THE WATER METABOLISM OF RESIDENTIAL BUILDINGS IN ADAMA CITY, ETHIOPIA

Kedija Fedlu Jemal

A Thesis submitted to

The department of Architecture

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of

Master of Science in Environmental Architecture

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

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APPROVAL OF BOARD OF EXAMINER

We, the undersigned, members of the Board of Examiners of the final open defense by **Kedija Fedlu Jemal** has read and evaluated her thesis entitled "**The water metabolism of residential buildings in Adama city, Ethiopia**." and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science in Environmental Architecture.

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DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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This MSc Thesis has been submitted for examination with my approval as a thesis advisor.

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To: **Architecture department**

Subject: **Thesis Submission**

This is to certify that the thesis entitled "**The water metabolism of residential buildings in Adama city, Ethiopia"** submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Architecture, the Graduate Program of the Department of Architecture, and has been carried out by Kedija Fedlu ID. No PGR/18268/11, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby she can submit the thesis to the department.

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Name of major Advisor	Signature	Date

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ACRONYM AND ABBREVIATION

AWSSE	Adama Water Supply and Sewerage Service Enterprise
GIS	Geographic Information System
GTP II	Growth and transformation plan II
L	Liter
LCA	Life cycle analysis
L/C/D	Liters per capita per day
m.a.s.l	Mean above sea level
RWH	Rainwater harvesting
UN	United Nation
WHO	World Health Organization
WSC	Water sensitive city

ABSTRACT

Water is the basic metabolic requirements of a city. The fastest population growth and raise per capita income put pressure on the water resource. Within the scarce supply, consumption intensifies the scarcity. The research aims to identify water consumption pattern, recycled water use, and rainwater harvesting potential of residences in the Oromia region Adama city using 203 samples selected by combined stratified and simple random sampling. Resident's consumption data using interview and meter reading from Adama water supply, sanitation, and sewerage enterprise were used. MS Excel was used to analyze data and plot graphs. The result of the analysis had shown inconsistent supply in which 84% was consumed for hygiene purposes including 33.7% for cloth washing and 24.7% for toilet flushing. Indoor utilities, frequency, and duration of indoor activities, and family size affect consumption volume directly. The consumption trend is linear where the input water expelled without further uses. From 20,199.4m^2 sampled residents roof area with 804mm mean annual rainfall potentially 15,428 m^3 of rainwater can be harvested that could support the supply. It is concluded that the water management of Adana residents is poor with low environmental consciousness. The largest percentage of potable water is used for non-potable purposes which can be easily compensated by rainwater harvesting and greywater reusing. It is finally recommended to offset the non-potable use of water by harvesting rainwater and aware consumers the importance of roof water harvesting system to be sustainable enough. Tariff adjustment can also be done for those who used rainwater and offset most of their potable water demand from the municipality.

Keywords: consumption, demand management, potable water, rainwater, water supply

CHAPTER ONE

INTRODUCTION

Water is the blood of life. Human life and the ecosystem depend on the availability of efficient water for existence. Adama city is located in the major transportation corridor and is one of the fastest-growing intermediary cities of Ethiopia with a high rate of migration which Intensifies water stress. Due to this fact, the motive for this research is the desire to contribute a sustainable solution that is environmentally and financially acceptable both by the residents and stakeholders for the critical survival question of water scarcity in Adama city.

This chapter describes the background information around the topic area that has been done before, states; the problem, objective, research question, scope, and significance of the study.

1.1 Background

The water treatment expert Wolman introduces the concept of urban metabolism in 1965. Inhabitants of a city require resources for their livelihood. Metabolic flow refers to the flow of material and resources in cities. Urban metabolism is broadly subdivided into two processes as anabolic which refers to resource consumption to produce products and catabolic refers to decomposition and recycling of wastes (Zhang et al., 2015). Water is the most essential resource required for life. Life exists with water and perishes without it. Human activities in the environment are water-centered and also Two-thirds of the human body is composed of water and requires water to live (Chaplin, 2001).

Cities are the center of human activities which represent an important point of contact between natural and socio-economic systems. The expansion of cities and unsustainable urban development challenges the water supply which becomes the basic metabolic problem of cities globally (Zhang et al., 2015). The history of urban hydro-social transition shows from human and nature interdependence to a biocentric approach. In hydro-precarity which is the first era, water management objective was based on expanding the service later on at the era of hydro-modernism changed to industrializing and after 1992 hydro-security focuses on multi-functioning and sustainable approaches like rainwater harvesting. Each country experiences its geo-historical sequence of water service development but in developing countries, there are still billions of peoples without adequate access to basic water service (Meissner et al., 2017).

This century marks the proportion of the urban population surpassed living in a rural environment which makes sustainable practice hard (Brown et al., 2009). The urban population is expected to increase from 3.6 billion to 6.3 billion by 2050 also by the same year it's expected that the global population to increase from its current level of 7 billion to 9.2 billion (UN, 2012). This along with unprecedented economic development leads to unparalleled stress in the water system.

Increasing city density due to urbanization was one of the factors for the expansion of urban water service but in developing nations the water service system is still poor due to a lack of clear governmental policy and economic weakness in addition to urbanization, population growth, demand-driven supply which didn't follow sustainable approaches, and Peri-urban areas that combine urban and rural characteristics (Meissner et al., 2017). This implies most of the developing countries are in the era of hydro-precarity where water is not secure and institutions work mainly on expanding the service.

Globally, the water supply is in critical stress due to demand leading cities to a challenge of effective water resource management. Supplies that support large populations are becoming compromised like the world's largest rivers such as the Colorado River, Rio Grande, Indus River, and the Yellow River is running dry long before they reach their river mouths. Also, land-use dynamics affect indoor demand-supply it creates a storm at the level of cluster and sub-catchment (Willuweit & O'Sullivan, 2013).

A resource is a key to the sustenance of a city and water as a crucial resource is depleting globally which should be managed efficiently. All over the world cities are facing a range of regional pressure especially the developing nations. The problem is not only the supply but disposal, environmental impacts, and overutilization so to develop solution studies should be done on a global and regional scale. After all the studies should be used for the management of urban water as a design parameter and monitoring consumption (Vairavamoorthy, 2007)

How water is managed affects the health of ecosystems. While climate change will create important pressures on water, it is not currently the most important driver of these pressures outside the water sector. The most important drivers, forces, and processes generated by human activities are demographics and the increasing consumption that comes with rising per capita incomes. Growing pressure on water resources affects ecosystems and threatens the ecosystem goods and services on which life and livelihoods depend (United, n.d.).

Water demand management should be based on forecasted water demand, stormwater, and the whole life cycle cost therefore it important to quantify water resources by expressing input-output in the form of a chart to determine the daily metabolic requirement of a city (Willuweit & O'Sullivan, 2013; Zhang et al., 2015).

1.2 Statement of the problem

Access to water is recognized as a human right by the United Nations. Although residence covers the largest percent coverage in land use, the primary goal of water service should be consumers or residents because development comes after survival. The fastest urbanization and increasing consumption that comes with rising per capita incomes put pressure on water resources. By nature, the human interest is unlimited while the resource is limited and within this situation, resource consumption should be wise for the sustainability of the ecosystem but the less concern and awareness of this critical condition create a gap in the use of resources in developing countries. This time the human race is facing threatening challenges due to resource depletion. The increase in per capita income of developing countries led to an increase in demand for comfort and luxury which lead to extravagance and waste. Misunderstanding of Globalization trends in the developing countries is creating vast consumption problems that could lead to crisis. Evaluating product from inputs to outputs and potential environmental impacts throughout its life cycle is necessary. Water as a vital survival component of the environment should be evaluated regarding human consumption.

The study undertaken by Fekrudin & Ababa, (2019) in eight kebeles of the three Adama sub-cities (Boku, Dabe, and Lugo) showed that Adama water supply doesn't satisfy the increasing population and the demand. According to the GTP II standard, it was planned to address 80 l/c/d but 48.6 l/c/d is supplied for residents of Adama. Population growth, urbanization, migration, and an increase in per capita income intensified water scarcity in Adama. The scarce and intermittent supply of water exposes Adama residents to water scarcity. Knowing this fact and understanding that even if atmospheric water is one of the resources that one can get easily with no cost the collection and use of rainwater seem not that much practical by the residents of Adama. Another is reusing used water which is coined in the literature of Architectural sustainability. This is also not practiced as it is found in a short mockup observation of the use of water in residents of the city.

The water supply performance of Adam city was examined by Fekrudin & Ababa, 2019 only in three sub cites of Adama. The study didn't assess the end-use of water which intensifies scarcity so this study intended to fill the gap in the water supply system which is driven by the demand by understanding and quantifying the domestic water metabolism of Adama city in the eighteen kebeles to make the residents sustainable.

1.3 Objective of the study

General objective:

To understand the domestic water metabolism of Adama city.

Specific objectives:

1. To assess residential water consumption patterns.
2. To estimate the recycled water use.
3. To compute rainwater harvesting capacity from the resident roof.

1.4 Research question

1. What type of water use pattern is practiced by Adama residents?
2. How much water is recycled?
3. How much water can be harvested from the resident's roof and to what extent it augments the water needs?

1.5 Scope of the research

The study focuses only on Adama city's residential water consumption after the water has been delivered to the resident's house by a pipe. Residential water is highly essential since it is needed for survival. It has been confined within the 18 Kebeles of Adama city and spans for seven months from March to August 2020 at which rainwater, is both scarce and abundant.

1.6 Significance of the research

Water is vital for the livelihood of residents in any city. Supplying potable water for residents to the level of their satisfaction is critical. The domestic water metabolism shows the residents' habit of their water consumption from cradle to grave. By this, residents will understand their extravagant usage of the scarce water resources supplied from the municipal main spending huge resource to water each resident. They could also learn to utilize untapped rainwater at their compound to offset their municipal water demand thereby spares their finance for any other crucial benefits (i.e. save money). The sole supplier of water for the city, the municipality of Adama, would also benefit to reroute its supply to other uses such as industrial and urban agriculture activities. It also relieves the administration from public annoyance which can be escalated to political unrest as water is critical for survival. The study is also beneficial for researchers to do similar types of research for other cities of Ethiopia so as to contribute their part for sustainable water use.

1.7 Limitation

It has been tried to address the objective of this research as much as possible however, the sudden outbreak of the COVID-19 pandemic has affected the face-to-face data collection and forced to use of secondary data gained from Adama water supply, sanitation, and sewerage enterprise. Besides, as the residents do not measure each of their water use for different activities, standards from different pieces of literature, have been used to estimate the quantity of water. Except for all these, the research has been done diligently.

1.8 Description of the study area

Adama is one of the cities found in Oromia National regional state of Ethiopia. The city is located about 100 km southeast of the national capital Addis Ababa along the main highway leading to Djibouti. It is situated between 8.25^0-8.37^0 N longitude and 39.12^0-39.22^0 E latitude at an altitude that ranges from 1444 to 1974 m.a.s.l covering 134.1 km^2. It has a tropical wet-dry climate according to Köppen climate classification. Its average annual temperature and precipitation are 20.5 °C and 804 mm, respectively (fig.1).

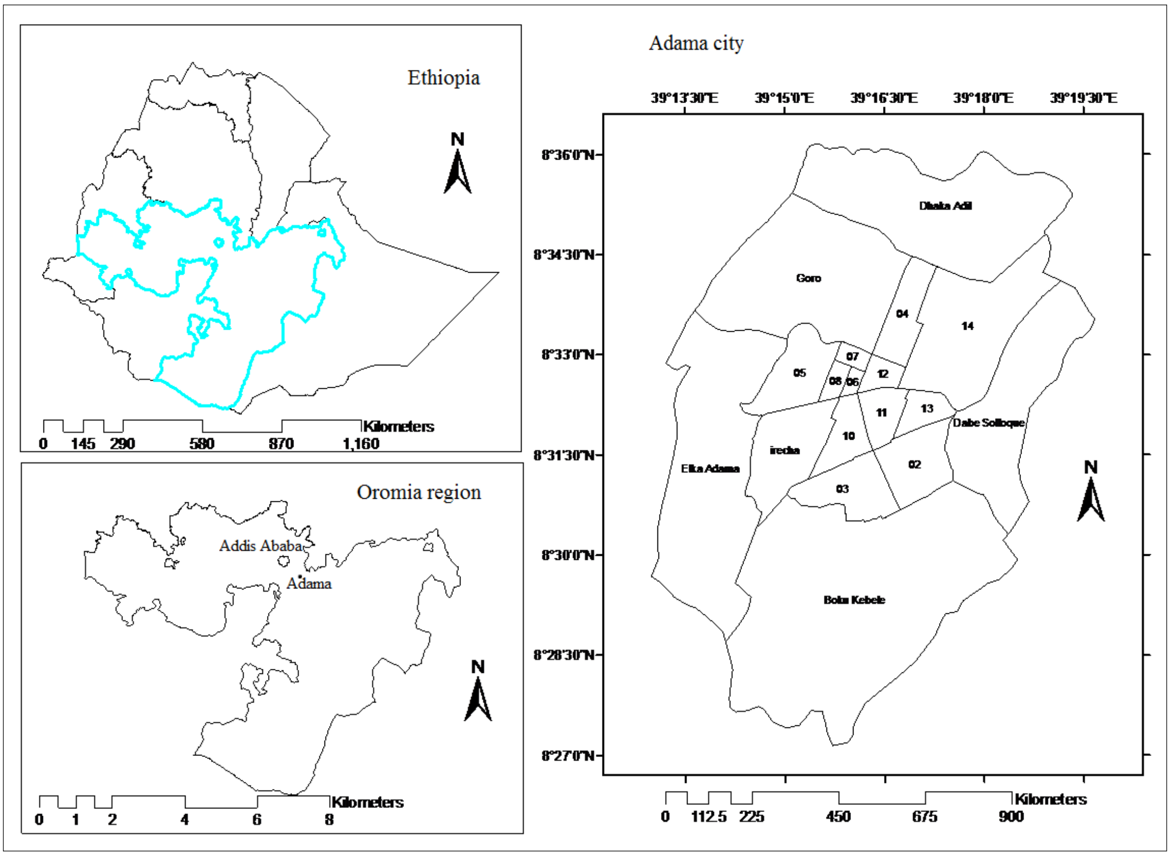


Figure 1: The study area

1.9 Definition of key terms

Metabolism: Quantitative assessment of resource flow to evaluate city sustainability.

Anabolic processes: Resource consumption to produce products.

Catabolic processes: Decomposition and recycling of wastes.

Urban water metabolism: Framework used to study water flowing through and being transformed and consumed.

Linear water metabolism: Removal of water after a single-use.

Circular water metabolism: Recycling and reusing of water.

Water consumption pattern: The end use of water for indoor and outdoor activities.

Rooftop rainwater harvesting: The easiest and most common method of capturing rainwater for utilization.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical review

2.1.1 Water basics

Water is the largest percentage composition of the environment and an essential element for life. "We all live on this beautiful water planet which we have mistakenly chosen to call earth" Anonyms. Even though water covers the largest percentage of the earth only 3% of it is fresh the rest is saline and ocean-based. Even from 3% of the freshwater, only 1% of it is easily accessed with much of it taped in snowfields. The Hydrological cycle is responsible for rain; which is the primary source of water in the form of precipitation after surface evaporation and precipitation (McMullan, 2018). Water is a source of life. Early human lived near water source by which survival and emigration pattern was affected. Reliable water supply was the base for settlement (C.J. Kroehler, 2014). Because of its clear importance, water is that the most studied material on Earth. Even though it is crucial for survival and well-studied, it is poorly understood not only by human beings but also by scientists working with it every day (Chaplin, 2001). Nowadays ground and surface water are becoming the two main sources of the modern water supply system. Groundwater is found under the earth's surface in rock fractures and soil pores space. It is an important resource for a nation. It requires skill and finance to access. It is not directly connected to the hydrology cycle and due to urbanization, the hydrological cycles have got into profound impact. Urbanization transforms the natural surface into an impermeable surface by construction and pavement which reduces the infiltration of water to recharge groundwater and increases runoff (Lawrence et al., 1998). Even if surface water is directly connected to the hydrological cycle, overutilization is affecting it (Arpke & Hutzler, 2006). The ecosystem balance is getting an endangered and critical challenge due to unparalleled human activity.

2.1.2 Basic water requirements for domestic consumption

Domestic water is all the water used for activities taking place in the resident's house. The activities subdivided broadly as consumption, hygiene, and amenity. In some cases, water is used for additional productive purposes such as small scale gardening and livestock to support the economy and livelihood consumption of residents. The volume of water being consumed depends on accessibility or service level, reliability, and the cost of water (Howard & Bartram, 2003). Furthermore, an individual's life standard or economic status, climatic condition, and culture have an impact on consumption volume. The above variables and human unpredictable behavior make it difficult to generalize the standard water demand pattern Agudelo-vera et al., (2013) but some norms have been proposed for the quantity of water to be supplied and used (Table 1). According to the WHO report and sphere, a minimum of 7.5l/c/d meets most people's needs under most conditions. Humanitarian Charter and Minimum Standards in Humanitarian Response states 50 liters per person per day as the minimum acceptable amount of water in an urban middle-income context (Sphere Association, 2018). Drinking water volume varies regarding the human-environmental interaction and personal experiences based on this WHO standard is 1-2.4L for normal condition, 2.8-3.4L for average high temperature, and above 3.7 for moderate activity (Guy Howard, 2003).

