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Assessing Rainwater Harvesting as an Alternative Source of Non-Domestic Water Supply: Case Study at Jemo-1 Condominium

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Abstract

Water supply systems in Addis Ababa provide service to approximately 55% of the demand. Simple mechanisms that address urgent problems had to be used to supply citizens with water. Rainwater harvesting (RWH) systems have been in use since ancient times, and these days its use is increasing. Rainwater catchment systems are simple solutions that can be adopted in many parts of the city; many houses are already equipped with storage tanks and catching rainwater would require only a basic catchment system and make the most from the natural resources available.

Rainwater harvesting is one option worth analyzing for Jemo-1 condominium site. The total area of the study catchment is 111,030 m^2 which is composed of 333 blocks (the total area of 1 block is 290 m^2) and 50 communal (the total area of 1 communal is 266 m^2). From this 107,442 m^3 of water will be collected in a year but this will satisfy only 18.45 % of the total non-domestic water demand.

In this study, household scale rainwater catchment systems were analyzed, where water can be channeled through pipes installed on each building roofs. The pipes transport water to aboveground reservoirs. Precipitation data for Jemo-1 was used to determine the amount of water that can be collected. In the end, all aspects were analyzed to determine whether this could be a solution worth implementing in Jemo-1 to alleviate water scarcity problems as well as the possible positive and negative impacts it would have on the economy, society and the environment. It has also been tried to design the RWH components based on design criteria. Based on the design and analyses performed, it becomes clear that rainwater harvesting is not the only solution that will solve all water scarcity issues in Jemo-1. Storage tanks need to be much larger, precipitation has to be more abundant, roofs need to have a bigger area and tanks need to be cheaper for it to be the major source of water supply in the area.

Key Words: Rainwater Harvesting, Jemo-1, Catchment, Non-Domestic Demand, Daily Per Capita Demand, Observatory Station

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Acronyms

AALIS-Addis Ababa Land Information Center

AAWSA-Addis Ababa Water and Sewerage Authority

CIS- Corrugated Iron Sheet

ITCZ-Inter Tropical Convergence Zone

Km^2 - Square km

Lpcd-liter per capita per day

m.a.s.l - meter above sea level

NMA-National Meteorological Agency

PVC-polyvinyl chloride

RWH-Rainwater Harvesting

UNEP-United Nations Environmental Proclamation

WHO-World Health Organizations

Table of Contents

List of Tables

List of Figures

1. INTRODUCTION

1.1 Background

Water is very important renewable natural resource and it is available in many areas of the world. But fresh water is scarce because of unplanned withdrawal of waters from rivers and underground aquifers causing severe environmental problems like arsenic contamination.

In many countries, the amount of water being consumed has exceeded the annual amount of renewal creating a non sustainable situation (Choudhury & Vasudevan, 2003).

During heavy rainfall, if the drainage system is not properly designed it will leads to accumulated flooding in urban areas.

Water sustains life and life support processes. The amount of water available for each person will continue to decrease as the world's population expands. Unfortunately our present and future water supplies in many parts of the world are being degraded by pollution from domestic waste water, solid waste, industrial effluent and agricultural drainage to mention a few. As natural waters become more polluted, less water is available to fulfill the demands and the needs of the natural environment.

Every year, approximately 25 million people die either by drinking polluted water or because they do not have enough water to meet their daily needs. A single person needs at least half a liter per day to meet basic survival needs and two liters per day to avoid thirst. Some 27 to 110 liters are needed per person per day for drinking, sanitation, bathing and cooking (UNEP, 2009).

Household water needs vary depending on the type of dwelling, number of residents and type of plumbing fixtures. Traditional sources of water to meet our needs typically include surface waters (rivers and lakes), groundwater (water stored below-ground in aquifers) and rainwater.

Direct capture, storage and use of rainwater, called Rainwater Harvesting (RWH) is the oldest method of securing water, having been practiced by ancient civilizations for more than 4,000 years. This technique continues to be an important means of supplying water in many communities, especially those located far away from municipal potable water supplies and in areas the number of population and the availability of water is not proportion.

RWH continues to be among the most simple and low-cost means of water supply, employing technologies that are generally easy to install and maintain.

Addis Ababa, the capital city of Ethiopia, is one of the largest urban centers in sub Saharan Africa. It is located between 8° 49' 56" and 9° 5' 54" North latitude and between 38° 38'17" and 38° 54' 20" East Longitudes. The city covers an area of approximately 52,000 hectare of land with an altitudinal zone ranging from 2,054 to 3,023 meter above sea level. It is situated in the foothills of the 3000 meters Entoto Mountains and rambles pleasantly across many wooded hillsides and gullies cut through with fast flowing streams (AALIC, 2014).

The aim of this study is to assess an alternative solution for the shortage of water in the Jemo-1 condominium site and to evaluate how much percentage of non-domestic water demand can meet from RWH system.

1.2 Problem Identification

In Addis Ababa water sources for public and domestic use varies from place to place. Presently the city faces a serious deficit in the water supply due to increased population and changing of lifestyle. Addis Ababa Water and Sewerage Authority is the only organization responsible for the distribution of water for the city.

The city has started getting water supply in 1901. During the years between 1942 and 2010 many water supply projects have been implemented that the construction and upgrading of Legedadi dam and treatment plant, improvement of the distribution, groundwater and spring (wells) development of among them (AAWSA, 2004).

In 2020 the total municipal water demand rises to 978,231.0 m^3/d in the city. The domestic demand (DD) alone requires 575,430.0 m^3/d municipal water. The non-domestic demand (NDD) and Unaccounted for Water needs go up to 230,172.0 m^3/d and 172,629.0 m^3/d respectively within the next five years from today. (Addis Ababa Alternative Water source Study & Design Project Draft Inception Report). The water production capacity of AAWSA increases to 725,159.0 m^3/d both from completed and on-going projects. This will allow the Authority to cater for 74.13 % of the total municipal demand in 2020. (Addis Ababa Alternative Water source Study & Design Project Draft Inception Report). At this stage of the project, we have clearly understood that the use of water from the municipal water supply system for non-domestic purposes has aggravated the situation of water shortage and the problems of water distribution in the various service areas of the city. In addition, the future water production from completed and on-going water supply projects definitely will not be adequate even to satisfy the domestic, unaccounted for water demands and part of the non-domestic demand requiring drinkable water quality in the city. (Addis Ababa Alternative Water source Study & Design Project Draft Inception Report).

Addis Ababa Water and Sewerage Authority has planned to cover the gap between the demand and the production of water by finding alternative sources of water for non-domestic water supply.

AAWSA's Proposed Alternative Water Sources are: River flowing across the city and in the proximity of the city's boundary, abandoned groundwater wells, Effluent from publicly owned sewage treatment plants (POSTP), and Rainwater harvesting.

