–20	>20
Revenue generation to cover costs	Recovering operation and maintenance costs	%	0–60	0–60	70–80	80–90	90–100
Unauthorized uses	Number of unauthorized uses	number/year/10,000 subscribers	>300	200–300	100–200	50–100	<50
Customer grievances	Total number of complaints regarding leaks, water shortages, and blockages	number/year/10,000 subscribers	>300	200–300	100–200	50–100	<50

Appendix VI. List of Published and Ongoing Articles

Article Title	Rapid Urbanization and the Growing Water Risk Challenges in Ethiopia: The Need for Water Sensitive Thinking
Status	Published
Article number	01
Type of article	Original Research
Authors	Abraha Tesfay, Tibebu Assefa and Ephrem Gebremariam
Journal name	Frontiers in Water (Water Resource Management)
Publication Date	22 June 2022
Pages	1-17
DOI/URL	https://www.frontiersin.org/journals/water/articles/10.3389/frwa.2022.890229/full https://doi.org/10.3389/frwa.2022.890229
Indexed at	Web of Science and Scopus
Journal Metrix	Total views=6,9K Total download= 1,4k Citation =10
Impact factor	2.6
Quartile	Q1

Article Title (02)	Tracking and tracing water consumption for informed water sensitive intervention through machine learning approach
Status	Published
Article number	02
Type of article	Original Research
Authors	Abraha Tesfay, Tibebu Assefa and Ephrem Gebremariam
Journal name	Springer Nature (npj Clean Water)
Publication Date	09 April 2024
Pages	1-19
DOI/URL	https://www.nature.com/articles/s41545-024-00309-6 https://doi.org/10.1038/s41545-024-00309-6
Indexed	Web of Science and Scopus
Journal Metrix	1, 011 accesses
Impact factor	10.4
Best Quartile	Q1

Article Title (03)	Analyzing urban water metabolism of Adama city using water mass balance method for advancing water sensitive interventions
Status	Published
Article number	03
Type of article	Original Research
Authors	Abraha Tesfay, Tibebu Assefa and Ephrem Gebremariam
Journal name	Frontiers in Water Section Water and Built Environment
Publication Date	31 October 2024
Pages	1-14
DOI/URL	https://www.frontiersin.org/journals/water/articles/10.3389/frwa.2024.1427788/full
Indexed	Web of Science and Scopus
Journal Metrix	555 view and 260 download
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Article Title	Quantifying urban water security performance for water sensitive intervention decision support system the case of Adama City, Ethiopia
Status	Published
Article number	04
Type of article	Original Research
Authors	Abraha Tesfay, Tibebu Assefa and Ephrem Gebremariam
Journal name	Elsevier (Heliyon)
Date of submission	23rd April 2024
Pages	---
Preprint	https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4828926 Available at SSRN: https://ssrn.com/abstract=4828926 or http://dx.doi.org/10.2139/ssrn.4828926
Indexed	Web of Science and Scopus
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