Table 1: Water supply standard 2.1: water quantity, minimum basic survival water needs

Needs	Quantity (liter/person/day)	Adapt to context based on
Survival: water intake (drink and food)	2.5-3	Climate and individual physiology
Hygiene practice	2-6	The social and cultural norm
Basic cooking	3-6	Food type, Social, and cultural norm
Total basic water	7.5-15	

(Source: The Sphere Handbook: *Humanitarian Charter and Minimum Standards in Humanitarian Response)

2.1.3 Water supply Challenges

Water supply is the provision of water by public utilities, commercial and community organizations, or private endeavors using pumps and pipes. Water supply is a crucial element of human survival. Cities around the world are facing challenges in the management of ever scarce water resources due to depletion and overutilization (Vairavamoorthy, 2007).

Population growth is the main global phenomenon creating pressure on resources. As the population grows peoples migrate from an agricultural-based rural area to industrial-based urban areas for a better life standard which put a critical impact on water supply (C.A. Grady et al., 2014). In developing countries, unstructured settlements in urban areas along with high demand create a concern of supply and shortage whereas still, large sections of the community are living without a safe water supply (Serrao-Neumann et al., 2017). Hydrology is an interrelated section of the environment with land use planning. Historically land fabric affects hydrology and now the world is facing water management issues due to the above urban settlement and expansion issues (Serrao-Neumann et al., 2017).

The new era of economic development and modernization had created an impact on the natural environment and resources. A variety of environmental movements has been exploded globally because of industrialization and economic development consequences in consumption and removal of resources. Such movements aim at creating Environmental consciousness in the use and management of resources. According to the study by Arpke & Hutzler (2006), indoor water uses have a large impact on the water supply.

From the institutional level up to the individual units, neglected water management strategies are the other challenges for the water supply. habitual consumption trends in society are the main indicators of poor water management (Bauer et al., 2010; McMullan, 2018). The future is in the question of a clean source of drinking water. Individuals strive for increased comfort, therefore, the emphasis will thus be got to place on reducing energy and water requirement without decreasing either comfort level or living standard (Bauer et al., 2010).

The water supply system is based on the rate of production and consumption. This supply requires extraction, purification, and delivery cost. Although in the developing nations the supply rate is very low related to the industrial world the socio-economic and political situations play its role in the scarcity(Vairavamoorthy, 2007). To meet this challenge there should be a paradigm shift in the way water being used and removed (Vairavamoorthy, 2007).

2.1.4 Origin of urban metabolism for planning water sensitive cities

The metabolism concept originates from the contradiction between economic development and the ecological environment due to the industrial revolution and urbanization. It was first used by Wolman in 1965 to evaluate environmental resources and consumption (Zhang, 2013). Metabolism is a quantitative assessment of resource flow used to evaluate the sustainability of a city. Sustainability is maintaining the natural system. The planet carrying capacity depends on natural limitations (Mostafavi et al., 2014). From the ranges of urban resource sustainability evaluating approaches, metabolism is preferred the most (Zhang, 2013).

A water metabolism study is crucial for the future city's sustainability and high relevance to the water industry. Urban sustainability comes from each unit. Water is the most critical element in urban flow. Water sensitive urban design focuses on water management, runoff use, reuse, and water-saving measures (Paolini & Cecere, 2015).

Cities around the globe struggle to become water-sensitive and enhance livability (Rogers et al., 2020). Water service plays an important role in cities' livability, sustainability, and productivity (Chesterfield et al., 2016). Water-sensitive city concept emerging coiled to the Australian academic sector due to the millennium water drought which becomes top of political and community concern of the country. The target of the concept was the delivery of safe water service to all sustainably based on three pillars; water supply catchment: diversify source also reduces the sole dependence on large capital-intensive infrastructure network, providing ecosystem service: featuring green spaces, and comprise water sensitive community. Academically it is considered the final stage in the evolution of urban water management. The shift in urban water management promotes reliable water supply, quality of water at the point of use, and increase technical, economical, and environmental resilience performance (Bichai & Cabrera Flamini, 2018).

WSC index is a tool used to benchmark a city's current performance based on the seven goals of water sensitive city (indicators ensure good water-sensitive governance, increase community capital, achieve equity of essential services, improve productivity and resource efficiency, improve ecological health, ensure quality urban spaces, and promote adaptive infrastructure) in three dimensions; societal, biophysical, and ecological. The goals were further organized into 34 corresponding indicators (Chesterfield et al., 2016; Rogers et al., 2020). WSC index is a quantitative framework based on a qualitative rating description used as a diagnostic tool to set targets and track progress, inform management response to improve water-sensitive to enable the transition to a Water Sensitive City; and Foster industry collaboration (Rogers et al., 2020).

Higher integration between water and land-use coming up is important for each urban system departments to still exist whereas reducing their impact on water resources at the city-region scale (Paolini & Cecere, 2015; Serrao-Neumann et al., 2017). Urban design and planning for a sustainable city should integrate ecosystem service which is necessary for all other ecosystems like water cycling into the urban environment, focuses on building Water Sensitive Communities and Institutions, and create water Supply Catchments Cities (Mostafavi et al., 2014).

The urban water performance evaluation of the three Australia city regions by water metabolism framework helps to better understand the impact of water sensitive intervention and inform water management by comparing the current water use and after the implementation of water sensitive interventions which helps by improving water efficiency and diversifying supply by the use of rainwater and recycling (Renouf et al., 2018).

To solve current urban water issues, it's necessary to investigate and solve the metabolic processes by reducing metabolism and reusing water in consideration with the standard of the demand. In a circular model, the input water is reused many times that minimize wastage. Reducing material flows in the city with increasing human livability and overall well-being represents each a transparent property pathway and also a challenge (Paolini & Cecere, 2015; Serrao-Neumann et al., 2017).

2.1.5 Domestic water use study using LCA

LCA is a cradle to grave analysis or comparative tool used for evaluating the production, consumption, and environmental burdens of a product. It is a process-based framework used to evaluate the metabolic flow of resources within a city. LCA is an accepted comprehensive method by the environmental research community. The domestic water cycle has four phases'; natural existence as a source, treatment, consumption, and removal with the use of energy in the transition of each phase (Arpke & Hutzler, 2006).

It took energy and finance to treat and deliver water to users (S. Lawson et al., 2014; McMullan, 2018). cleaning water through settling, filtering, and disinfecting took place before millennia (C.J. Kroehler, 2014). Water-energy nexus is the energy that took to collect, clean, store, distribute, and dispose of water. It depends on the source of water. Drinking water in the USA requires 0.51 KW/m^3 energy and 0.39 KW/m^3 in Australia. It's been increasing throughout the years due to demand and energy intensive-sources. Groundwater extraction takes 30% more energy than surface water whereas it took 4.3KW/m^3 for desalination and 1.7KW/m^3 for recycling (S. Lawson et al., 2014;).

2.1.6 Water conservation and tools for conservation

Conservation means generally the wise use of resources. Water conservation is managing the entire water cycle, starting from door-step resources like rainwater and try to get as many uses out of that water as possible (Yudelson, 2007). The efficient use of water resources is one of the criteria for a green building. Households are the main consumers of water resources as a result efficient utilization minimizes water footprint and promotes ecosystem sustainability (Bauer et al., 2010). There are a lot of factors that affect water consumption volume in residents. According to the national institute of building science, from the main factors which put pressure on the water resource one of them is inefficient home appliances water consumption which includes toilets and urinals flush, showerheads, dishwashers, and washing machines (Inman & Jeffrey, 2006). For instance, the Standard washing machine consumes 114-189 liters of water per wash but a new energy star certified washer takes 38 liters per wash which minimizes water consumption 30-60%. Low flush toilets that use 3.8-6 liters save 15-25% of water (Lancaster, 2014). Water conservation technologies and strategies are often the most overlooked aspects of whole building design strategies but it is crucial to consider such aspects for the efficient utilization of water resources. (*Water Conservation | WBDG - Whole Building Design Guide*, n.d.).

The tools for residential water conservation review by Inman & Jeffrey (2006) implies a work that should have to be done on the demand-side management for the water scarcity around the globe than exploiting new resource as a solution. A small amount of water is required for drinking but much for washing and cleaning (McMullan, 2018). On average 68% of drinking water is used for toilet and washing, 19% for laundry and dishwashing, the remaining for cooking, drinking, and gardening (Bauer et al., 2010). Low level of Environmental consciousness, need for comfort and luxury, and consumption habits are other factors that affect consumption volume. Some habits like leaving the tap running at the time of shaving, face washing or teeth cleaning, utensils and vegetable washing, and taking shower for a long time wastes water. As statistics show shower decrease 35% of water instead of a bath, and 75% of tooth-cleaning water decrease if the pipe opens when needed (Bauer et al., 2010).

Implementing water conservation tools needs commitment from both sides; institutions and consumers. Awareness creation, maintenance, regulations, water pricing with the consideration of low-income customers, and outdoor consumption restriction are some of the measures that could be adopted to manage demand and promote conservation for managing the scarce demand. (Inman & Jeffrey, 2006).

Due to the fact that the rate of the hydrology cycle doesn't meet demand nowadays, the traditional approaches like rainwater harvesting and conservation are coming back as a trend for sustainable approaches (Lancaster, 2014). Innovative management and water sensitive interventions like supply diversification and efficient use are required to withstand the water demand stress (Renouf et al., 2018).

2.1.7 Empirical experience of water consumption globally

European Mediterranean coasts (France, Italy, and Spain) volume of water consumption increase in the 1960s and 1970s, reaching its highest peaks in the late 1990s and early 2000s due to city expansion and population also the interest of green areas incorporation by the scientific community in the urban areas. In the metropolitan area of Barcelona (Spain) percentage of indoor water consumption for toilets and taps is high (29-34%) followed or sometimes precede by hygiene (bath and shower) (22-34%). Other uses consist such as; Laundry (14-17%), dishwashing (16-12%), food and drinking (5-10%), and other uses (3-5%) (Morote et al., 2016).

Water usage drops in the mid and later 1990s on European Mediterranean coasts. For instance in Germany between 1994 and 2004 water consumption drop by 13%. The average personal consumption of water per day reaches 126L. In Spain, in 2005 the personal consumption of water per day was 225L which drops by 23% in 2012 to 198 l/c/d, and in Denmark 1989-2008 consumption drop by 22%. Comparatively from the European Mediterranean coast countries Jerusalem (650 l/c/d), Sydney (206 l/c/d), London (154 l/c/d), and the USA (409 l/c/d) consume a large volume of water (Inman & Jeffrey, 2006; Morote et al., 2016).

Factors for the drop in the consumption trend include; progression of personal habits (citizens awareness with water-saving), social and demographic changes, higher water price, technological advancements (efficient technologies for home appliances), and drought which translate water use (the use of greywater and rainwater) (Morote et al., 2016). The study by Thompson et al., (2000) in selected East Africa countries urban areas implies the factor of available water in the consumption volume. The mean per capita daily water use of households with a pipe is 64.2 litters but unpiped households consume only 24.3 L per day. Kenya, Tanzania, and Uganda consume at average daily 45.2, 70.5, and 47 liters of water per person, respectively.

Developed nations are now working on minimizing consumption and promoting conservation and sustainable approaches due to the environmental impacts and supply challenges whereas developing nations are struggling with addressing efficient water supply that neglects the incorporation of sustainable approaches (Morote et al., 2016; Thompson et al., 2000).

2.1.8 Rainwater harvesting

Rainwater harvesting is the capturing, storage, and use of rainwater close to where it falls. Rain is the first form of water in the hydrologic cycle in the continuous circulation of water in the earth-atmosphere system. It is a freely available resource and naturally distilled through evaporation (Lancaster, 2014). Historically it has been recorded that many cultures throughout the world used captured rainwater (Kinkade-Levario, 2007). Roof runoff was the main source of Water in the 6thcentury B.C. for the Phoenician and Carthaginians settlements. It's been practiced in Italy and Rome from 300-600 A.D and 4,000 years old tradition in the Indian subcontinent. It also practiced in China 6,000 years before and 2,000 years back in North Africa, the Mediterranean, the middle east, and Thailand (Lancaster, 2014).

Rainwater captured from roof catchments is the easiest and most common method used to harvest rainwater which can be used for residential potable water. The amount of water collected depends on catchment size, surface texture, surface porosity, and slope conditions. It provides easily and economically in a cheap way a self-sufficient water supply located close to the user which reduces the use and dependency on municipal water, mitigates urban flooding, and as a result, reduces soil erosion in urban areas Kinkade-Levario (2007) but gradually this tradition moved to ground and surface water pumping and utilization as a source of water in the modern water management system over the past 150 years. This system highlight rainwater as a source of a flood that should be drained (Lancaster, 2014). The impact on the ecosystem and resource is now implying the measures that should have to be done on the utilization of the neglected resource. Rainwater use was limited in the areas where water access was limited but worldwide this century brought water supply challenge, accordingly rainwater harvesting system become an alternative water supply system. Systematic rainwater utilization reduces drinking water consumption by half. 68% of the drinking water is used for toilet and washing so rainwater which is soft doesn't have calcium carbonate or magnesium needs less powder could help the demand for hygiene and amenity. On the other hand, rainwater is a natural fertilizer having sulfur and other minerals from the atmospheric dust for plants nourishment and growth which makes it suitable for gardening purposes (Bauer et al., 2010; Lancaster, 2014).

2.2 Contextual review

2.2.1 Ethiopian Water Resource Management

By Article 55 (1) of the Constitution of the Federal Democratic Republic of Ethiopia (FDRE, 1995), Proclamation No. 1997/2000, Ethiopian Water Resource Management was proclaimed on the 9th of March 2000. The purpose includes ensuring that the water resources of the country are protected and utilized for the highest social and economic benefits of the people of Ethiopia (Proclamation No, 197/2000). Under this proclamation, water resource is defined as surface or groundwater which doesn't include rain or stormwater as a resource to be utilized. Also states water resource management as; utilization, conservation, protection, and control of the existing water resource. Ethiopia water authority is the responsible institute for the execution.

2.2.2 Adama Town Water Supply system

Adama is a rapidly growing economic center and transportation hub of Ethiopia situated in Rift valley within the Awash River watershed. It was established in 1916 on flat terrain characteristics and surrounded by plateaus, mountainous, and ridged topography. The first water supply system was constructed by the former Ethiopian Electric Light and Power Authority (EELPA) in 1948 using Ten Boreholes at the place Melka Hidda along Wonji Road. The water was characterized by high Fluoride concentration. It serves till 1979 and transferred to Water Supply and Sewerage Authority. In November 2002 again restructured to Adama Water Supply and Sewerage Service Enterprise which is a municipality-owned company responsible for water and sewerage service in Adama (Enterprise, 2012). In Ethiopia, the cities of Addis Ababa, Adama, and Hawassa are facing the issues of urban dynamics due to their uncontrolled fast-growing nature Terfa et al., (2019)Which puts pressure on the water supply system.

Even though Ethiopia is the source of many major rivers including the Nile which constitute more than 85 %, groundwater is being used for drinking as the main source. The country access only 3% of the water resource (Keredin Temam Siraj, 2016). In the case of Adama, the groundwater contains fluoride in high content. There are more than 20 boreholes, from which only 3 of them are operational for the case of emergency and as an alternative source. Also, there are private boreholes with permission. The main source of fresh drinking water for the city is the upper catchment of the Awash River.

The Awash River stretches 1,200 km; located 15 km from the center of Adama and 3 km downstream of the Koka dam. The quantity of raw water being used from the Awash River sources was around 285 l/s (24,624 m^3/d) before the upgrade system. The newly upgraded system provides 411 l/s which cover only 78% of the demand. From the total demand, residence covers 63%. It is estimated that domestic water Demand will increase by a double rate in 2025 (Enterprise, 2012).

The strategic direction of the second growth and transformation plan of Ethiopia in the potable water sector is the efficient utilization and development of potential water resources with increasing total coverage. The planned period for the achievement of the goal is about to come to an end but the goals are not achieved fully. According to GTP II standard, it was planned to satisfy the water demand by the provision of, (rural; 25 l/c/d within 1km radius, Urban: based on-demand categories of 100, 80, 60, 50 and 40 l/c/d from first to fifth level towns, respectively). The cities ranked based on the population size (National Planning Commission, 2016). Adama is categorized under Level-II city with a population of 220,212 (CSA, 2007) and the current population based on a CSA official population projection is 410,738 but the average per capita consumption of Adama city doesn’t fulfill the standard, and still, there is demand and supply gap with 34.67% water loss from system input volume (Fekrudin & Ababa, 2019). The rural, urban, and national level water supply coverage was estimated as 59%, 51%, and 58% respectively (National Planning Commission, 2016).

2.3 Summary of literature review

Water is the basic requirement for life and a well-studied but still misunderstood resource. Globally the increase in water demand creates supply challenges so frameworks developed for quantitative assessment of resource flow for sustainability such as urban metabolism and LCA. Also, water sensitive city concept developed by the pillars of minimizing water usage and diversifying water supply using; recycled greywater, and harvested rainwater and stormwater to minimize the demand-supply gap.

Under the proclamation of Ethiopia Water Resource Management greywater, rainwater, and stormwater are not proclaimed as water resources. Currently, Adama city is struggling with the water supply challenges of the unsatisfied and ever-increasing demand by a centralized water supply system that neglects sustainable approaches that are financially and economically reliable.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Sampling technique

Adama city is divided into six sub-city administrations, which are in turn divided into 18 kebeles. The sampling unit is households with individual connections located in the 18 kebeles. A combination of simple random and stratified sampling technique was used since it gives the proportional probability for all the sampled populations.

The National Census report shows 59,431 housing units (CSA, 2007) found in Adama city. It is estimated that the current number of housing units could be 64,701 from those housing units 30,416 connected to the municipal water line based on the AWSSE report so taking this number as a population the sample was extracted by using the Taro Yamane (1967:886) sampling formula. The samples were selected randomly to represent the large population without bias. Similar hydrology studies like (Asgedom, 2014; Umegbolu, 2017) use the formula for determining sample size.