Jemo-1 site is one of the biggest condominium sites with a serious of water problems. The last 3 years water consumption reports from AAWSA Mekanisa branch office shows that the average per capita water consumption of the residents is about 15 l/c/d. this number shows that the water consumption of the people is much less than the required water demand.

The main sources of water for the condominium site is being extracted predominantly from different water wells found near the site. This is practiced by the Addis Ababa Water and Sewerage Authority (AAWSA) and is not very sustainable because it cannot meet the demands for the growing population and some Boreholes have dried up. It is for this reason that the condominium site constantly having no water specially third and fourth floors.

Residents of the condominium site are facing a big challenge due to water shortage problem to run their daily life. If no water no life exists. Therefore looking for an alternative ways of supporting the municipal water supply as well as solving the problem of flood (as storm water management) in the site Rainwater Harvesting can be considered as an essential alternative solution to overcome this problem.

1.3 Objectives of the research

1.3.1 General Objectives

Due to the above stated problems; scarcities of water for both domestic and non-domestic uses, the research objective of this study has focused on the following general objective.

To investigate the feasibility of providing water for non-domestic uses by applying rainwater harvesting system for Jemo-1 condominium site.

1.3.2 Specific Objectives

- To provide an overview of the RWH-technology
- To indentify the main challenges on the promotion of RWH projects
- To assess the alternative methods being used to collect water in the research area.
- To investigate the possibility of providing rainwater collection system at the research site for non-domestic use.

This study is focused on analyzing rainwater catchment specifically the Jemo-1 condominium site.

1.4 Assumptions

- No environmental or any form of contamination other than those from the catchment area will be present in the harvested rainwater.
- The rainwater harvesting method is socially accepted in the study area.
- The per capita Non-Domestic water consumption is assumed to be 40 lpcd.
- Average home accommodates 4 peoples.

1.5 Definitions

- **Catchment Area**

Catchment area is the net roof surface, in square feet/square meters, from which rainwater is collected

- **Cistern/Storage Tank**

A cistern or a storage tank is a receptacle built to catch and store rainwater. They range in capacity from a few liters to thousands of cubic meters. Cisterns are usually built underground

- **First Flush**

First flush is the first part of the rainwater runoff after a dry period, which contains higher concentration of contaminants than a subsequent flush

- **Gutters**

Gutters are channels fixed to the edges of roof all around to collect and transport rainwater from the roof to the storage tank.

- **Down pipes**

Down pipe is the pipe, which carries the rainwater from the gutters to the storage tank.

- **Runoff Coefficient:**

Runoff coefficient is the factor which accounts for the fact that all the rainfall dropping on a catchment cannot be collected. Some rainfall will be lost from the catchment by evaporation and retention on the surface itself. In other words it is the ratio of runoff to rainfall.

- **Potable Water:**

Potable water is the water of sufficient quality which is fit for human consumption

- **Municipal**

Of or relating to a town or city or its local government

1.6 Description of the Study Area

1.6.1 General

Addis Ababa is the capital and largest city of Ethiopia. The site for Addis Ababa was chosen by Empress Taytu Betul and the city was founded in 1886 by emperor Menelik II, as initially a king of Shewa province. Atse Menelik and his wife decided to move the palace from Ankober to the present Addis Ababa at Entoto Mountain. The place had strategic importance to the then king of Ethiopia and his empire. The king and his wife were also astonished and attracted by the beauty of the virgin land of the area. The land was originally endowed with abundant natural resources. However, the king and his wife lost their interest to grow the capital city at the freezing mountains of Entoto perpetually. The original place was not a comfortable place to welcome guests in the palace because of its freezing weather. Finally, Itege Taitu re-located and founded Addis Ababa as the capital city of Ethiopia in the present palace area where the Finfine hot springs added a natural pleasure to the local people and strangers visiting the capital.

Addis Ababa has the status of both a city and a state. It is where the African Union is and its predecessor the OAU was based. It also hosts the headquarters of the United Nations Economic Commission for Africa (ECA) and numerous other continental and international organizations. Addis Ababa is therefore often referred to as “the political capital of Africa “due to its historical, diplomatic and political significance for the continent.

Addis Ababa in its present location was covered and surrounded by the abundant natural resources that existed from the most elevated grounds of mount Entoto with altitudes exceeding 3000 m.a.s.l to the low lying Southern parts of the city where the Akaki and Kality areas exists with ground elevations reduced to 2300 m.a.s.l. Addis Ababa has a subtropical highland climate. The city has a complex mix of highland climate zones, with temperature difference of up to $10^{o}C$, depending on elevation and prevailing wind patterns.

The city has shown dramatic increase in area from 240 Km^2 to about 540 Km^2. According to the 2007 population census, it has a population of 3,384,569 with annual growth rate of 3.8 % out of which the male population accounts for 1,624,593 (48%) and the female population of 1,759,976 (52%). The average household size is about 4.1 persons.

In the present development context, the city is divided in to ten (10) boroughs, called sub cities and 116 woredas. The rainfall formation and distribution in these areas of Addis Ababa is highly influenced by the Inter-Tropical Convergence Zone (ITCZ). The temperature is constant throughout the year between 20 ^{o}C and 25 ^{o}C during daytime and between $7^{o}C$ and 11 ^{o}C during the night.

Jemo-1 condominium site shown on Figure 2 below is one of the biggest condominium site built by Addis Ababa house development agency, found in the south western part of Addis Ababa city which is in Nifas Silk Lafto sub-city, woreda 01 and it is among the big sites in which water demand and flood problems are evident from residents reflection. The site has about 337-blocks and 50 communal holding 9,800 houses those serve about 42,140 population (AALIC, 2014).

Addis Ababa Water and Sewerage Authority (AAWSA) is a public institution in the city that is responsible for the supply of potable water and collection, treatment and disposal of sludge for the city. The authority tries to fill the water demand-supply gap from all sources of water.

The main source of water for the site comes from different boreholes found near the site namely (site 1, site 20, site 24, site 25, site 26 and site 28) but, that is not enough to meet the daily water demand of the people due to the rapid population growth and some of the boreholes are not functional.

The project area experiences two annual rainfall seasons. The main season (locally known as Kiremt) mostly extends from end of June through end of September. And, the small rainy season (known as Meher) occurs from end of February to middle of May. The rest of the months are generally dry and sometime experience sporadic rainfall. The annual average rainfall of the area is 1209.6 mm.