Formula 1: $n = N / (1 + Ne^2)$

Where; n= sample size, N = population size (30,416), and e = Margin of error (MoE) which is 0.07 for 93% confident level. The total sample is 203. Graphically the digitized Samples are illustrated under Fig. 2.

Tables 2 present the samples per each Kebele using the method of proportional allocation defined by the formula:

Formula 2: $n_{per\ Kebele} = n_{total} \times p_{per\ kebele}$

Formula 3: $p_{per\ Kebele} = \frac{N_{Per\ Kebele}}{N_t}$

Table 2: Samples per kebele

Kebele	Total number of residences with a private connection (population)	Sample size
01	4,948	33
02	2,624	18
03	1,244	8
04	3,415	23
05	711	5
06	507	3
07	685	5
08	526	4
09	2,034	13
10	438	3
11	3,082	21
12	681	4
13	3,441	22
14	3,414	23
Boku shana	597	4
Dhaka Adi	1,153	8
Dabe Sollogee	460	3
Melkaa Adaamaa	456	3

The randomly selected customer's water meter GPS data collected all together in an excel sheet and added to ArcGIS software as a table data to allocate it exactly in the Adama kebele shapefile, then this data converted into KMZ file format to be interpreted in Google Earth. After conversion, the data loaded to Google Earth, and the related house roofs were digitized from it. The Google Earth digitized image is saved back as a KMZ file format. Again using the conversion tool in Arc GIS the KMZ file converted to the Arc GIS layer (Fig. 2).

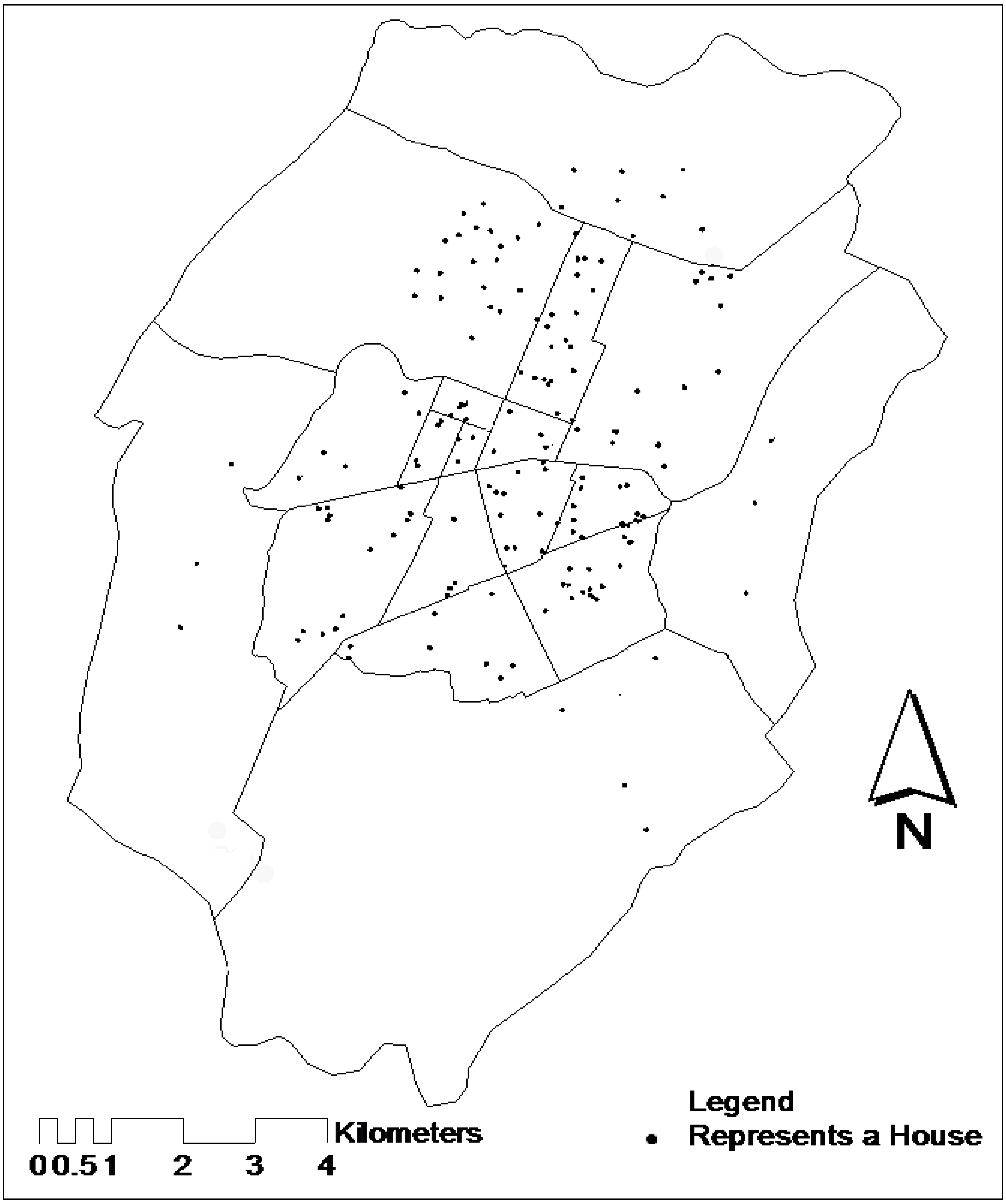


Figure 2: Digitized Samples (Google Earth lastly updated 09.09.2019)

3.2 Data

The monthly billed water consumption in meter cube, the roof area of the residential houses in meter square, and rainfall data in mm were collected. Data sets were collected from residents, Adama town water supply and sewerage enterprise reports, unpublished documents, journals, water consumption standard documents, aerial photos, meteorological data, and books.

3.3 Data collection

Before the pandemic, it was planned to collect the data using a questionnaire by conducting house to house survey. Before this, to be sure a pilot study has been done using this questionnaire (appendix-1) from March 1-7, 2020. As it is explained in (Project, 2018) the best way to collect water consumption data is by using observation and questionnaires or group discussion. But due to the pandemic, the resident's water consumption volume for different activities was collected by using a phone interview. The data collection method for each objective and methodology is generalized in Table 5 below.

3.4 Methods

3.4.1 Residential water consumption pattern

To get a wider view of consumption; sampled residents volume of consumption collected from the households head by interview using their contact number registered on the AWSSE customer report by raising the questions organized under Appendix-1 and meter reading data was taken from AWSSE customers report. The mean value of annual consumption data divided by the number of days (30) and organized by family size to determine the correlation between consumption and family size using regression. Under each category, the maximum and minimum range identified and mean and standard deviation calculated using the formulas;

Formula 4: Mean: $\bar{x} = \sum x / N$

Where; x = sum of all data points, N = number of data points/population

Formula 5: Standard deviation $\sigma = \sqrt{\sum (x_i - \bar{x})^2 / N}$

Where; x_i = each value from the population, $\bar{x}$ = the population mean, N = size of the population *

3.4.2 Recycled water use of Adama residents

The mean volume of water used by residents diagrammatically presented using the Sankey diagram. Each square represents 10L of water and the arrow width represents the volume of water used for specific indoor/outdoor activity. The performance level rated by the ecological dimension of the WSC index goal "Improve productivity & resource efficiency" using the maximized resource recovery indicator (Table. 3). Scoring was based on a rating from 1 to 5, assigned according to the description that Adama city best fits its current situation.

Table 3: WSC index goal 4 indicator 1

Indicator	Rating Scale
Optimized resource recovery: Optimize the recovery of water, energy, heat, and nutrients through the circular design of water systems.	1. No resource recovery occurs. All recoverable resources are wasted 2. Low level of recovery. Resource recovery is considered but remains incidental and limited to specific recoverable resources such as recycled water. 3. Fair level of recovery of one or two recoverable resources usually wastewater recycling or biogas, occurs. 4. Fairly high levels of resource recovery of a number of recoverable resources occur. New infrastructure and demonstration projects used to provide proof-of-concept for novel ideas and innovation in technology.

	5. High levels of resource recovery across most recoverable resources. Practices are common across all new infrastructure, and progressive upgrade of existing infrastructure occurs.

(Source: Water Sensitive Cities Index: A diagnostic tool to assess water sensitivity and guide management actions.)

3.4.3 Rainwater harvesting

By calculating the annual rainfall from station five (fig. 3) and digitize the roof area from Google Earth (fig. 2) the total volume of water that can be harvested from the residence's roof calculated by;

Formula 6:

$$\text{net runoff } (m^3) = \text{catchment area}(\mathrm{m}^2) \times \text{runoff coffiecent} \times \text{rain fall (mm)} \times (0.001)$$

Table 4: Estimated runoff coefficient for urban surfaces

Coefficient	Surface
0.85-0.95	Impervious paving or a building’s roof
0.2-0.75, average 0.35-0.55	Bare earth
0.05-0.35, average 0.1-0.25	Grass/lawn

(Source: Lancaster, 2010. Rainwater Harvesting for Drylands and Beyond Volume 2. Rainsource press. Page number 354)

The nine weather stations rainfall data taped from the NCEP site around Adama city arranged in an excel sheet by their geographic coordinate and inserted into Arc GIS. The shapefiles representing the stations and Adama city also inserted and using Thiessen polygons under the Analysis tolls of Arc GIS the proximate weather station developed for the study area (fig. 3). Thiessen polygons divided the area covered by the stations to the proximal zones so Adama represented by station five or Boset wereda.

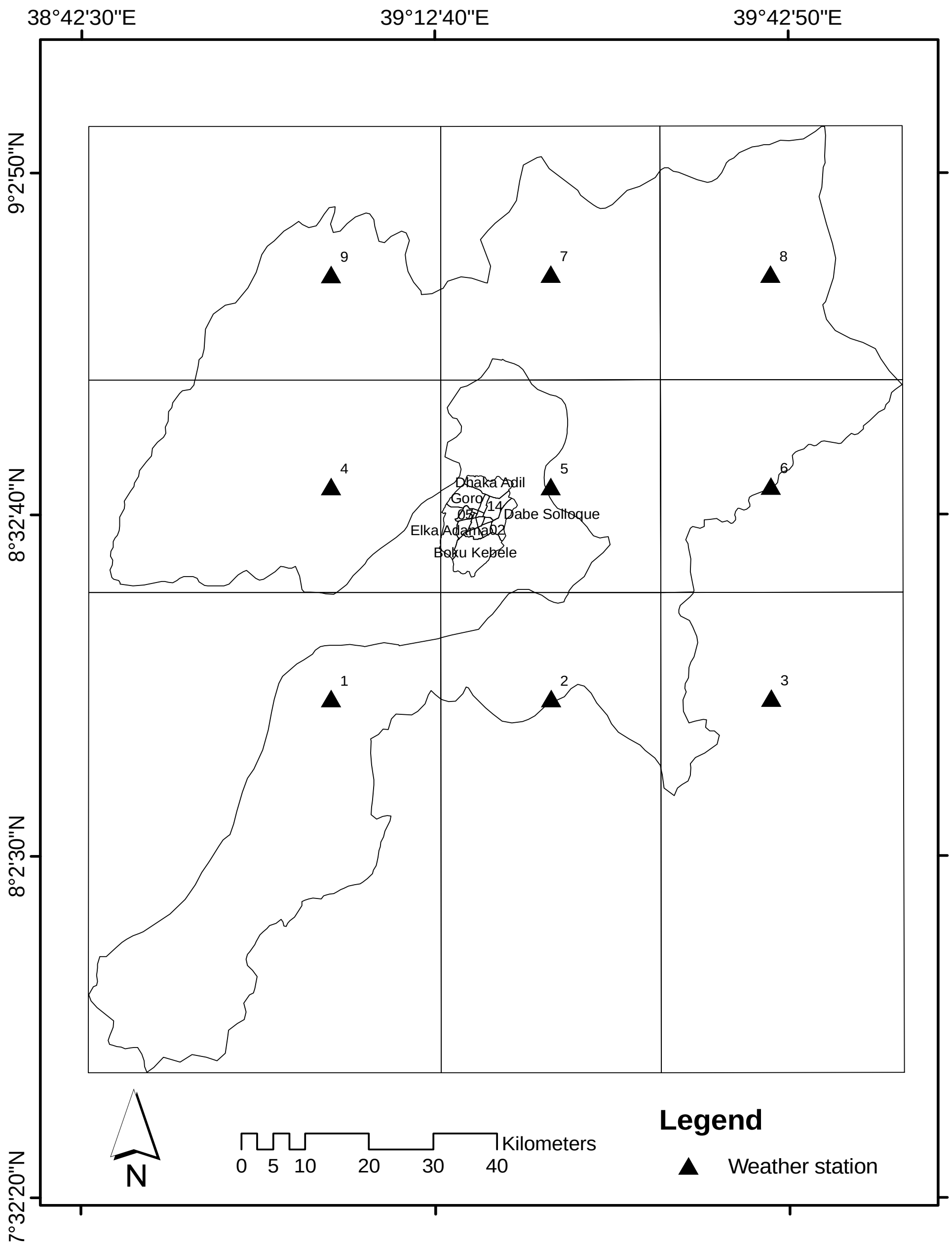


Figure 3: Thiessen polygon

Annual Percentage cover of rainwater for non-potable water use was calculated by:

Formula 7:

$$\frac{Avarage\ personal\ consumption\ volume\ per\ day\ (L)\ \times household\ size \times 365 \times 100}{potential\ estimated\ harvested\ rainwater\ (m^3) \times 1000}$$

Table 5: Summary of methods

No	Specific objective	Data used	Source of data	Collection method	Instrument used	Analysis
1	To identify residential water consumption patterns	Municipal water volume used by the residents in m^3 per day, month, and year for home use	AWSSE and residents	Phone interview and Secondary data (customers report)	phone	Compute using Standards $\bar{x} = \sum x / N$ $\sigma = \sqrt{\sum (x_i - \bar{x})^2 / N}$
2	To measure the recycled water volume.	Input water volume, consumed volume, and reused volume	Sampled residents	Phone Interview	Phone, bucket	mean volume of water flow in the residents and WSC index
3	To compute Rainwater harvesting capacity	Residence water meter to allocate their roof for area calculation, digitized satellite image, and rainfall data	Google Earth, AWSSE, and NCEP weather site	Secondary data (customers report), and published literature sources	Computer	catchment area(m^2) $\times$ runoff coffiecent $\times$ rain fall (mm) $\times$ (0.001) $=$ net runoff (m^3)

3.5 Data Analysis

3.5.1 Residential water consumption pattern

The generated data from the administered interview and AWSSE customers report data analyzed and simplified using Microsoft Excel (Excel 2013). The meter reading data analyzed with the range of maximum and minimum, mean values, and standard deviation. The end-use analysis includes consumption, hygiene, and amenity. The data is presented in a pie chart, graphs of cluster column, line, Scatter plots, and simple tables to clearly show the result.

During the survey, the available indoor utilities with the volume of water consumption were collected but toilet water consumption was analyzed using standards from the literature due to the resident's uncertainty of the water used for toilet flush. The modern world strives for a better life standard by minimizing effort and increasing comfort. These innovations perform in the natural system using natural resources so studies have been developing in the integration of these two polar with the minimum impacts one on another. The analysis comparatively presents conventional methods to the modern way regarding resource consumption.

3.5.2 Recycled water use of Adama residents

The recycled volume of water used by residents who recycle water is estimated based on the survey data; water used for the last rinsing of cloth and kitchen purpose. The mean volume of water flow from the supply to the end disposal illustrated and in general, using the WSC index the level of water recycling in the city was rated.

3.5.3 Rainwater harvesting capacity

To be sure about the rainfall, data tapped from NCEP from 1979-2008 (30 years) and a Thiessen polygon was developed. The city falls in a polygon represented by station five (fig. 3). This data was used for estimating the amount of water harvested by each sampled house. The mean annual rainfall for the years 1979-2008 is 804 mm. From the four climatic seasons, keremt (summer) is the rainy period from (Jun-August) also there is an average rainfall in Tseday (spring) in September. The average amount of rainfall in these three months is 200mm, 207mm, and 94mm, respectively (Refer to annex-4). The proportion of precipitation in these three months is about 62.3% of the annual total. The built-up area was calculated for each sampled plot and the total yearly harvested water volume has been calculated.

3.6 Research design

The analytical procedure of the research presented in (fig. 4)

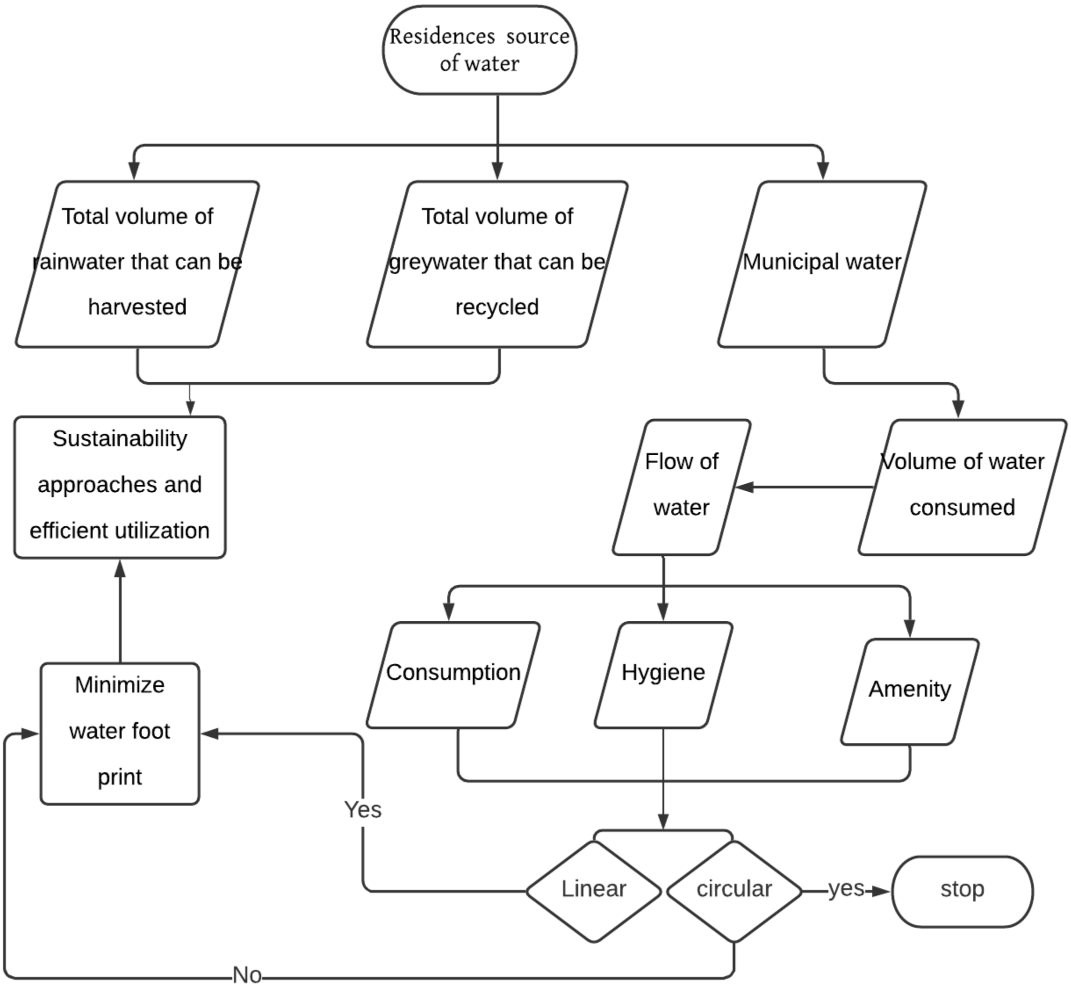
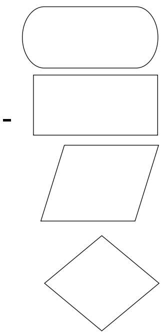


Figure 4: Research design

Legend:



Terminator

Data

Process

Decision

CHAPTER FOUR

RESULT

4.1 Residential water consumption pattern

I. Water availability

The availability of efficient water is the main concern of the modern world. From the surveyed sample 19% of the residents used to get 24-hour water access, 23% (16 hours), 16% (pick hour), and 42% of the residents used to get with schedule or day off but the supply in all the above categories is not regular within the mentioned time boundaries it fluctuates (fig. 5). Residents in Kebele 06, 07, 08, 12, 14, and 04 got an average of 18 hours/day of water access whereas expansion areas (Boku Shana, Dhaka Adi, Dabe Sollogee, and Melkaa Adaamaa) got intermittent supply with a schedule. The other kebeles got an average of 4 hours/day water supply.

79 % of the residents use elevated storage and Jerrycans to store 1,000-5,000 liters for indoor, outdoor, and emergency use.

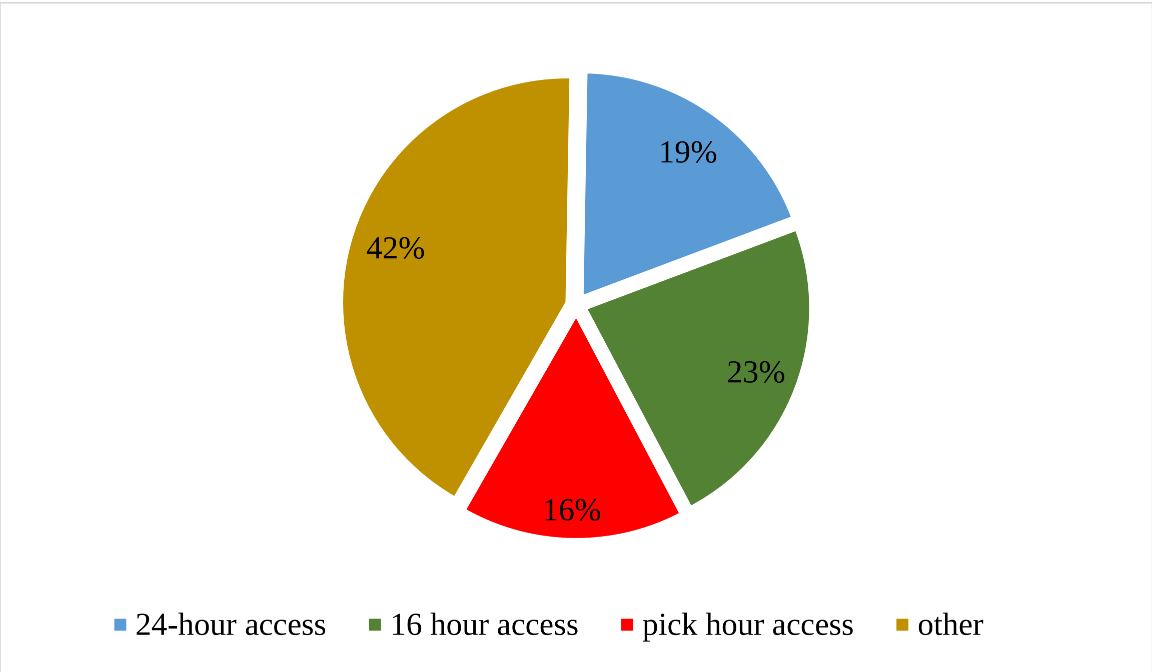


Figure 5: Tap water availability

II. Percentage volume of water consumed for indoor and outdoor uses

Residents use piped water almost for everything including cleaning their house compound, gardening (small-scale farming and livestock), car washing, and toilet flushing. More water is consumed for hygiene purposes 75.64 l/person/day (7 times the consumption water use 12.3L). Under the hygiene category, cloth washing takes the largest percentage consumption (33.7%) followed by toilet flush (24.7%) and bath (16.8%). The utility factors in the consumption of the three hygiene categories have been explained below. The other is cleaning (9.2%) which includes utensil, house, and compound cleaning. Drinking and cooking together consume 7.9% of the total consumption. Gardening (5.5%) and other water use contribute 2.2% of the total consumption (fig.6).

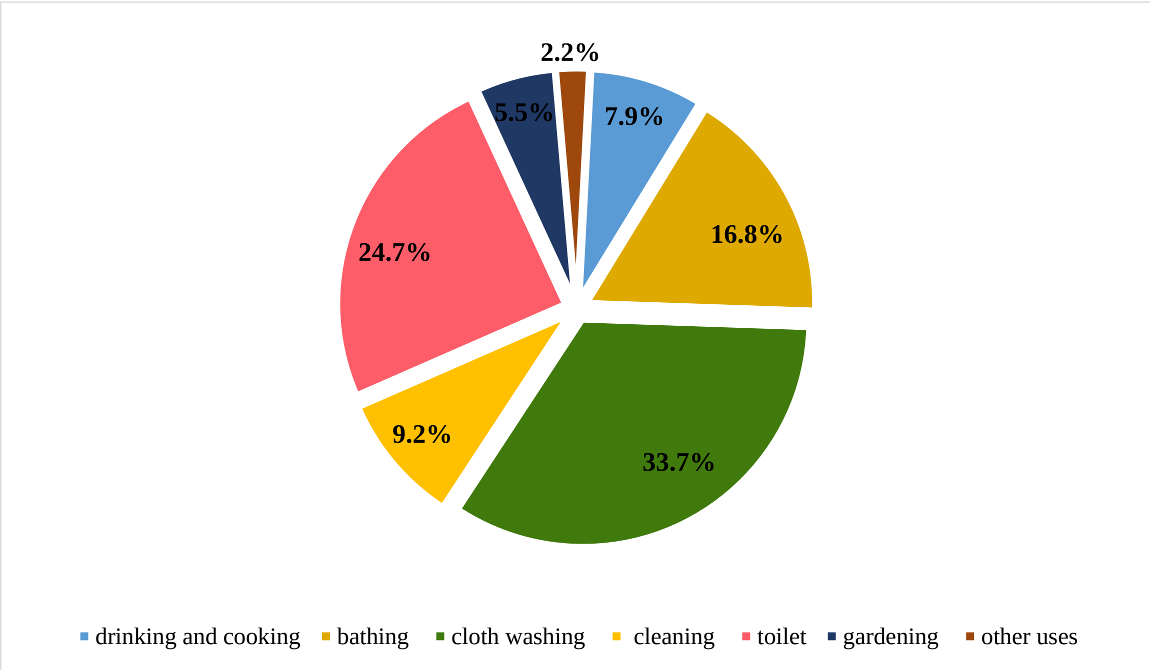


Figure 6: Average indoor water use in percentage

III. Water consumption by utilities

A. Toilet flush

Of the sampled residents 24.1% of the residents use only the squat toilet. This means 241 individual users. The rest of the 656 individual users use combined sitting and squat toilets. On average the 241 individuals use 395.8 m^3 of water annually for squat toilet flushing; 1.5L of water used per flush with the frequency of three times a day and the 656 individuals use an average of 2,772.6 m^3 of water using 4.5L per flush three times a day (Table 6).

Table 6: Volume of water used for toilet flush

Toilet type	Households	No of users	No of flush per day	Average volume per flush (L)/day	Volume of water used annually (m^3)
Pit toilet	49	241	3	4.5	395.8
Combined pit and siting	154	656	3	1.5	2,772.6

B. Shower

The question survey includes only the bathtub and overhead shower but during the survey, some respondents reply to the use of bucket water for shower. 85% of the residents use an overhead shower with a range of 5-15 min duration and 1-5 times frequency per week. (Fig. 7) present the total volume of water per liter calculated using a 7.5 average flow rate per min (lpm).

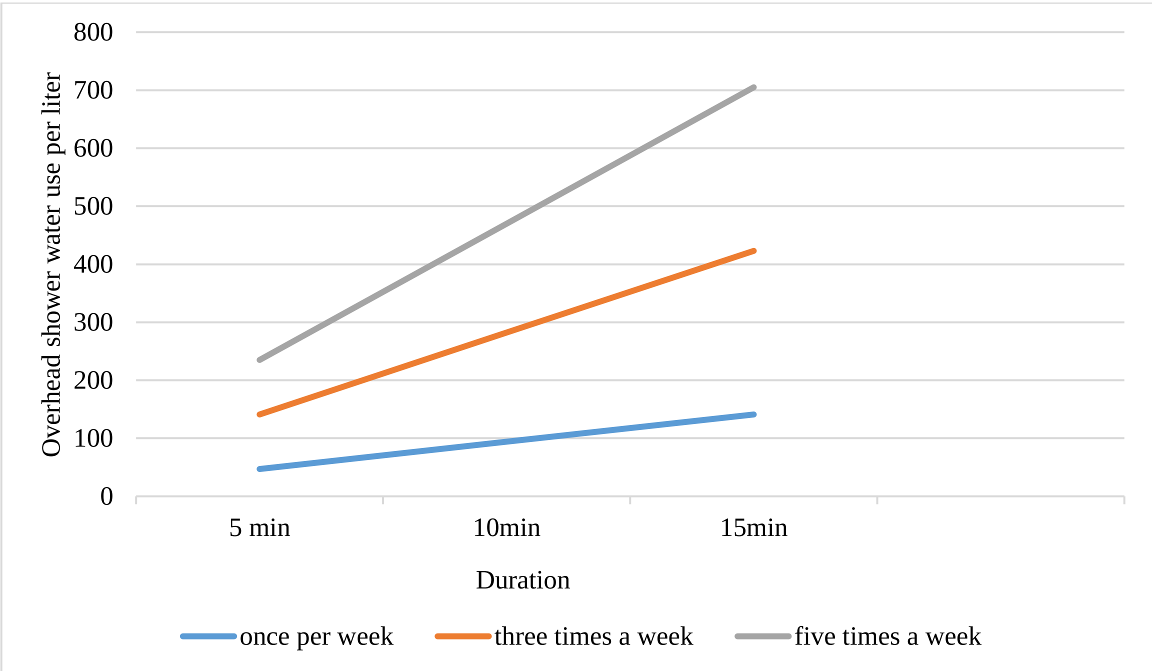


Figure 7: Overhead shower water use by duration (min) and frequency per week

The duration and frequency of the shower are related directly to the volume of water used. 11% of the residents take shower at average using10-20 liters of bucket water. Time duration doesn't affect the volume of water while using bucket water for the shower but the frequency per week related directly to the total volume of water being used per week. Taking a 5min average duration and frequency of 3 days per week 85% of residents use 1,092.4 m^3 of water within 52 weeks of the year. 11% of the residents use 102.9 m^3 of water annually with an average of 15 liters per shower (Table 7).

Table 7: Volume of water used for Shower

Shower	Households in percentage (%)	Volume of water used annually (m^3)
By bucket water	15	284.9
Overhead	85	1,092.4

Duration: 5min, frequency: 3 times a week, flowrate: 7.5 l/pm

C. Cloth washing

Washing by hand takes energy, time, and labor compared to mechanical cloth washing but consumes comparatively less water. The volume of the water washing machine used depends on the type of machine. The mean volume of water used by the residents for cloth washing using a washing machine is 115 L per wash load. 67% of the survey residents wash their clothes by hand and the rest 33% of them use a washing machine. From the survey on average, a person uses 25 - 40 L of water to washcloth. 67% of the residents consume 3,042 m^3 annually with an average of 32.5 L per wash three times a week whereas 33% of the residents using the washing machine consume 5,289 m^3 of water (Table 8). The statistics show washing machine users; half of the residents who wash by hand with the same frequency per week consume a large volume of water

Table 8: Volume of water used to wash cloth

Cloth washing technique	Households in percentage (%)	Volume of water used annually (m^3)
By hand	67	3,042
Machine	33	5,289

IV. Family size and water consumption

A. Correlation

Household size and water consumption have a positive linear association (fig. 8). The volume of water consumed is correlated (r = 0.88) to household size. The volume of water being consumed increases as household size increases. (Refer annex 2&3)

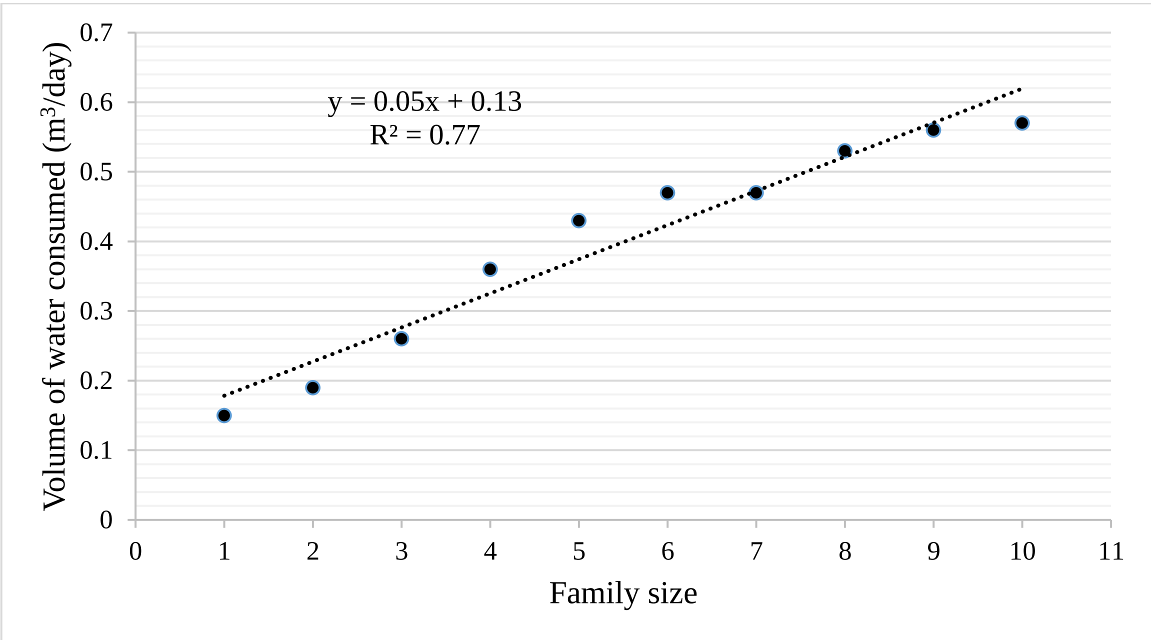


Figure 8: Relationship between the volume of water consumed and family size

B. Mean water volume used per day

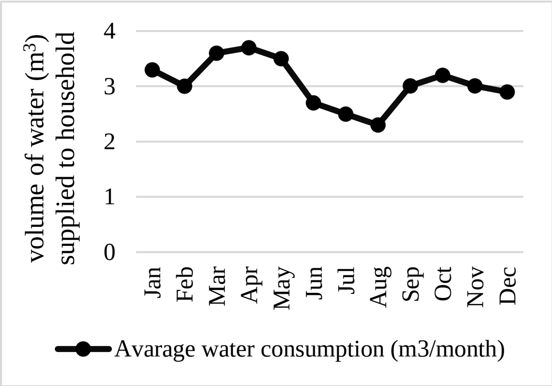
Table 9 relates household size with the meter reading volume of consumption. The SD shows the range of water consumption volume within the same family size comparing to the mean value. A low standard deviation indicates each household's water consumption volume tends to be very close to the mean (family size 1) whereas a high standard deviation indicates that the average volume of household water consumption is spread out over a range of value. (For further detail refer to annex-1)

Table 9: Family size and water consumption

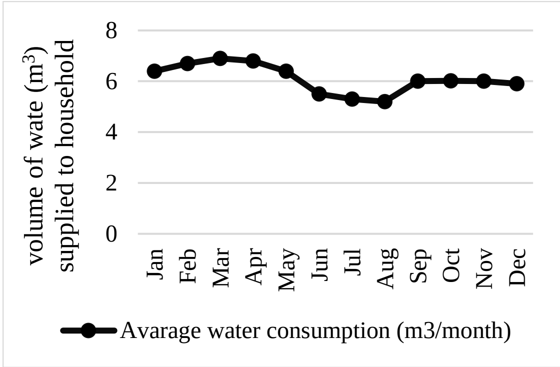
Demographic data		Water consumption (m^3/day)			
Family size	Number of households	Min	Max	Mean	SD
1	7	0.04	0.16	0.15	0.14
2	13	0.14	0.23	0.19	0.02
3	29	0.22	0.30	0.26	0.04
4	68	0.32	0.42	0.36	0.03
5	53	0.39	0.46	0.43	0.02
6	14	0.43	0.55	0.47	0.04
7	6	0.44	0.52	0.47	0.03
8	6	0.49	0.56	0.53	0.03
9	4	0.54	0.57	0.55	0.02
10	3	0.53	0.58	0.56	0.01

C. Average monthly consumption

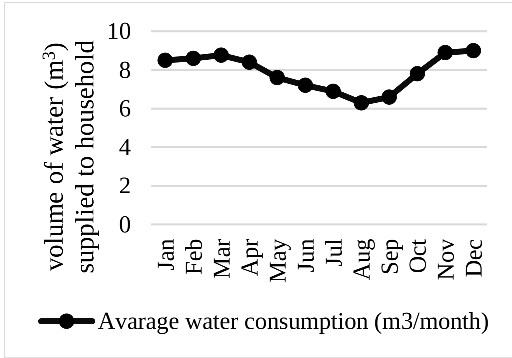
The monthly meter reading cubic water consumption data of the residents presented graphically under (fig. 9). Relatively there is a higher consumption in March and April whereas minimizes in August and September.