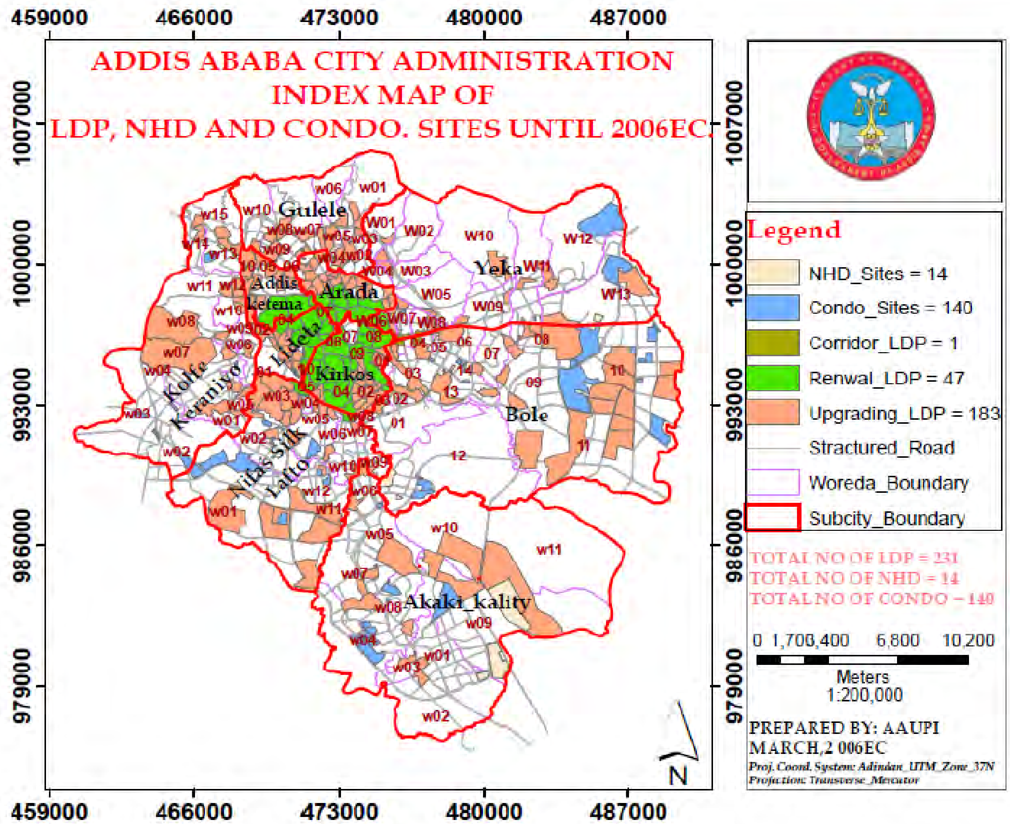

Figure 1: Index Map Showing Administrative Boundaries of the Sub Cities (Source: AAUPI)

Figure 2: Location of Jemo-1 Condominium Site (Source: Google Earth)

1.7 Research Questions

The objective of this study is to investigate the feasibility of providing water by applying rainwater harvesting system for non-domestic purposes. To meet this objective, it is first necessary to answer the following research questions:

- Is rainwater harvesting a sustainable solution for the condominium site to meet their non-domestic water demand?
- What are the benefits and limitations of rainwater harvesting?
- Will rainwater harvesting be environmentally and socially acceptable?
- What is the water supply service level to the people from the rainwater harvesting project in terms of quantity and accessibility?

1.8 Significance of the Study

The findings of this study serve as the basis for further improvement of rainwater harvesting systems in Addis Ababa condominium sites in general and the study area in particular.

Therefore, the outcomes of the study can serve as a guide to any person or organization involved in planning and designing of water related projects in which rainwater harvesting is under consideration.

1.9 Scope and limitations of the study

- ❖ Rainwater harvesting systems are completely dependent upon the frequency and amount of rainfall. There will be shortages during dry spells or prolonged droughts, which can be exacerbated by low storage capacities. If greater storage capacities are provided, the additional construction and operation costs may be expensive.
- ❖ This study covered only one condominium site, conclusion and recommendations based on the findings might be difficult to generalize for the larger context.
- ❖ Quantity of water used for non-domestic purposes i.e. liters per capita per day (lpcd) taken in to account to analyze water supply service level of households is based on assumptions.
- ❖ This study doesn’t make comparisons between rainwater harvesting and other alternatives such as River flowing across the city and in the proximity of the city’s boundary and abandoned groundwater wells.
- ❖ This study didn’t consider cost benefit analysis

1.10 Organization of the Project

This study contains five chapters. Chapter one deals with introduction, that covers the general background of the study area, objectives of the project, problem identifications. Chapter two incorporates literature review part. Chapter three comprises methodology part that includes: background of the study area, data collection, and the research process. Chapter four discuss about results and discussions in which Precipitation Results, water demand, design of storage tanks, sizing of gutters and downpipes were analyzed. Chapter five deals with conclusion and recommendations. Finally, chapter six contains the reference materials.

2. LITERATURE REVIEW

2.1 Historical background

The history of rainwater harvesting in Ethiopia dated back as early as the pre Axumite period (560 BC). It was a time when rainwater was harvested and stored in ponds for agricultural and water supply purposes. Anthropologist has documented evidences of the remains of ponds that were once used for irrigation during this period (Fattovich, 1990).

Other evidences include the remains of one of the old castles in Gonder (Fasiludus), constructed in the 15-16th century, which used to have water harvesting set up and pool that was used for religious rituals by the king (Getachew,1999).

Rainwater harvesting is a common practice in the countries and areas where the annual precipitation is high and pure drinking and usable water is scarce. All over the world, economical condition has prompted the low-income groups to harvest the rainwater for household and essential uses. Several countries of the world in different regions have showed the popularity of this method. Originated almost 5000 years ago in Iraq, rainwater harvesting is practiced throughout the Middle East, the Indian subcontinent, in Mexico, Africa as well as in Australia and United States. As the population of the world increased, irrigation, the most water consuming human activity, as well as domestic water usage increased, leading to a consequence of crisis of water supply in different regions. Among other available alternative sources for water supply, rainwater harvesting has become the most economic solution for the water crisis (Sultan, 2007).

Rainwater harvesting measures in Sumida city were first initiated in 1982 when the utilization of rainwater was proposed to the Japan Sumo Association in the Kokugikan (Sumo stadium) in Tokyo.

Rainwater utilization systems were introduced into Tokyo sky tree which is the highest broad casting tower in the world, of which height is 634m for flood control, water conservation and securing emergency water in May 2012. That is, rainwater falling on the roof of the two observation sites which are set up at 350 m and 450 m of Tokyo sky tree with neighboring buildings is collected into the basement tank of which capacity is 2650 ton, used for flushing toilets and watering green roofs and emergency water. At now, there are more than 1000 buildings which have installed in Tokyo. (Dr. Makoto Murase, 2013).

2.2 General

Rainwater harvesting can be defined as the capture of rainwater before it reached the ground and its storage on tanks for its use. It is the interception of rainwater that would otherwise end up in surface or groundwater. Rainwater catchment can be done at a domestic level for household uses, industrially for use in factories or at an agricultural level for irrigation purposes. For each of these types of uses, water can be stored differently; however, the way it is collected is always the same, sometimes rainwater is even used for groundwater recharge.

There are numerous reasons to implement RWH including desired to reduce storm water runoff, desire to avoid extending water distribution systems to rural areas, relative cost compared to developing new water supplies and quality of rainwater compared to existing water source. (Mark A. Jensen, 2008).