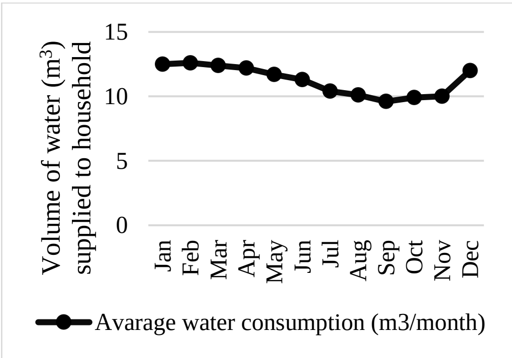
(a) Solo consumer



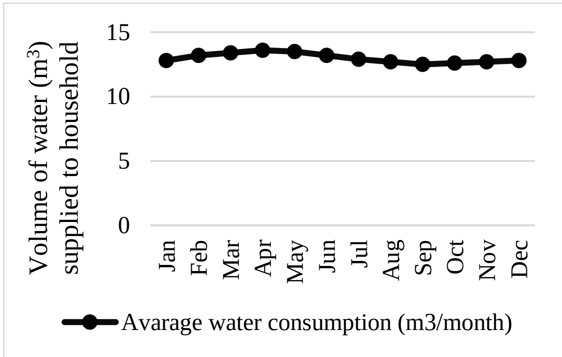
(b) Two consumer



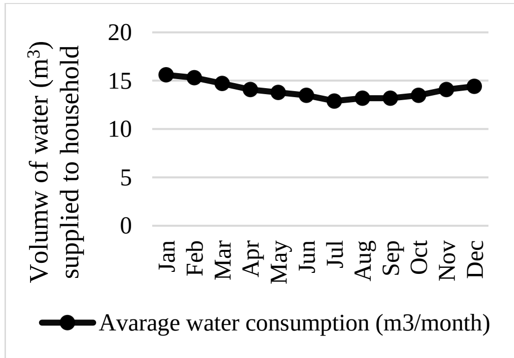
(c) Three consumer



(d) Four consumer



(e) Five consumer



(f) Six consumer

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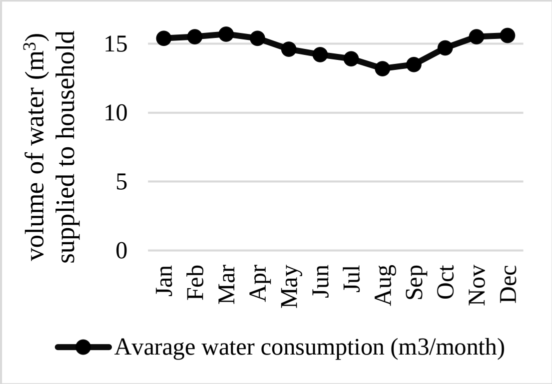
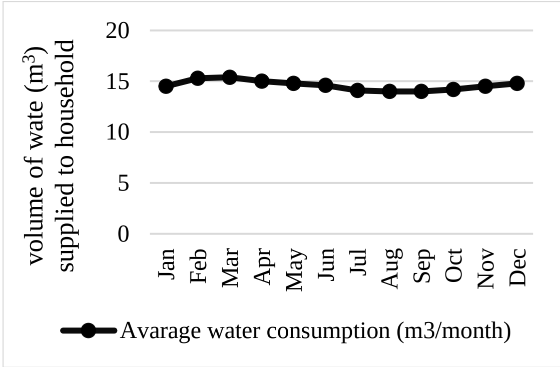
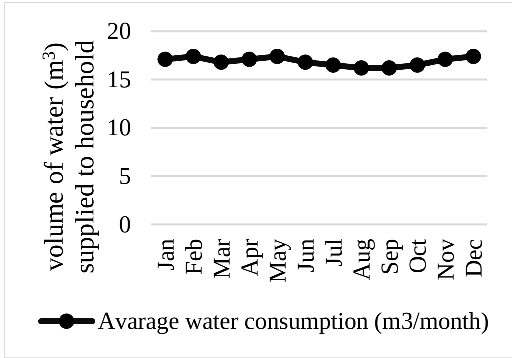


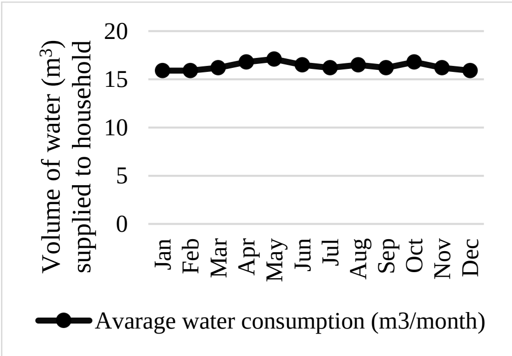




(g) Seven consumer

(h) Eight consumer

(I) Nine consumer



(j) Ten consumer

Figure 9: Monthly average water consumption by family size

4.2 Recycled water use of Adama residents

Only 12.65% of the households reuse the water used for the last cleaning of cloth for the pit toilet cleaning and water used for cooking pasta, washing vegetables, and fruits for gardens. From a total of 26 residents (124 individuals) 693.84 L of greywater is reused (Table 10).

Table 10: Volume of water reused by residents

Number of households	Family size	Volume of water reused L/day
5	3	94.08
9	4	229.32
6	5	164.64
3	6	86.3
2	8	50.9
1	9	68.6

87.35% of the residents expelled the tap water to the environment after a single-use. In general, the consumption pattern of the surveyed residents is linear (fig. 10). There is no recycling of used water.

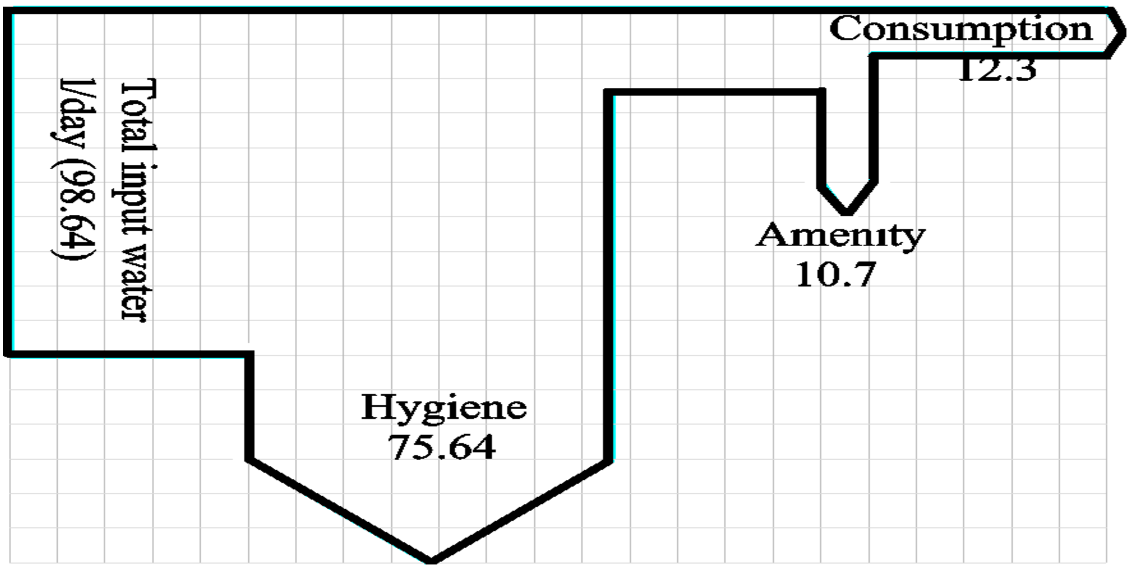


Figure 10: Linear water flow per person per day

The current linear water metabolism of Adama city best fits rating 1 “no resource recovery occurs” of the “optimized resource recovery” indicator for the ecological goal “improve productivity & resource efficiency” of the WSC index.

4.3 Rainwater harvesting capacity

14 % of the sampled residents collect rainwater for day to day purpose of cleaning and washing but they didn’t store it for future consumption. From the total residents who harvest rainwater 79.6% of them found in the category of the residents with schedule or day-off tap water availability. A total of 203 sampled residents cover a 20,199.4 m^2 roof area and from this, it is potentially estimated that a total of 15,428 m^3 of water can be harvested annually (Refer annex-1). Within rough estimation, it costs around 210,448.11 birrs with the current Adama water tariff system (Refer annex-6).

Within the months of the rainy seasons, a total of 9,750.02m^3 of water can be harvested from the 203 sampled roof area (20,485.4 m^2). It is possible to collect 3892.2 m^3 in July, 4028.5 m^3 in August, and 1829.3m$^{3\ \text{in}}$ September (fig. 11).

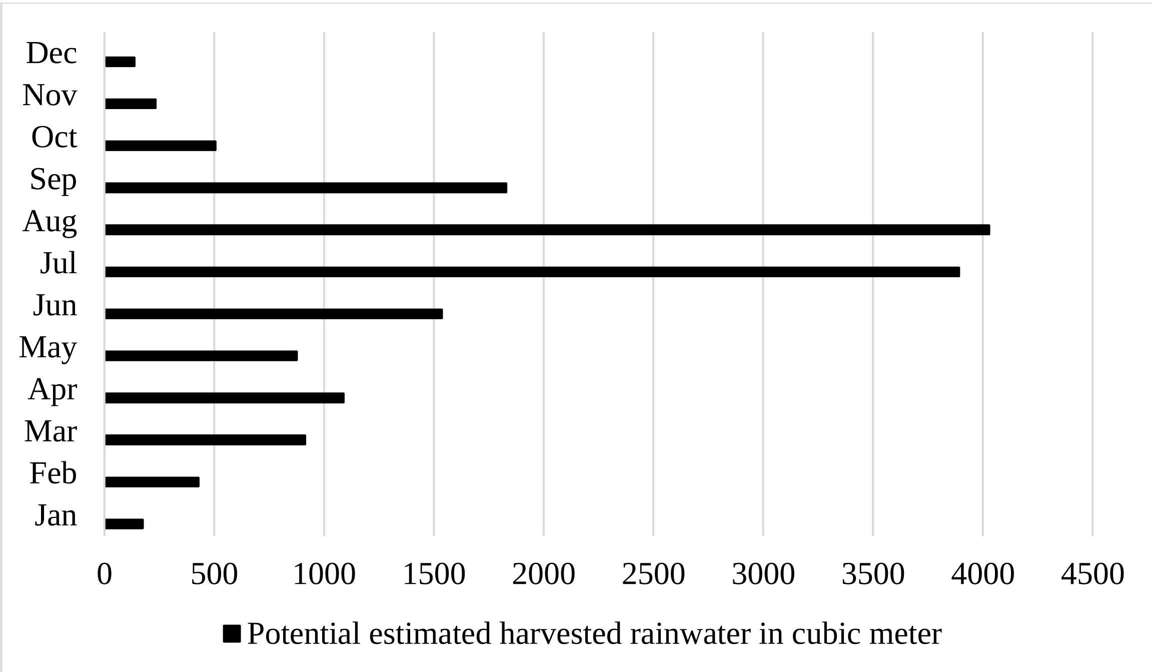


Figure 11: Monthly potential volume of rainwater

July, August, and September separately contribute 25%, 26%, and 12% respectively to the total annual harvesting potential. Together the three months covers 62.3% of the total rainwater that could be harvested annually (fig. 12).

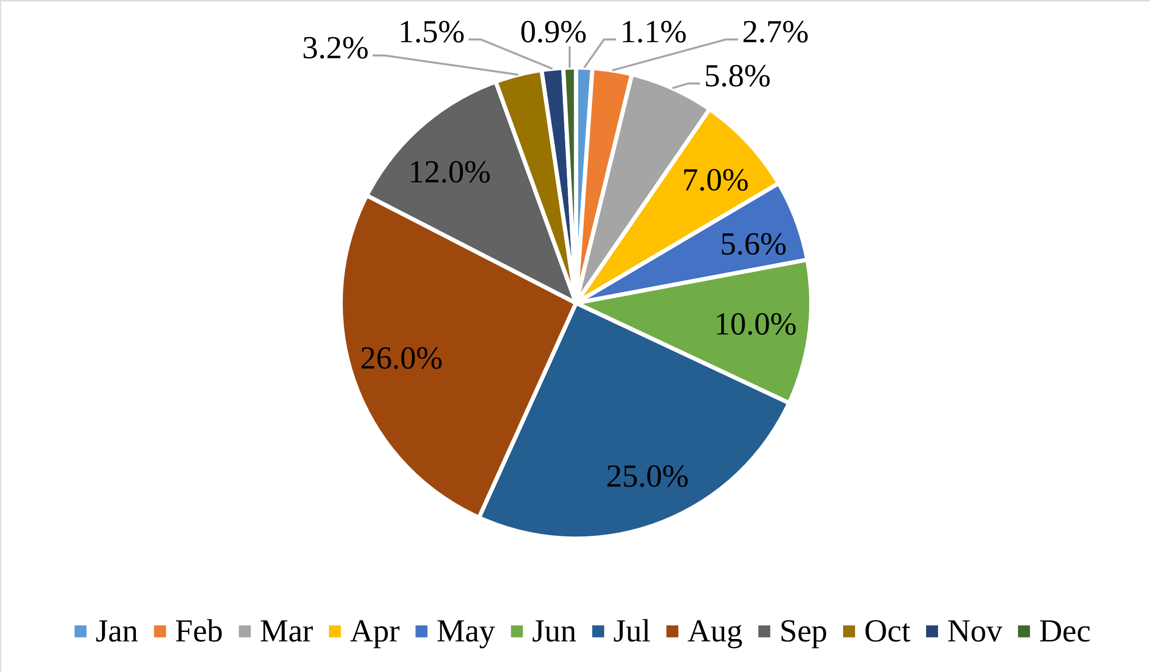


Figure 12: Monthly percentage contribution of rainwater harvesting potential

Fig 13 illustrates the potential estimated volume of rainwater that can be harvested from the resident's roof area. The volume of water harvested from the roof is directly related to the roof area.

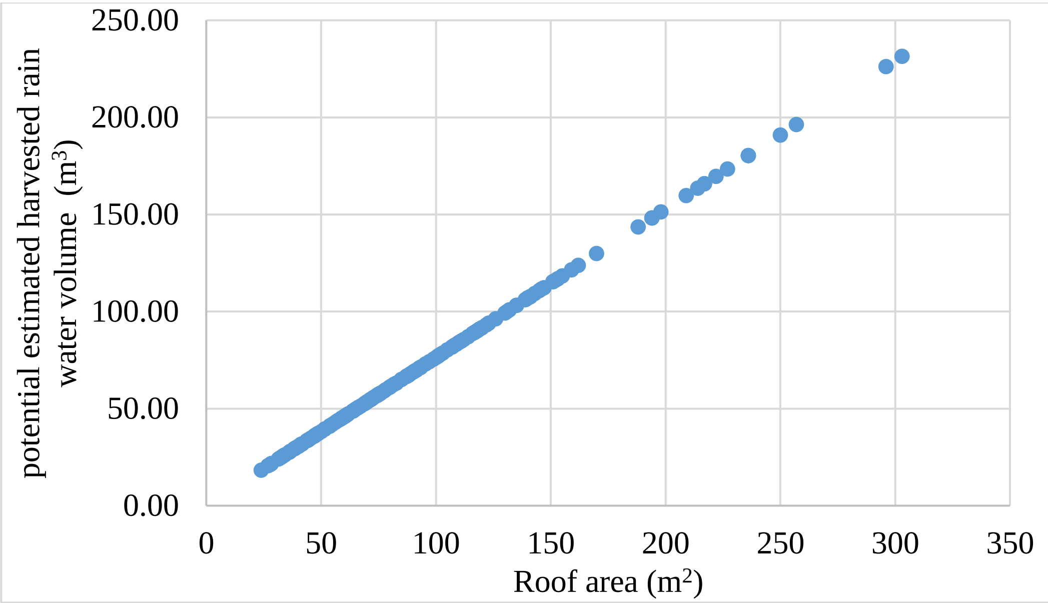


Figure 13: Potential estimated harvested rainwater volume

Annually harvested water from single households can entirely cover the non-potable water demand of the residents (Table 11). As the family size increases the percentage demand cover of the rainwater harvested decreases but still supports the demand and promotes sustainability. The volume of harvested water depends on the roof area (fig. 13). (Refer annex-7 for each household Annual % coverage of rainwater for non-potable demand)

Table 11: Potential support of Rainwater for potable water with family size annually

Family size	Number of sampled households	Total roof area (m^2)	Potential estimated harvested rainwater (m^3)	Annual % coverage for non-potable demand
1	7	533.6	407.6	101
2	13	953.2	728.1	48.5
3	29	2,064.9	1,577.2	31.4
4	68	7195.8	5,496.2	35.03
5	53	4393.5	3,355.9	21.9
6	14	2044.1	1561.3	32.2
7	6	726	554.5	22.8
8	6	1052	803.5	29
9	4	563	430	20.7
10	3	673	514	29.7

CHAPTER FIVE

DISCUSSION

5.1 Residential water consumption pattern

Cities require natural resources for the survival of its population. According to the UN report, cities occupy only two percent of the earth's surface but consume over 75% of the natural resource. Water is the main essential natural resource for cities. The growth and expansion of cities with an increase in the inhabitants exacerbate the issue of sustainability. Metabolism provides a metaphorical framework for the study of material flow, the interaction of a natural and human system, and tracks the level of sustainability in cities.

The availability of water, utilities used at home, and the size of the family affect the volume of water consumed by the residents. The distribution of water in the city is not equal. 42% of the surveyed residents found water within schedule. Other than the 17% of the residents who use bottled water for drinking the residents depend on the tap water supply for indoor and outdoor activities so they collect when water is available using water tankers.

From the anthropogenic water uses hygiene takes the lion share by which cloth washing contributes the largest percent 33.7 followed by toilet flush 24.7% and bath 16.8%. This implies the water that passes through various levels of tests for drinking purposes is being used for hygiene. The volume of water used for the three hygienic activities depends on the fixture type, frequency of the activity, and time duration. For instance, the dual flush toilet provides an alternative volume of flush for liquid waste and solid waste removal while older toilets use the same amount of water for both waste removal. Modern world innovations only have a choice to be environmentally friendly as long as it depends on nature. Specifically, toilets which are located indoor require regular cleaning unless it could be a source of indoor air pollutant so water is the most essential element for the toilet. Squat toilet consumes less water to remove waste than the western toilets and is very easy to clean it also due to the lack of direct contact with the seat it's more hygienic to share. The survey data shows residents with sitting indoor toilets also have alternative outdoor squat toilets. Technological Fixtures and Appliances used at home could help residents in daily life routines and give them extra comfort but comparatively for the same amount of cloth the washing machine could take 50-100 liters of more water than hand washing also washing water volume and frequency depend on the family age composition, work exposure, and habit. As indicated in other researches (Arpke & Hutzler, 2006; Wada et al., 2013) consumption intensifies the global water crisis.

Taking both the survey and volume of water used by residents the size of the household was directly related to the volume of consumption. Currently, the water supply covers 78% of the total water demand and 45% (10,132.82 ha) of the city master Plan by area. The supply is expanded in the low laying areas which intensify water scarcity in the high laying zones. As a level II city, the supply doesn't satisfy the GTP II planed standard (80 l/c/d) also the population is increasing at an exponential rate. Residence covers the largest percentage of the land-use composition and is a place where life starts and flourish so it's the primary line in the supply system but due to the incompatible demand and supply and water-energy nexus the resource becomes scarce. The recognition of sustainable approaches helps to manage the ever-growing water scarcity.

Within the same family size, residents' utility utilization alters the volume of water being consumed. Even though rainwater harvesting and greywater harvesting reduces demand for tap water and promotes sustainability it does not contribute to a reduction in water consumption so studying metabolism helps to identify the gap and promote efficient utilization.

In general, the monthly consumption of the residents creates a pattern that flows throughout the year with minimum fluctuation. Relatively there is higher consumption in March and April whereas minimizes in August and September. Within the scarce supply diversified water source than the centralized distribution system helps minimize the demand-supply gap and also promotes sustainability.

5.2 Recycled water use of Adama residents

Circular metabolism aims to reuse or treat an outgoing resource as a new incoming resource so the waste would be a resource instead of a problem. The pressure is on reducing water demand by reducing wastage and reusing as much as possible. This helps to minimize or reduce the impact of consumption in the environment and promote sustainability. Recycled water has become a new alternative and reliable source of water in the cities. Wastewater has been recognized by the UN through the world water development report as a resource (Angelakis et al., 2018). Cities of the future improve today on sustainable models. Currently, 800 million peoples live under water stress predicted to be 3 billion in 2025 (Oteng-Peprah et al., 2018).

The recycled use of water by the residents estimated by the end-use of water delivered to the residents from the AWSSE. 12.65% of the residents reuse the water used for the last cleaning of cloth and food preparation for the squat toilet cleaning, house compound cleaning, and gardens. This helps to save tap water and use water resources to its maximum utilization level rather than removing it from the system with limited uses. Compared to other cities around the world with water recycling trends almost no one recycles water in Adama. The flow of water is linear. Once the tap water was used, the quality diminished and become wastewater and it was removed from the urban system. As a city which is struggling with supply challenge consumption and removal are basic segments

The reuse of greywater is an old practice. Nowadays greywater reuse is an alternative water supply in water stress areas (Oteng-Peprah et al., 2018). Greywater accounts for 75% of wastewater which increases to 90% if a dry toilet is used. 14-116 liters of greywater generate in Africa and the middle east, 75-225 L in Asia, and 123 L in the USA per person per day (Oteng-Peprah et al., 2018). The generated greywater can be a source of water rather than a waste to be removed by the means of recycling for compensating the growing water stress. Currently, china increases the water reuse rate due to the water crisis (Zhu et al., 2018). In Australia, the millennium drought (2000-2019) changes water reform policy to diversify water source and secure continuous supply. This led to the expansion of recycling and the provision of dual-pipe for drinking and recycled water (Radcliffe & Page, 2020).

By collecting the gray water, settling, filtering with natural charcoal and sand, and disinfecting households can reuse wastewater and reduce potable water use by 25 - 30 %. The use of recycled water for drinking, however, is less common, but a few countries like Singapore, Australia, and Namibia, and states such as California, Virginia, and New Mexico use recycled water for drinking (Menge, 1997).

5.3 Rainwater harvesting capacity

Rain is the major component of the hydrologic cycle and source of fresh water. Residents depend on water supplies rather than using rainwater. Only 14% of the residents collect rainwater for daily use but do not store it for future use. The development of cities changes the natural landscape into impervious surfaces like roads and buildings. Such changes affect the hydrology of the city and create runoff and flood. Rainwater harvesting can not only be a source of water but reduce runoff, erosion, and can be stored for future use to compensate for scarcity. It also increases water security by decentralized supply and reduces rural conflictive invasion due to rural water sources cater to urban demand. Such sustainable practices are being parts of the industrialized nations and urban areas (García Soler et al., 2018).

Roof-top water was a source of domestic water in small Islands in the Caribbean for more than three Centuries and still, 500,000 peoples depend on it similarly 100,000 Jamaicans depend on rainwater catchment. Honduras, Brazil, and Paraguay use rainwater as an important source of water (Sendanayake, 2016).

From a total of 20,485.4 m^2 roof area, it is potentially estimated that a total of 15,646.7m^3 of water can be harvested annually from 203 residences. By harvesting rainwater, residents can support their Annual non-potable water demand. Australia is the driest inhabited continent with the highest water use (300,000L) annually per household. In 2004 17% of the total water source was rainwater. In southern Australia, 48% of households depend on rain for drinking. From the ten most water-stressed countries Jordan with a low potential where 85% evaporates back and 4% recharge the ground 5.6% of total domestic water supply can be meet by RWH (Sendanayake, 2016). Within the blessed nature, rainwater is an unrecognized free resource in Adama that can be harvested cheaply by the residents and can be used directly or with further simple steps. It's a lot for a city that is struggling to address the water demand problem.

In many countries to address water sustainability, Rainwater harvesting integration in new buildings is enacted in law. US Virgin Islands, Sri Lanka, Bermuda, and Guinea-Bissau are some of the countries that enacted RWH by law. Belgium enforces RWH system installation and storm attenuation for buildings more than 100m^2 roof area, Singapore mandates the RWH system installation for new developments, and in Brazil, the government supports 1 million RWH system installation to semi-arid areas. From east Africa Northern Kenya and Somalia construct brick-lined large holes in the ground for water retention (Sendanayake, 2016). The finding of the study compared to the global trend implies the vast work that should have to be done in the sector of rainwater harvesting in residential buildings to support their water demand. Promoting rainwater harvesting and developing water sensitive city fosters livability and development in a sustainable base.

CHAPTER SIX

FINDING, CONCLUSION, AND RECOMMENDATIONS

6.1 Finding

The municipal water supply is the main source of water in Adama city. The supply is inconsistent where the largest volume of water is used for hygiene purposes (7 times the consumption volume). Flush toilet takes (3times) water than a pit toilet. The volume of water used for overhead shower depends on the shower duration and flow rate of the tap. The annual volume of water used both by an overhead shower and bucket water depends on the frequency per week. Washing cloth by machine takes (3.5 times) more water than washing by hand. In general, the volume of water consumption is directly related to the size of the family in the household. The average annual consumption of Adama residents relatively increases in April and March and minimizes in August and September.

The water metabolism of the residents is linear. Within the rainy season (July to September) it is possible to collect rainwater that can compensate for the non-potable use of residents from their respective roofs.

6.2 Conclusion

Adama city is one of the fastest-growing cities in Ethiopia. This puts pressure on the water supply along with poor management, increase demand with an increase in population and per capita income, and less awareness of users towards environmental resource and consumption. The projected population of Adama city in 2020 is 410,738 which will be 513,374 in 5 years. The population residing in Adama is expected to exceed 1M in near future. Within the next five years, the domestic water demand will grow from 19,971 m^3/d to 27,017 m^3/d. The current upgraded system covers 78% of the total demand in which the production rate should increase from 411 l/s (35,510.4 m^3/d) to 511 l/s to satisfy the demand. Adama residents are living under water scarcity. According to WHO 50l/c/d is an intermediate supply level, in order to assure optimal supply minimum of 100 l/c/d should be supplied. 80l/c/d was the service level aimed to be attained at the end of the GTP II but the current supply is 48.6 l/c/d (Refer annex-5). Only increasing production rate couldn't coup up with the exponentially growing demand. Understanding the end-use of water helps in focusing on conservation methods that are financially and environmentally acceptable.

There is no recycling of water by the Adama residents. The critical resource is discarded without any further use also 84% of the total water demand, is used for non-potable usages such as hygiene and amenity uses. The municipal water line is the only water source for the residents so the scarce treated water is being used for non-potable purposes while drinking water is the question of many other peoples.

Adama residents can support their non-potable water demand by harvesting rainwater and reusing greywater but such sustainable approaches are neglected both by the officials and residents.

6.3 Recommendation

- Understanding consumption and applying demand-side management rather than exploiting a new resource should be done to address the demand-supply gap and promote sustainability.
- Environmental issues need to be centralized with knowledge, research, and awareness. The overall process should be supported with such studies, awareness-raising, and education which are very important for changing the current trend and develop a sustainable society. This needs to be addressed by media, governmental, and non-governmental institutes working on the water sector by organizing public awareness programs. Evolving environmental consciousness in society is the key to a change.
- Adama residents should have to be aware of the importance of; appropriate fixtures choice for home, efficient water consumption habits, roof water harvesting systems, and water recycling to be sustainable enough.
- The tap water passes through a variety of disinfecting stages to remove all the potential hazards for human health and wellbeing which consumes resources such as; energy, finance, and time; therefore the non-potable use of water should have to be offset by harvesting rainwater and reusing greywater.
- Tariff adjustment should be done for those who used rainwater and offset most of their potable water demand from the municipality.
- AWSSE should develop strategies for the application of sustainable approaches like rainwater harvesting and greywater reuse and implement it to support the demand-supply gap.
- The integration of a rainwater harvesting system in the Architectural design of residential buildings should be enacted in law.

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APPENDIX-1

ADAMA SCIENCE & TECHNOLOGY UNIVERSITY-(ASTU); Kebele

Department of Architecture, Post Graduate Program/ MSc in Environmental Architecture Block no.

Domestic water Use of Adama residents surveying form Date

Demography **Meter serial number**

- Family size

Water Availability Scarce Efficient

Water Availability per day

24 hr.

16 hr.

Peak hour

Other

Average Water use per litter per person per day

- **Consumption**

Drinking Cooking

- **Hygiene**

Bathing ________

Teeth washing ________

Hand and face cleaning ________

Cloth washing ________

Utensils washing ________

House cleaning ________

Toilet flush ________

Toilet flush

Gravity Fed Toilet Flush toilet

Bathing

Bath Tub Shower head

Frequency per day Time duration

Cloth washing

Washing machine manually

- **Amenity**

Gardening Car washing Other use

Rain water harvesting

- Did you collect Rain Water? Yes No
- For wat purpose do you use the rain water? Consumption Hygiene Amenity
- Roof area

Waste water treatment

- Did you recycle water? Yes No
- For what purpose do you use the waste water

Water storage

What Volume of water did you store? Tanker size

Annex 1. Consumption data

No	kebele	Customer Code	Latitude	Longitude	Family size	Annual average volume of water consumed (m^3)	Roof area (m^2)	Annual potential estimated harvested rainwater (m^3)
1	kebele 01	OC01-1999.739	8.5585741	39.26770084	4	9.7	123	93.95
2		OC01-1087.01	8.56225	39.27130167	4	9.9	120	91.66
3		OC01-1097.1.6	8.565585	39.26910333	3	6.7	91.1	69.58
4		37183	8.57288	39.26618117	3	8	85.2	65.08
5		7467	8.5730149	39.2808295	4	9.6	222	169.56
6		46084	8.5758966	39.26657178	5	11.9	110	84.02
7		51946	8.5677853	39.26078428	4	11.2	170	129.85
8		OC01-1105.003	8.5630633	39.27001833	4	12.5	87.3	66.68
9		38483	8.5739673	39.2683925	4	10.1	95.5	72.94
10		OC01-1999.71	8.5644382	39.26043442	5	13.8	93.7	71.57
11		20472	8.5557937	39.26221156	4	10.8	303	231.43
12		46136	8.5558226	39.25973163	1	1.25	139	106.17
13		OC01-1039.05.18	8.5557438	39.26430156	3	7.3	28.4	21.69
14		9085	8.5743304	39.27623588	5	12.3	44.3	33.84
15		18552	8.554319	39.26633799	4	11.7	394	300.94
16		OC01-1130.03.01	8.5720363	39.26441607	5	11.9	112	85.55
17		2679	8.5724506	39.27360636	3	8.2	75.3	57.51
18		20241	8.5651193	39.274047	6	13	198	151.23
19		OC01-1108.008.42	8.5694617	39.27066667	5	12.75	56.2	42.93
20		2287	8.571315	39.27138833	4	11.31	48	36.66
21		42540	8.5735932	39.27006613	4	10.98	111	84.78

No	kebele	Customer Code	Latitude	Longitude	Family size	Annual average volume of water consumed (m^3)	Roof area (m^2)	Annual potential estimated harvested rainwater (m^3)
22		28993	8.5772887	39.26916981	5	13.8	39	29.79
23		OC01-1107.5	8.5691311	39.26784368	6	13.9	118	90.13
24		OC01-1122.2	8.5640325	39.26370833	4	10.1	116	88.60
25		OC01-1468	8.5675611	39.26365775	5	11.9	131	100.06
26		9825	8.5611697	39.27589462	4	10.2	76	58.05
27		OC01-1114.02.1	8.5628	39.26374833	5	12.5	41.4	31.62
28		OC01-1123.06.1	8.563365	39.26483	3	7.9	57.3	43.77
29		OC01-1385.0026	8.5550114	39.26046429	6	14.4	135	103.11
30		OC19-19159.001	8.5445779	39.26617385	4	9.7	100	76.38
31		OC19-19079.02	8.5435193	39.26730445	6	13.9	105	80.20
32		OC19-19031.01	8.5419144	39.26668377	4	12.4	80.4	61.41
33		OC19-19040.01	8.5419539	39.26680908	5	12.5	93.3	71.26
34	kebele 02	26279	8.5209895	39.27700361	4	11.1	101	77.14
35		19948	8.5245204	39.27995848	5	13	48	36.66
36		26369	8.5231604	39.28262133	3	7.7	60.5	46.21
37		29198	8.523552	39.28162551	5	13.4	38.6	29.48
38		26621	8.5305508	39.28780935	3	7.1	48.7	37.20
39		25460	8.5268397	39.28257091	4	11.3	47.2	36.05
40		26615	8.5266474	39.28033764	5	12.2	93	71.03
41		26355	8.5226265	39.28344187	4	9.9	26.9	20.55
42		28770	8.5327993	39.28683357	5	13.6	72.9	55.68
43		26567	8.5301983	39.28743782	4	10.7	40.2	30.70
44		26373	8.5227999	39.28291205	5	13.7	45.6	34.83
45		26387	8.5244226	39.28418887	5	12.2	75	57.29
46		1035	8.5226318	39.28028894	3	7.6	51.5	39.34