RWH systems can be categorized in to two groups based on type of catchment surface and uses. According to catchment type, RWH could be roof catchments, rock catchments, ground catchment and according to use check and sand dams. Roof and rock catchment systems could be directly used for domestic purposes with little effort exerted on improving water quality while ground and check or sand dams could be used for livestock watering, nurseries and small-scale irrigation and some domestic purposes.

RWH system provides an innovation solution to meet local water needs. In recent years, the system has become cheaper and more predictable in the performance.RWH systems deliver good quality water directly or at every shorter distance to the targeted community. This qualifies it to be one of the options of water supply via reducing burden of water caring particularly for women and female children who are traditionally believed to be responsible.

Moreover, RWH is not limited as mean for provision of water supply rather it is more importantly practiced in the developing countries as supplementary water sources during long dry spells for food production i.e. vegetables and subsistence crop production (Lakew, 2004). A number of researches have been carried out in the world to improve the technology of RWH techniques to be affordable to the community, sustainable and safe source of water supply. Subsequent sections shall discuss the definition and Principles, benefits, components, overviews of Global and national RWH experiences.

2.3 Definitions of RWH

Different authors define RWH as follows:

Water harvesting in its broadest sense can be defined as the "collection of runoff for its productive use”. Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral watercourses. Water harvesting techniques, which harvest runoff from roofs or ground surfaces fall under the term ‘Rainwater Harvesting’ while all systems which collect discharges from watercourses are grouped under the term ‘Floodwater Harvesting’ (African development bank 2007, rainwater harvesting handbook).

Rainwater harvesting can be defined as activity of direct collection of rainwater and storage of rainwater as well as other activities aimed at harvesting and conserving surface and groundwater, prevention of loss through evaporation and seepage and other hydrological studies and engineering inventions aiming at most efficient utilization of rainwater towards best use for the humanity (Er. Krishan Kumar 2002, rainwater harvesting and conservation manual).

Rainwater harvesting is the capture, diversion and storage of rainwater for a number of different purposes including landscape irrigation, drinking and domestic use, aquifer recharge, and storm water abatement (Texas water development board 2005, The Texas manual on rainwater harvesting).

RWH is the collection of water that could be otherwise have gone down the drainage system, into the ground or been lost to the atmosphere through evaporation (UK Environmental Agency, 2007)

A system of RWH by which Roofs are an obvious choice of a catchment surface (as their elevation protects them from contamination and damage) to harvest the natural endowed rainfall and store for pre-specified domestic purposes (T. H. Thomas, 2003)

2.4 Requirements for Rainwater Harvesting

For rainwater harvesting to be viable there are a number of environmental requirements:-

- Rainfall should be over 50mm/month for at least half of the year (unless other sources are extremely scarce). (WHO, Male, Maldives, 2009)
- Local roofs should be made from impermeable materials such as iron sheets or tiles.

- There should be an area of at least 1m2 near each house upon which a tank can be constructed
- There should be some other water source, either groundwater or (for secondary uses) surface water that can be used when the stored rainwater runs out.

2.5 Advantages and Disadvantages of Rainwater Harvesting

Advantages

- Relatively cheap materials can be used for construction of containers and collecting surfaces
- An available natural resource that should not simply wasted;
- Construction methods are relatively simple;
- Low maintenance costs and requirements;
- Collected rainwater can be consumed without treatment, if a clean collecting surface has been used;
- Provides supply of safe water close to homes, schools or clinics, encourages increased consumption, reduces the time women and children spend collecting water, reduces back strain or injuries from carrying heavy water containers;
- The quality of rainwater is high, especially in developing country (where the level of industrialization is very low and the occurrence of acidic rain is minimal);
- No energy costs are needed to run the system;

Disadvantages

- Supplies can be contaminated by bird/animal droppings on catchment surfaces and guttering structures unless they are cleaned/flushed before use
- The amount of water harvested is limited by rainfall amount and available Roof area or size and quality. Supplementary water sources may be needed; for long dry seasons, the required storage volume may be too high/ expensive;

2.6 Rainwater Quality and Health

Rainwater is often used for drinking and cooking and so it is vital that the highest possible standards are met. Unfortunately, often rainwater does not meet the World Health Organization (WHO) water quality guidelines. This does not mean that the water is unsafe to drinking. Generally the chemical quality of rainwater may fall within the WHO guidelines and rarely presents problem. There are different issues when looking at the quality and health aspects of RWH: There is the issue of bacteriological water quality. Rainwater can become contaminated by faeces entering the tank from the catchment area. It is advised that the catchment surface to be always kept clean. Rainwater tanks should be designed to protect the water from contamination by leaves, dust, insects, vermin, and other industrial or agricultural pollutants.

Tanks should be located away from trees, with good fitting lids and kept in good condition. Incoming water should be filtered or screened, or allowed to settle to take out foreign matter. Water which is relatively clean on entry to the tank will usually improve in quality if allowed to settle for some time inside the tank. Algae will grow inside a tank if sufficient sunlight is available for photosynthesis. Keeping a tank dark and located in a shady spot will prevent algal growth and also keep the water cool. (WHO, Male, Maldives, 2009)

There is also a number of ways of diverting the dirty water 'first flush' away from the storage tank. The area surrounding a RWH should be kept in good sanitary condition, fenced off to prevent animals fouling the area or children playing around the tank. Any pools of water gathering around the tank should be drained and filled. (WHO, Male, Maldives, 2009)

2.7 Conceptual Frame work

The basic source of all water on the earth is rainfall/precipitation, snow etc. about 70 Percent of the precipitation that reach on the land area is evaporated or transpired directly back to the atmosphere; 10 Percent socks in and becomes groundwater, and 20 Percent runs off in to lake streams and rivers (B. C. Punmia, J. Ashok, J. Arun (1995).

Thus using RWH system we can use the rainwater/rainfall before any of the losses mentioned in the above paragraph and avoid the difficult to regain it back by investing huge amount of money for pumping, construction of Dams or reservoirs, construction of purifications or treatment plants and convey the stored water from head works to each house through various pipes size and length etc. Figure below shows the main forms of rural water supply (T. H. Thomas, 2003).