No	kebele	Customer Code	Latitude	Longitude	Family size	Annual average volume of water consumed (m^3)	Roof area (m^2)	Annual potential estimated harvested rainwater (m^3)
47		1138	8.530277	39.2876674	4	9.8	70.9	54.15
48		26433	8.5246232	39.2792456	2	5.9	139	106.17
49		OC02-2240	8.5608169	39.27375488	4	10.8	123	93.95
50		29194	8.5272569	39.28641762	5	11.9	64.5	49.27
51		28624	8.5333265	39.28887298	4	9.7	61.9	47.28
52	kebele 03	35328	8.5160255	39.2523878	5	13.5	41.7	31.85
53		OC01-1041.30.06	8.5144787	39.2522104	4	10.8	101	77.14
54		1023	8.5159276	39.26236831	8	16.9	114	87.07
55		1187	8.520539	39.2631062	2	6.9	87.9	67.14
56		888	8.5137545	39.26946589	4	11.6	153	116.86
57		684	8.5233428	39.27027846	5	12.1	53.6	40.94
58		OC03-3822	8.5131766	39.27286455	3	8.4	143	109.22
59		6815	8.5116158	39.27143374	6	13.1	227	173.38
60	kebele 04	OC12-12284.01	8.5474213	39.28034054	4	10	59.1	45.14
61		OC12-12385	8.5481326	39.27853446	8	16	119	90.89
62		OC03-3150	8.5538515	39.27383872	1	3.5	98.9	75.54
63		OC03-3017.05	8.5600417	39.27716768	6	12.9	107	81.73
64		OC03-3070.398	8.5618633	39.27783083	4	12.3	152	116.10
65		OC03-3070.043	8.5584576	39.27947128	5	13.9	59.3	45.29
66		OC03-3070.11	8.557437	39.28008463	4	12.4	79.9	61.03
67		OC03-3075	8.5541185	39.28070216	5	13.3	119	90.89
68		OC03-3000.87	8.567445	39.28097333	4	11.7	84.9	64.85
69		OC03-3000.2	8.5696217	39.28210333	3	7.3	87.6	66.91
70		OC03-3070.326.1	8.5651574	39.28305061	5	12.6	33.6	25.66
71		OC03-3519	8.569345	39.28394167	8	14.7	236	180.26
72		OC03-3069.498	8.5620533	39.28103667	4	9.9	89.1	68.05

No	kebele	Customer Code	Latitude	Longitude	Family size	Annual average volume of water consumed (m^3)	Roof area (m^2)	Annual potential estimated harvested rainwater (m^3)
73		OC03-3000.99	8.5694117	39.28103667	8	16.3	214	163.45
74		OC03-3119	8.5527702	39.27779281	3	8.8	60.4	46.13
75		OC03-3019.03	8.5574181	39.27777596	2	5	27.7	21.16
76		OC03-3109.0	8.5529984	39.27671804	3	7.6	53.8	41.09
77		OC03-3169	8.5530852	39.27570764	5	11.9	92.7	70.80
78		OC03-3125	8.5521731	39.27733993	4	10.2	47	35.90
79		OC04-4041	8.5525683	39.27460274	1	3.7	74.5	56.90
80		OC04-4130	8.554209	39.29660165	4	12.4	61.3	46.82
81		OC04-4228.5.7	8.549865	39.28387333	5	12.9	69.9	53.39
82		OC04-4507.2	8.5480917	39.29576167	4	9.7	28.2	21.54
83	kebele 05	OC16-16490.041	8.549838	39.25819866	6	15.7	257	196.30
84		OC16-16488.0051	8.5512041	39.2592997	4	10.1	217	165.74
85		OC16-16306.0001	8.5408238	39.25053365	2	6.6	81.7	62.40
86		OC16-16296	8.5392448	39.24577684	5	12.1	72.4	55.30
87		OC16-16290.61	8.5429399	39.24893475	4	10.5	63.8	48.73
88	kebele 06	OC20-20087.01	8.54471	39.26595667	5	13.7	209	159.63
89		OC19-19114	8.5439779	39.26747481	5	12.3	82.7	63.17
90		OC19-19144.002	8.5441099	39.26675342	5	13.8	435	332.25
91	kebele 07	OC18-18020.001	8.5463068	39.26963009	3	8	23.9	18.25
92		OC18-18085.03	8.5470846	39.26796684	1	2.7	38.3	29.25
93		OC18-18098	8.5473553	39.26776097	4	9.6	46.9	35.82
94		OC18-18110	8.5467231	39.26758759	5	11.7	60.2	45.98
95		OC18-18066	8.5467768	39.26841237	9	16.9	111	84.78
96	kebele 08	OC20-20055	8.5447775	39.26375583	5	13.4	118	90.13
97		OC20-20065.02	8.5445483	39.26512833	3	11.6	31.9	24.37
98		OC20-20184	8.5409767	39.26147417	4	10.6	87	66.45

No	kebele	Customer Code	Latitude	Longitude	Family size	Annual average volume of water consumed (m^3)	Roof area (m^2)	Annual potential estimated harvested rainwater (m^3)
99		OC20-20232	8.5410167	39.26091833	5	12.8	50.1	38.27
100	kebele 09	OC09-9045	8.5351584	39.24936336	6	15.3	130	99.29
101		OC09-9049.01	8.5335308	39.2496041	4	12.1	109	83.25
102		OC09-9142	8.5181307	39.24636543	5	13.3	58.8	44.91
103		OC09-9146	8.5169591	39.24569081	3	7.6	68.9	52.63
104		OC09-9517.3.13	8.5333824	39.25954867	4	11.3	159	121.44
105		OC09-9018.02	8.5350628	39.2484037	5	12.9	145	110.75
106		OC09-9357.09	8.5314361	39.25788344	4	11.9	162	123.74
107		OC09-9276.5.2	8.5293557	39.25486788	2	5.3	69.3	52.93
108		OC09-9050.03	8.5340799	39.2496989	4	11	194	148.18
109		47774	8.5176611	39.24886686	3	6.9	60.8	46.44
110		1060	8.520262	39.25129229	5	13.6	40.9	31.24
111		OC09-9490.01	8.5380737	39.25858785	8	16.4	250	190.95
112		OC09-9517.002	8.534436	39.25993751	2	5.1	155	118.39
113	kebele 10	OC01-1091.01	8.5248886	39.26559733	4	11.1	108	82.49
114		OC03-3887	8.5231569	39.2645987	3	8.4	75.6	57.74
115		31676	8.5336546	39.26567203	6	13	140	106.93
116	kebele11	6462	8.5293655	39.27666645	4	11.5	194	148.18
117		OC13-13287	8.5416066	39.27665398	5	12.2	78	59.58
118		45599	8.534225	39.27631457	2	5.5	71.4	54.54
119		OC13-13334	8.5403859	39.27690252	8	14.9	119	90.89
120		OC11-112237	8.5382163	39.26987568	4	10.8	44.7	34.14
121		OC11-110048	8.5375048	39.27077875	7	13.3	151	115.33
122		OC11-110115	8.5340908	39.27110916	4	10.7	146	111.51
123		OC11-110088	8.5371793	39.27168927	5	13.1	68.7	52.47
124		OC11-110151	8.5296576	39.27206741	1	4	67.2	51.33

No	kebele	Customer Code	Latitude	Longitude	Family size	Annual average volume of water consumed (m^3)	Roof area (m^2)	Annual potential estimated harvested rainwater (m^3)
125		OC11-113084	8.5295989	39.2732128	3	7.6	71.7	54.76
126		OC11-112910	8.5400979	39.27338925	4	11.8	79.6	60.80
127		OC11-112873	8.5093178	39.28458994	4	11.3	60.4	46.13
128		OC11-111751	8.5322532	39.27778991	2	5.6	63.9	48.81
129		OC11-111174	8.5368906	39.2743325	2	4.2	41.4	31.62
130		23713	8.571943	39.2628892	3	9	117	89.36
131		OC11-111604	8.532128	39.27841927	5	12.8	101	77.14
132		OC11-111928	8.53507	39.282505	4	10.7	90.6	69.20
133		OC11-111196	8.5385648	39.27523322	5	12.4	74.5	56.90
134		OC11-111520	8.5366119	39.27696677	5	13.5	61.3	46.82
135		OC11-112055	8.5278235	39.27844634	4	10.2	69.9	53.39
136		OC11-113792	8.5364415	39.27979397	5	11.2	28.2	21.54
137	kebele 12	OC15-15305.1	8.5478871	39.27457397	5	12.2	88.3	67.44
138		OC15-15144.001	8.5464645	39.27378285	4	12.4	102	77.91
139		OC15-15459	8.5438153	39.27265977	3	7.1	66.2	50.56
140		OC15-15333	8.5444803	39.2733214	5	11.9	87.9	67.14
141	kebele 13	26611	8.5343322	39.28859741	5	11.7	43.7	33.38
142		26715	8.5334388	39.28841159	4	9.6	44.1	33.68
143		26246	8.5339587	39.28931492	2	6	66	50.41
144		41594	8.5316875	39.28048608	4	10	75.6	57.74
145		5632	8.5334608	39.2806875	4	12.5	135	103.11
146		26587	8.5353625	39.28069417	6	14	140	106.93
147		12225	8.5378939	39.28146576	10	16.9	118	90.13
148		18966	8.5311028	39.28149526	4	10.1	71.2	54.38
149		9394	8.5394343	39.28157858	9	17.4	188	143.59
150		OC13-13069.03	8.5381142	39.28647181	4	10.6	69.9	53.39

No	kebele	Customer Code	Latitude	Longitude	Family size	Annual average volume of water consumed (m^3)	Roof area (m^2)	Annual potential estimated harvested rainwater (m^3)
151		30671	8.5330029	39.28670495	3	7.3	36.6	27.96
152		OC13-13075.2	8.5382448	39.28724788	5	12.7	72.4	55.30
153		OC13-13007.006	8.5359169	39.29286031	4	12	36.3	27.73
154		OC13-13065.2.1	8.5392048	39.28468152	9	16.8	117	89.36
155		OC13-13022.2.3	8.5388791	39.28826208	3	7.9	141	107.70
156		OC13-13282	8.5420539	39.27641717	10	17.4	230	321.56
157		25149	8.5301151	39.29264609	4	10.6	60.4	46.13
158		18946	8.5340046	39.29658617	2	6.3	63.9	48.81
159		19668	8.5290085	39.30493771	5	13.1	41.4	31.62
160		OC13-13006.07.6	8.5329312	39.29664391	4	9.9	117	89.36
161		OC13-13021.3.10	8.5396106	39.28893329	5	12.7	101	77.14
162		OC13-13322	8.5407856	39.27808813	4	9.3	90.6	69.20
163	kebele 14	37933	8.5518966	39.29468879	3	6.8	91.5	69.89
164		6758	8.5631249	39.29920055	6	13.4	126	96.24
165		7446	8.5676997	39.29682479	7	13.9	153	116.86
166		OC14-14048.1	8.5458435	39.28571287	10	16.8	203	308.58
167		OC14-14293.0208	8.5438124	39.29121378	4	10.3	296	226.08
168		OC14-14025.09	8.5459758	39.28094483	3	7.5	103	78.67
169		OC14-14245	8.5409319	39.29208337	4	10.1	58.3	44.53
170		31662	8.551244	39.288613	4	12.5	122	93.18
171		18092	8.566387	39.2961266	9	16.3	147	112.28
172		13603	8.5668615	39.29810956	5	13.6	132	100.82
173		OC14-14114.001	8.5442081	39.28530574	4	9.7	74.6	56.98
174		33722	8.5671311	39.30046046	4	4.4	236	180.26
175		3472	8.5539391	39.29902601	5	12.2	151	115.33
176		12054	8.5650198	39.29889473	4	12.1	74.8	57.13

177		31662	8.551244	39.288613	7	13.6	107	81.73
178		OC14-14294.0267	8.5438756	39.29179776	2	4.9	51.7	39.49
179		OC14-14296.0625	8.5438819	39.2911348	3	7	59.6	45.52
180		OC14-14025.09	8.5459758	39.28094483	7	13.5	55	42.01
181		OC14-14032	8.5445644	39.28416379	5	12.6	33	25.21
182		38157	8.5714996	39.298492	5	13.4	47.1	35.97
183		OC14-14082.03	8.5451502	39.28980446	3	8.2	72	54.99
184		OC14-14114.001	8.5442081	39.28530574	5	11.9	59.7	45.60
185		OC14-14167.01	8.5437236	39.27978569	6	13.1	217	165.74
186	Dhaka Adi	OC02-2353.1	8.5767074	39.27920201	4	10.3	141	107.70
187		24135	8.5818274	39.28076308	7	15.6	140	106.93
188		57690	8.5777049	39.28615992	1	1.9	38.4	29.33
189		21923	8.58059	39.27488813	3	10.7	97.2	74.24
190	Melkaa Adaamaa	42912	8.5344973	39.23405919	5	13.3	47.2	36.05
191		43768	8.5185693	39.2307485	7	15.1	120	91.66
192		48578	8.5229823	39.23298643	3	7.3	31.5	24.06
193		48800	8.5229433	39.23666489	4	9.7	39.9	30.48
194		49420	8.5274279	39.23285314	2	5.3	34.3	26.20
195		49422	8.5257382	39.2327534	4	9.7	32.6	24.90
196		49482	8.5250706	39.23361031	4	10.8	48.7	37.20
197		53191	8.485539	39.24001665	6	13.4	90.2	68.89
198	Dabe Sollogee	53996	8.5449118	39.30627191	5	13.6	36	27.50
199		5766	8.5359215	39.30345396	4	11.9	65.1	49.72
200		7542	8.5444258	39.30561393	6	16.6	53.9	41.17
201	Boku Shana	OC10-10999.1057	8.5131309	39.25172107	1	3.8	77.3	59.04
202		43226	8.4905248	39.28972621	5	13.7	141	107.70
203		43092	8.4968474	39.2868689	3	8.6	73.7	56.29

Annex 2: Correlation "r"

$$\bar{x} = 5.5,\ \bar{y} = 0.4,\ SD_x = 3.03,\ SD_y = 0.15$$

X	Y	Z_X	Z_Y	Z_XZ_Y
1	0.15	-1.49	-1.64	2.43
2	0.19	-1.16	-1.38	1.60
3	0.26	-0.83	-0.87	0.72
4	0.36	-0.50	-0.27	0.13
5	0.43	-0.17	0.18	-0.03
6	0.47	0.17	0.43	0.07
7	0.47	0.50	0.49	0.24
8	0.53	0.83	0.86	0.71
9	0.56	1.16	1.07	1.24
10	0.57	1.49	1.11	1.65
Avg. Z_XZ_Y, r =0.88				

X: household size, Y: volume of water consumption

Formula: 8

$$z_{x_i} = \frac{(x_i - \bar{x})}{SD_x} \qquad z_{y_i} = \frac{(y_i - \bar{y})}{SD_y}$$

$R^2 = 0.77$

Annex 3: Linear Regression Equation

NO	X	Y	XY	X^2	Y^2
1	1	0.15	0.15	1	0.02
2	2	0.19	0.37	4	0.03
3	3	0.26	0.79	3	0.07
4	4	0.36	1.43	16	0.13
5	5	0.43	2.13	25	0.18
6	6	0.47	2.80	36	0.22
7	7	0.47	3.31	49	0.22
8	8	0.53	4.23	64	0.28
9	9	0.56	5.06	81	0.32
10	10	0.57	5.68	100	0.32
Total	55	3.98	25.93	385	1.79

Formula: 9

$$\mathbf{a} = \frac{(\sum \boldsymbol{y})(\sum \boldsymbol{x^2}) - (\sum \boldsymbol{x})(\sum \boldsymbol{xy})}{\boldsymbol{n}(\sum \boldsymbol{x^2}) - (\sum \boldsymbol{x})^2} \qquad \mathbf{b} = \frac{\boldsymbol{n}(\sum \boldsymbol{xy}) - (\sum \boldsymbol{x})(\sum \boldsymbol{y})}{\boldsymbol{n}(\sum \boldsymbol{x^2}) - (\sum \boldsymbol{x})^2}$$

a = 0.13 b = 0.05

y = a + bx

y = 0.13 + 0.05X

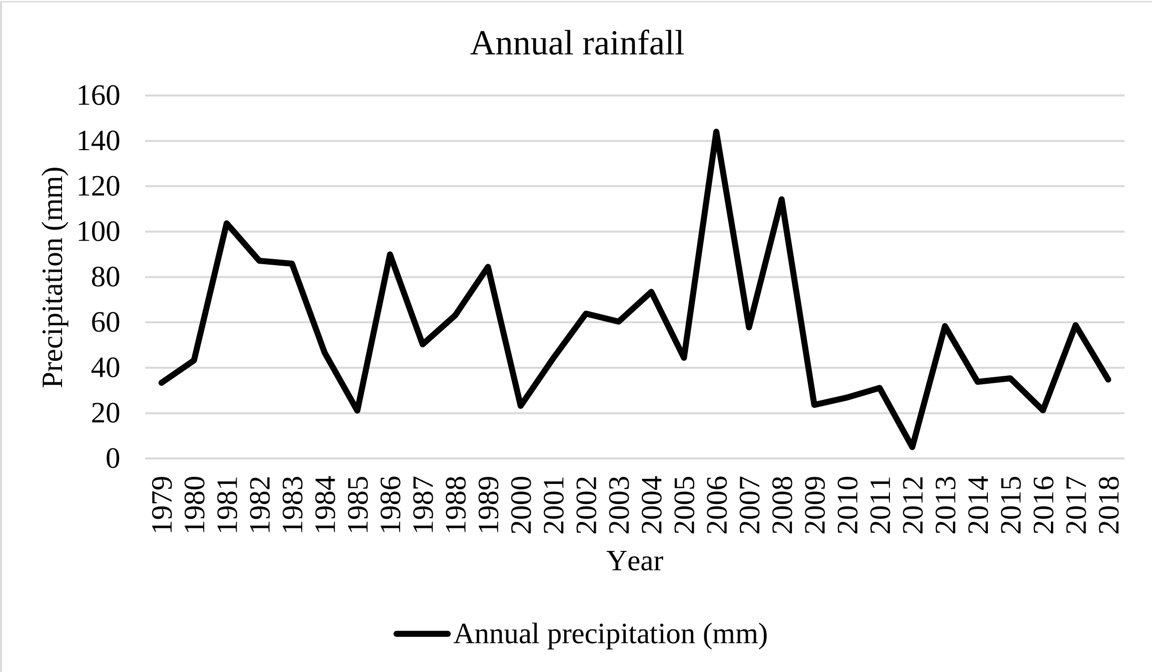
Annex 4: Annual rainfall and average monthly and annual rainfall in mm

The weather station is located at 39.375 longitudes, 8.586 latitudes, and 151 elevations.