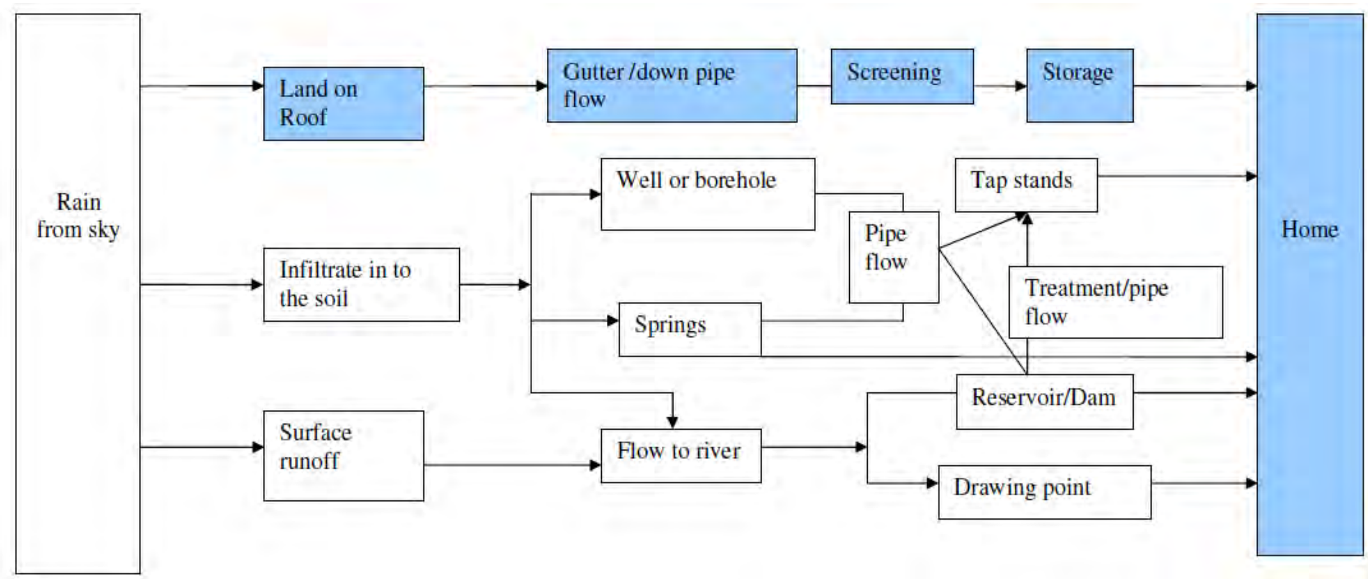

Figure 3: Model Rainwater Harvesting System (T.H Thomas, 2003)

2.8 factors determining the feasibility of rainwater harvesting

Feasibility is defined as something that is practicable or achievable. A series of interlinked factors determine the feasibility of rainwater harvesting. Rainwater harvesting becomes viable when the following factors become acceptable together and also separately:

a) Water availability:

The initial consideration of the feasibility of RWH concentrates on availability or depth of Rainfall as compared to its use or demand. The yield or supply of water depends on how much depth of rainfall the area received under normal and worst condition or the dependable Average annual rainfall of the area. As per the NMSA of Ethiopia the country is divided in to four (4) regions based on rainfall types. They are (i) Region B: mono modal type-1 (ii) Region D: Mono modal type-2 (iii) Region A: Bimodal type-1; and (iv) Region C: Bimodal type-2 (NMSA, 1996).

When the rainfall occurs in one continuous period of time in a year, this is termed as mono modal and when this occurs in two discontinuous periods in a year, this is termed as bimodal. Again, each of these are divided in to type1 or 2 based on the time of occurrence of the continuous period/s or by the prominence of rainy period.

Mono modal type-1: Dominates by a single maxima rainfall pattern

Mono modal type-2 /Diffused pattern/: Irregular rainfall pattern (does not have well defined rainfall pattern

Bimodal type-1: Characterized by quasi-double maximum peak in August

Bimodal type-2: Dominates by double maxima rainfall pattern with peak during April and October

In a more comprehensive manner the Ethiopia climate seasons could be classified in three seasons. These are given as Bega; which is generally the dry season that covers the period from October to January, Belg: Refer to a small rain season that covers the period from mid- February to mid-May and Kiremt: Refer to the main rainy season that cover the period from June to September. About 50 to 90 Percent of the main annual rainfall occurs in Kiremet season over the principal cropping Zone. In Bega season, the rainfall varies between 10 to 400 mm; this is about 25 to 600 mm in Belg season and about 10 to 1200 mm in Kiremt season (NMSA, 1996).

The average annual rainfall of the study area, Jemo-1 condominium site is about 1209.6 mm.

b) Acceptability:

Use of rainwater harvesting for drinking and other purposes has to be culturally accepted by the users. The positive impacts, i.e. the benefits, that the rainwater harvesting system brings to the community influences the level of acceptability towards the RWH system. The users are able to give expression to how valuable rainwater harvesting is to them. An analysis of the benefits that rainwater harvesting offers to the users will help to determine whether the amount of water collected makes a difference.

c) Cost of the system:

The cost of installing a rainwater harvesting system should not be substantially higher than other water supply options suitable at the area of study.

d) Water quality:

Quality of rainwater should be safe for human consumption. Operation and maintenance needs to be done properly to ensure good quality water.

2.9 Volume of Rainwater

The volume of water that can be harvested, thus tank size required, can be estimated by the product of roof area and precipitation:

$$V=A*P$$

Where:

V is the volume of water that can be captured from precipitation on rooftops, which will be available for reuse.

A is the area of the rooftops

P is the depth of precipitation in the area being considered for the technology to be applied.

Flow (Q) can be multiplied by 0.80, assuming an efficiency of 80 % if we consider 20 % of the water can be lost due to evaporation and runoff (Efficiency will depend on roof material).

2.10 Parts of Rainwater Harvesting System

2.10.1 Basic Components

Regardless of the complexity of the system, the domestic rainwater harvesting system comprises six basic components:

A. **Catchment Area/Roof:** the surface upon which the rain drops;

B. **Gutters and Downpipes:** the transport channels from catchment surface to storage;

C. **Leaf Screens**: first-flush diverters and roof washers, the systems that remove contaminants and debris from the captured rainwater before it goes to the tank

D. **Cisterns or Storage Tanks**: where collected rainwater is stored;

E. **Delivery system:** gravity-fed or pumped to the end use and

F. **Water Treatment filters and equipment**: additives to settle, filter, and disinfect.

A) Catchment Area/Roof

Roofs can be made from a variety of materials. Roofs made from thatch houses and those likely to generate toxic materials are not recommended. The typical roofing material include the following,

- Corrugated Iron Sheet (CIS) or plastic sheets, or tiles.
- Thatched roofs made from palm leaves (coconut and palms with tight thatching are better).Other thatching materials and mud discolor and contaminate the rainwater.
- Unpainted and uncoated surface areas are best. If paint is used it must be non-toxic (no lead-based paints).
- Asbestos-cement roofing does not pose health risks - no evidence is found in any research. However, the airborne asbestos fibers from cutting, etc. do pose a serious health risk if inhaled.

The project area, Jemo-1 condominium's site the roofing material is CIS. This is the preferred roofing material because of its smooth surface and durability.

The efficiency of rainwater collection depends on the materials used, the construction, maintenance and the total rainfall. A commonly used overall efficiency figure is 0.8. If cement tiles are used as roofing material, the year-round roof runoff coefficient is some 75 %, while clay tiles collect usually less than 50 % depending on the production method. Plastic and metal sheets do best with an efficiency of 80-90 %. (WHO, Male, Maldives, 2009). The runoff coefficient depends on the rooftop material as shown in table 1.