Using the Arithmetic mean method;

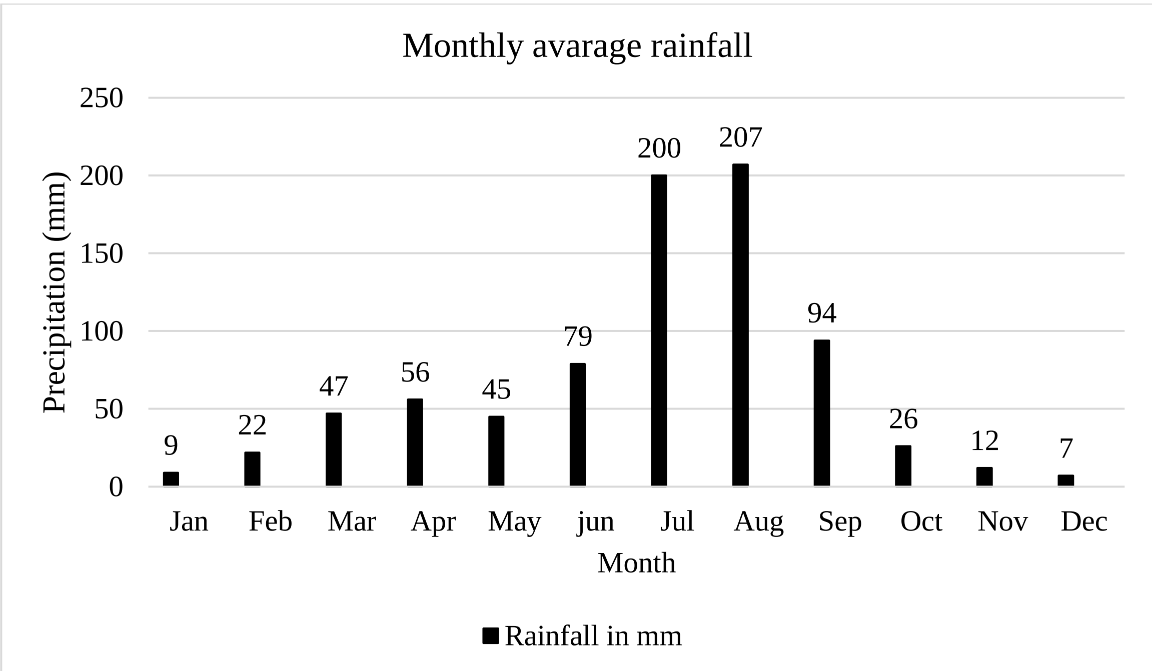
Average annual rainfall = total annual rainfall/period (30 years)

Average annual rainfall = 804



Annual rainfall in mm

July, August, and September are the wettest months of the year. December is the month with the lowest rainfall.



Average monthly rainfall in mm

Annex 5: per capita water supply calculation

From the total daily production of water 63% (19,971 m^3/d) supplied to residences. The per capita water supply (l/c/d) calculated for 410,738 population as:

Formula 10:

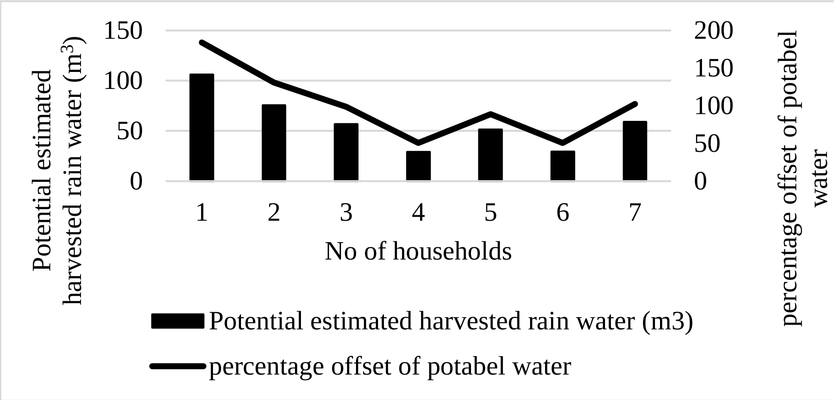
$$\frac{daily\ production\ (m^3)\ \times 1000l/\ m^3}{population\ number}$$

Annex 6: Adama city current water tariff

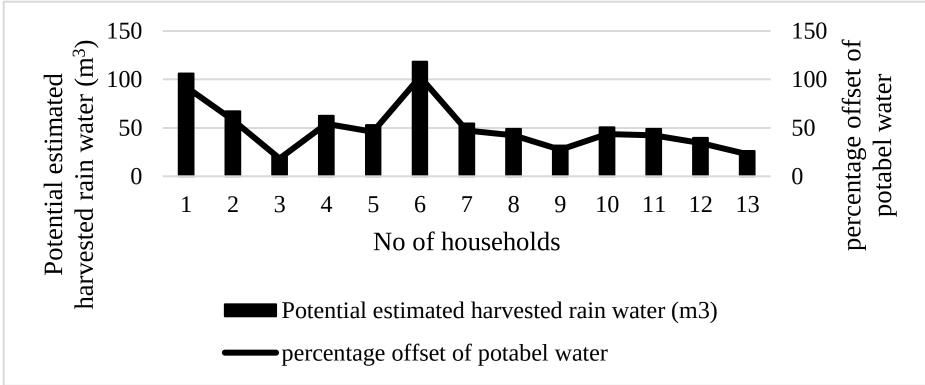
Water tariff		
Block	Range	Birr/ m^3
1^{st}	0-5 m^3	6.85
2^{nd}	6-10 m^3	7.80
3^{rd}	11-15 m^3	10.70
4^{th}	16-20 m^3	11.95
5^{th}	>20 m^3	13.45

(Source: Adama water supply, sanitation, and sewerage enterprise)

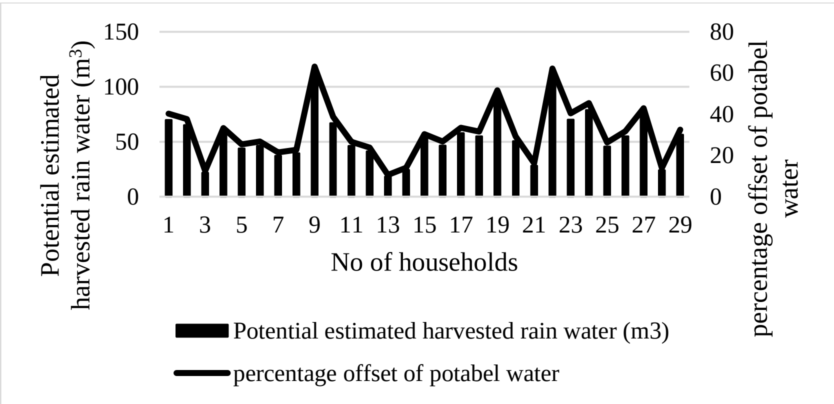
Annex 7: correlation between potential estimated harvested rainwater and percentage offset for non-potable water use with family size



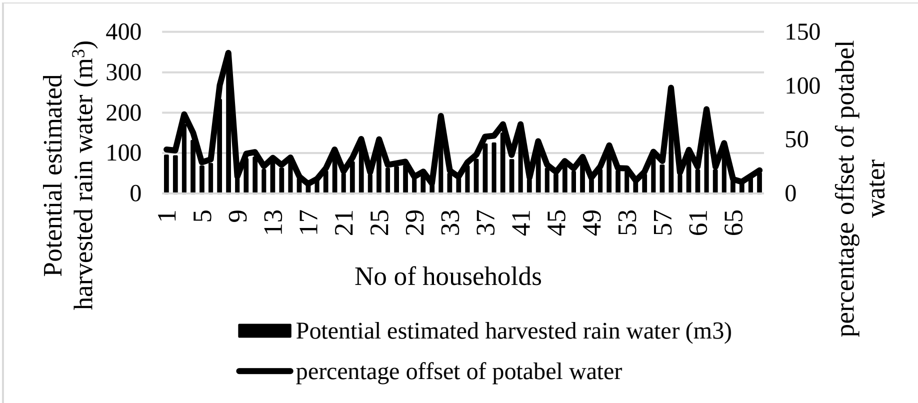
(a) One family households



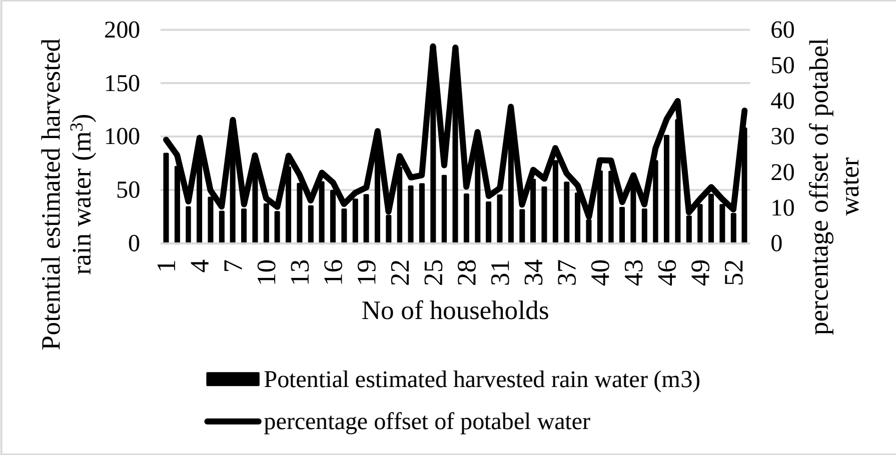
(b) Two family households



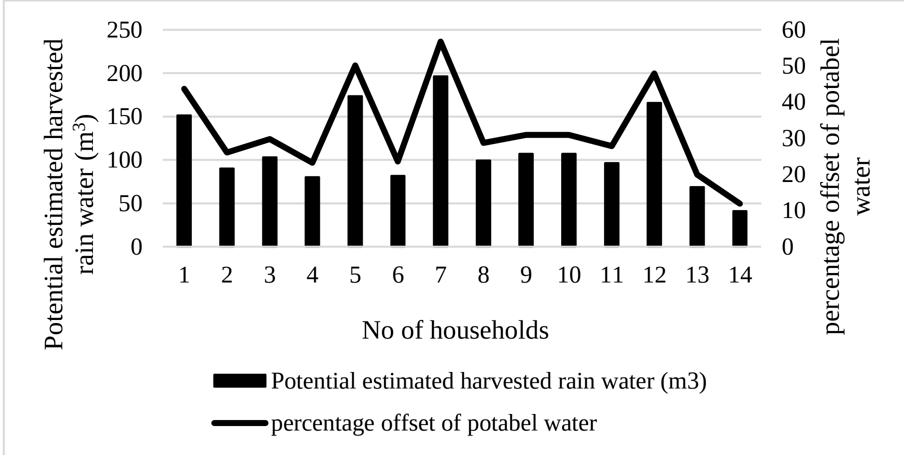
(c) Three family households



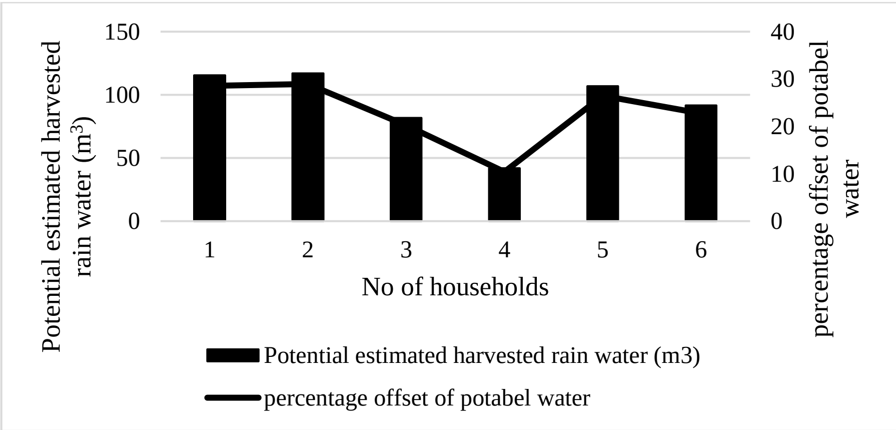
(d) Four family households



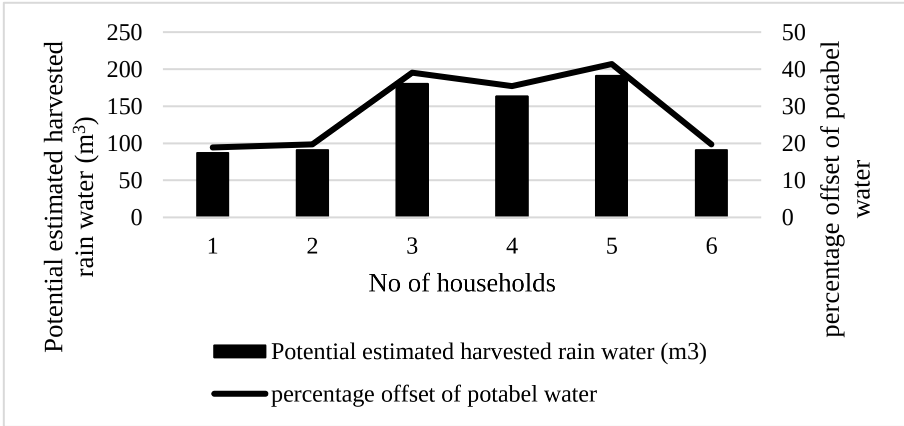
(e) Five family households



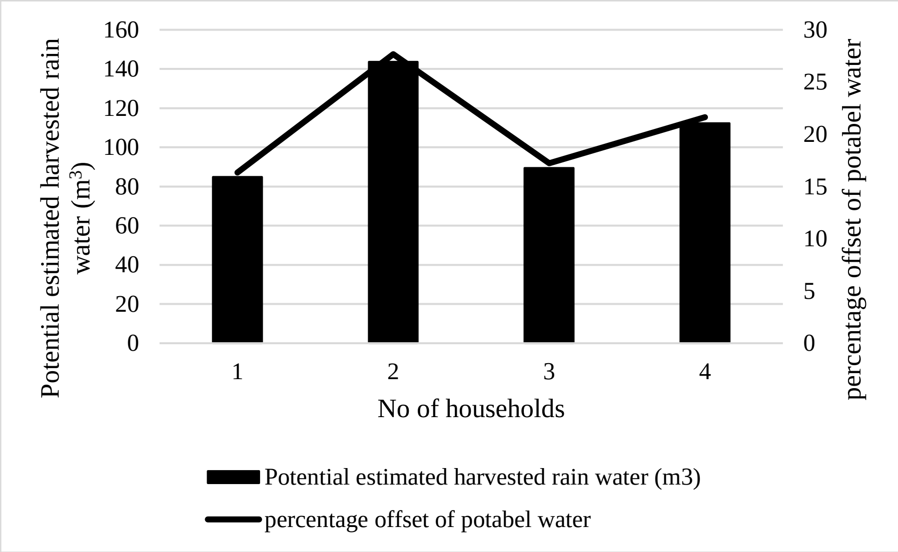
(f) Six family households



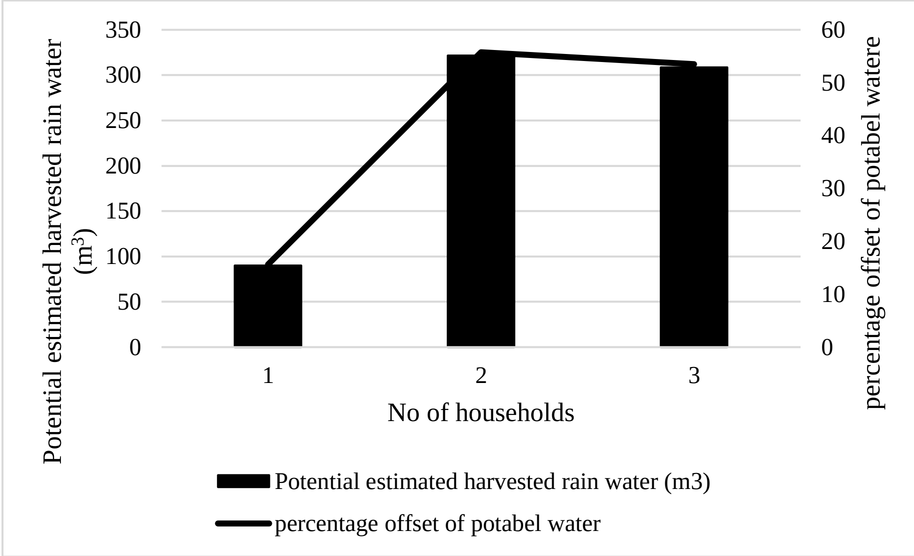
(g) Seven family households



(h) Eight family households



(I) Nine family households



(j) Ten family households