Table1: Runoff coefficients for various catchment types (Alphonsus Daniel, pers.comm.)

Type of Roof Catchment	Runoff Coefficients
A. Roof Catchments	
Tiles	0.8 - 0.9
Corrugated metal sheets	0.7 - 0.9
B. Ground Surface Coverings	

Concrete	0.6- 0.8
Brick pavement	0.5-0.6
C. Untreated Ground Catchments	
Soil on slopes less than 10 percent	0.1-0.3
Rocky natural catchments	0.2-0.5

B) Gutters and Down Pipes:

Gutters are channels fixed to the edges of roof all around to collect and transport rainwater from the roof to the storage tank. These must be properly sized, sloped and installed to maximize efficiency and minimize water loss. Gutters come in a wide variety of shapes and forms, ranging from the factory made PVC type to home-made gutters using bamboo or folded metal sheet.

Gutters are usually fixed to the building just below the roof and catch the water as it falls from the roof. For effective operation of RWH, a well designed and carefully constructed gutter system is crucial. 90 % or more of the rainwater collected on the roof will be drained to the storage tank if the gutter and down pipe system is properly fitted and maintained. Common materials for gutters and down pipes are metal and plastic; which are available locally. But also cement-based products and wood can be used. With high intensity rains, rainwater may shoot over the conventional gutter, resulting in a low production; splash guards can prevent this spillage. To keep leaves and other debris from entering the system, the gutters can have a continuous leaf screen made of quarter-inch wire mesh in a metal frame installed along the length of the gutter and a screen or wire basket at the head of the downpipes. Or, just clean out gutters regularly. Gutters can be prepared in semi-circular and rectangular shapes. Locally available material such as plain galvanized iron sheet can be easily folded to required shapes to prepare semi-circular and rectangular gutters. Semi-circular gutters of PVC material can be readily prepared by cutting the PVC pipes into two equal semi-circular channels. Bamboo poles can also be used for making gutters if they are locally available in sufficient quantity. Use of such locally available materials reduces the overall cost of the system. But, for this project the proposed Gutters material is Galvanized steel and the Downpipe material is PVC.

Figure 4: Typical PVC Guttering and Downpipe (Source: UNEP, 2009)

C) Leaf Screens

To remove debris that gathers on the catchment surface, and ensure high quality water for either potable use or to work well without clogging emitters, a series of filters are necessary.

Essentially, mesh screens remove debris both before and after the storage tank. The defense in keeping debris out of a rainwater harvesting system is some type of leaf screen along the gutter or in the downpipes. Depending upon the amount and type of tree litter and dust accumulation, the homeowner may have to experiment to find the method that works best. Leaf screens must be regularly cleaned to be effective. If not maintained, leaf screens can become clogged and prevent Rainwater from flowing into a tank. Built-up debris can also harbor bacteria and the products of leaf decay.

D) Storage Tanks

For rainwater catchment systems, the storage tank is usually the most expensive part, so the design and construction needs due attention. As well as having the appropriate volume with respect to the catchment area, rainfall conditions and demand, it should have a functional, durable and cost-effective design. Field experience has shown that an ideal universal tank design does not exist. Local materials, skills and costs, personal preferences and other external factors are important to take into consideration. Nevertheless, there are a number of key requirements common to all effective tank designs (Gould & Nissen-Petersen, 1999):

- Functional and water-tight design;
- Solid, secure cover to keep out insects, dirt and sunshine;
- Screened inlet filter;
- Screened overflow pipe;
- A manhole (and ideally a ladder) to allow access for cleaning;
- An extraction system that does not contaminate the water (e.g. tap, pump);

Table 2: Advantages and Disadvantages of Aboveground and Underground Storage Systems (WHO, Male, Maldives July, 2009)

Location	Advantages	Disadvantages
Above-ground	Allows for easy inspection for cracks (masonry structures) or leakage	Requires space for installation, particularly if large storage volume is needed; case for commercial and industrial uses
	Cheaper to install and maintain; particularly the case for small volume household supply needs	Masonry works exposed to deterioration from weathering
	Water extraction can be done by gravity with extraction by tap; allows for easy draining if needed	Failure of elevated support structures can be dangerous
	Tank(s) can be raised above ground to increase water Pressure	Requires the construction of a solid foundation which may be costly
	Surrounding ground lends structural support allowing lower wall thickness and lower installation costs	For relatively small storage requirements, is relatively more expensive

Underground	Can form part of the building foundation	Water extraction is more problematic, requiring a pump
	Unobtrusive - require little or no space above ground; useful where large volume storage is Required	Leaks or failures are difficult to detect; pose risk to building foundation failure if constructed on a slope
		Possible contamination of the tank from groundwater intrusion or floodwaters
		Possibility of undetected structural damage by tree roots; allows for entry of contaminates
		Cannot be easily drained for cleaning; requires pump-out

E) First-Flushing

First flush or the rain diverter is provided to flush off the first rain before it enters the storage tank. The first flush water will be most contaminated by particulate matter, bird droppings, and other material laying on the roof (debris, dirt and dust). When the first rains arrive, it is essential to prevent this unwanted material to go into the storage tank. This can cause contamination of water collected in the storage tank. After screening gutters a first flush device is incorporated in the Rooftop Rainwater Harvesting Systems to dispose off the 'first flush' water so that it does not enter the tank. This device will improve the quality of water lengthen the life of system components and reduce overall maintenance (WHO, Male, Maldives July, 2009).

There are two such simple systems. One is based on a simple manually operated arrangement, whereby, the down pipe is moved away from the tank inlet and replaced again once the first flush water has been disposed. In another simple and semi-automatic system, a separate vertical pipe is fixed to the gutter with a valve provided below the "T" junction. After the first rain is washed out through first flush pipe, the valve is closed to allow the water to enter the down pipe and reach the storage tank (WHO, Male, Maldives July, 2009).

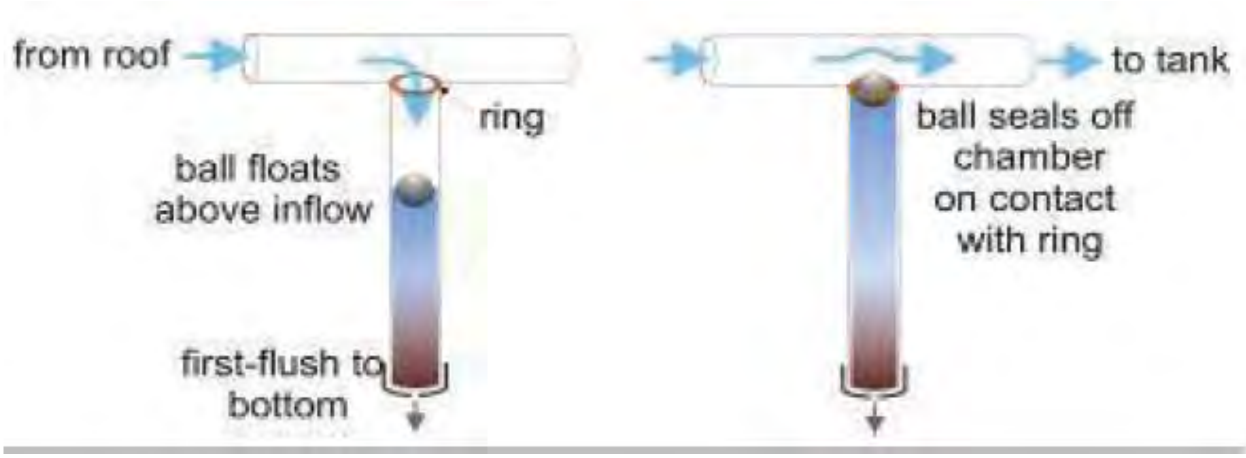

Figure 5: First-Flush Systems Using Float-Ball Mechanism (Source: UNEP, 2009)

F) FILTER

The quality of stored water can be much improved if leaves and other debris are kept out of the system by the use of a coarse filter or screen on the inlet of the tank. Without screens, leaves and other material may enter tanks and provide food and nutrients for micro-organisms to multiply. In the absence of such nutrients, bacteria eventually (within 2-20 days) die off from starvation. A filter or screen should be durable, easy to clean and replace, and should not block. It is essential that there are no gaps in the storage tank inlets where mosquitoes can enter or exit. Coarse filtration screens (made of stainless steel or synthetic mesh) are the simplest, most inexpensive and widely used technology. Typically these are mounted across the top inlet of the storage tank with the downpipe above the screen. Alternatively, the downpipe from the roof could enter the tank through an appropriately sized hole at the top of the tank with the filtration screen at the entrance to the downpipe from the gutter. Finer filter devices have been used to remove small sized sediment which would otherwise either be suspended in the water or settle to the bottom of the tank leaving sludge (SOPAC, 2004).

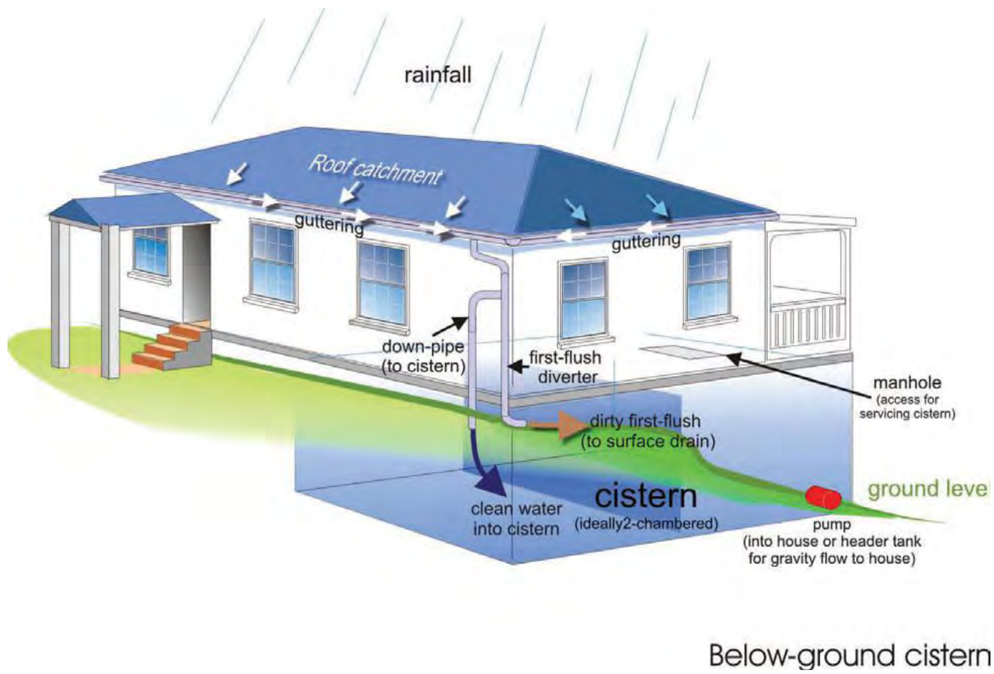

Figure 6: Typical Domestic RWH Systems Below-Ground Storage (Source: UNEP, 2009)

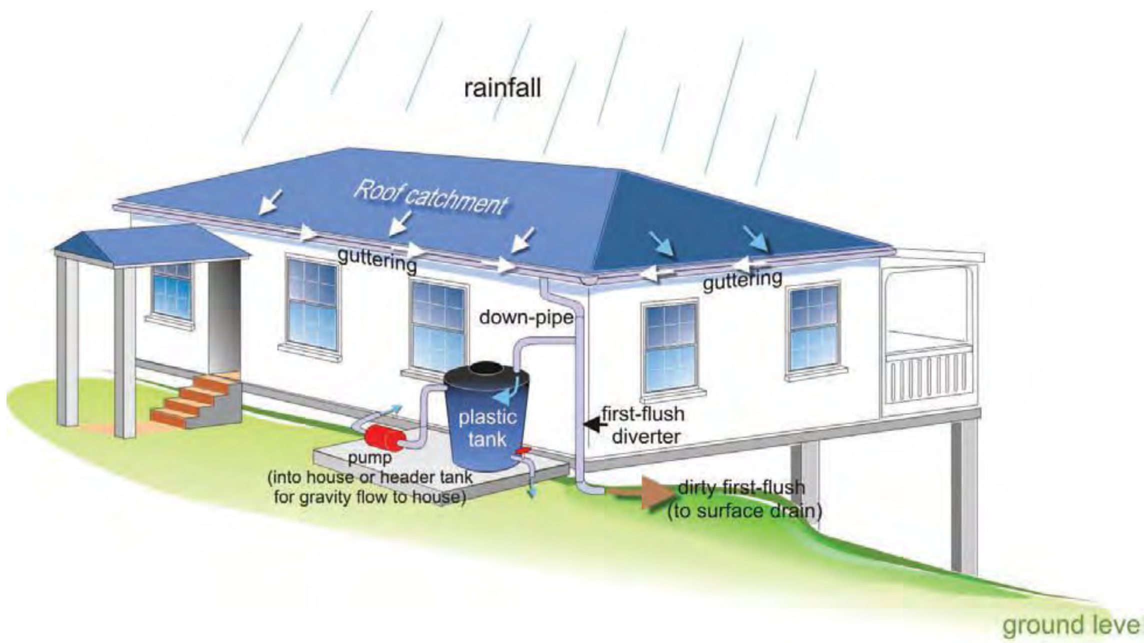

Figure 7: Typical Domestic RWH Systems Above-Ground Storage (Source: UNEP, 2009)

2.11 RWH for Non-Domestic Applications

2.11.1 Municipal Applications

Rainwater harvesting can be used in a variety of municipal applications. Direct roof capture off city buildings or capture of excess runoff from paved surfaces can be used to fill cisterns and other storage facilities that can be used for irrigation of green spaces and recreational facilities, washing and cleaning of streets and facilities, or for fire fighting. Such bulk water storage can be used to augment emergency water supplies following natural disasters when the potable supply may be out of operation. In this case filtration and treatment will need to be applied before distribution.

2.11.2 Agricultural Applications

Crop irrigation and livestock watering have heavy water demands. Under rain fed production, crop yields will drop significantly during the dry season unless supplemental irrigation is applied. Livestock production is similarly impacted where water is in short supply. RWH from farm building catchments and constructed surfaces can greatly contribute to meeting water demands during the drier months for sustained production.

2.11.3 Commercial and Industrial Applications

Rainwater harvested off roofs and surface catchments such as roads and parking lots can be stored and used as required to offset the need for use of the potable supply for non-drinking purposes. Typical applications will include washing and cleaning, cooling, fire fighting, bathing pool recharge and irrigation. Where water may be required for food preparation and other manufacturing processes, treatment will need to be applied.

2.12 Mean Areal Depth of Precipitation (P_{ave})

Point rainfall—it is the rainfall at a single station. For small areas less than 50 km^2, point rainfall may be taken as the average depth over the area. In large areas, there will be a network of rain-gauge stations. As the rainfall over a large area is not uniform, the average depth of rainfall over the area is determined by one of the following three methods (H. M. Raghunath, 2006).

(i) **Arithmetic average method**:

It is obtained by simply averaging arithmetically the amounts of rainfall at the individual rain-gauge stations in the area, i.e.,

$$\text{Pavg} = \sum \frac{p1}{n}$$

Where: Pavg = average depth of rainfall over the area

ΣP1 = sum of rainfall amounts at individual rain-gauge stations

n = number of rain-gauge stations in the area

(ii) Thiessen polygon method

This method attempts to allow for non-uniform distribution of gauges by providing a weighting factor for each gauge. The stations are plotted on a base map and are connected by straight lines. Perpendicular bisectors are drawn to the straight lines, joining adjacent stations to form polygons, known as Thiessen polygons (H. M. Raghunath, 2006).Each polygon area is assumed to be influenced by the rain gauge station inside it, i.e., if P1, P2, P3 ...are the rainfalls at the individual stations, and A1, A2, A3 ... are the areas of the polygons surrounding these stations, (influence areas) respectively, the average depth of rainfall for the entire basin is given by

$$\text{Pavg} = \sum \frac{A1P1}{\sum A1}$$

(iii) The isohyetal method

The isohyetal method—in this method, the point rainfalls are plotted on a suitable base map and the lines of equal rainfall (isohyets) are drawn giving consideration to orographic effects and storm morphology. The average rainfall between the successive isohyets taken as the average of the two isohyetal values are weighted with the area between the isohyets, added up and divided by the total area which gives the average depth of rainfall over the entire basin (H. M. Raghunath, 2006) i.e.,

$$\mathbf{Pavg} = \frac{\sum A1 - 2P1 - 2}{\sum A1 - 2}$$

Where: A1–2 = area between the two successive isohyets P1 and P2

P1-2= $\frac{P1+P2}{2}$

∑**A1-2=A=**total area of the catchment

P1 P2 = A = total area of the basin.

This method if analyzed properly gives the best results.

3. MATERIALS AND METHODS

3.1 Selection of the Study Area

This study is conducted on Addis Ababa city particularly in Jemo-1 condominium site. The site, is found in the south western part of Addis Ababa which is in Nifas Silk Lafto sub-city, woreda 01 and it is located between 8° 49' 56" and 9° 5' 54" North latitude and between 38° 38'17" and 38° 54' 20" East Longitudes. The place is chosen due to water shortage problem is high and flood problems are evident from resident's reflection. And also representing the current water shortage problems of the city especially in the condominium sites. Additionally, their data is relatively available.

3.2 Types and sources of data

Data for this study was captured from secondary sources. The majority of secondary data was collected from AAWSA documents, rainfall data from head office of National Meteorological Agency, population census reports from CSA and Addis Ababa land information center and areas of the roof and the project site were measured from cadastral map of Addis Ababa city.

3.3 Data Collection

The data used for this project is secondary data. Data required for study such as previous water consumption, area of the roofs, rainfall data, population and runoff coefficient are collected from different sources.

All meteorological stations are found out of the project Area, jemo 1 condominium site. And there is a station near the area but, due to the availability of only 11 years of rainfall data it is required to compare and select the station that is near and relatively describe the rainfall characteristics of the project area. Name of stations used for this research to compare the rainfall data for the nearest ayertena station are: observatory station, Akaki station and bole station. 40 years of Rainfall data (1974 to 2013) of each month are collected from national meteorological agency. All meteorological data are found from the National Meteorological Agency.

The estimated population, number of communal and blocks of the site were taken from Addis Ababa land information center documents.

The previous water consumption of the residents data (individual customer meter readings) were taken from water bill data of Addis Ababa Water and Sewerage Authority (AAWSA) Mekanisa branch office.

Calculations of the catchment areas (areas of the roof tops of the blocks and communal) are made by using AutoCAD Software from cadastral map of Addis Ababa city.

And also the data was collected using reviewing literatures and personal observations.

3.3.1 Existing data and working methodology

Existing available data describing the system have been gathered to generate the system.

A. From the system map of the network, monthly customers bill data and different documents the following information was collected from AAWSA.

The water distribution network is available in Auto CAD software having the following system informations.

- The existing water distribution network Layout.
- Locations and numbers of other system components like reservoirs.
- Background information such as:
  - ✓ Addis Ababa city roadways and 2005 Areal map.

B. 40 years of rainfall data of the observatory station were collected from national meteorological agency.

C. Distribution of conventional household has been collected from Central Statistical Agency of Ethiopia.

The last census is being counted on May 28, 2007 up to November 28, 2007. In the census, household is defined as a group of persons living together in the same housing unit.

Table 3: Distribution of conventional Households and their corresponding population by Region and by Urban and Rural Residence (AALIC, 2014).

Region	Urban + Rural (2007)			1994 house hold size
	Person	Number of house hold	House hold size	
Addis Ababa	2,687,593	655,118	4.1	5.1

D. previous year's Average monthly consumption of water per house level data will collected from AAWSA Mekanisa branch office.

Table 4: Average monthly water consumption in m3 per month per household (AAWSA monthly bill data 2006-2007E.C).

	Month											
year (E.C)	**sep**	**oct**	**nov**	**dec**	**jan**	**feb**	**march**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
2006	4.7	5.38	5.45	4.68	4.89	5.07	4.11	4.74	4.94	4.52	5.15	5.45
2007	5.32	9.97	4.96	4.8	5.09	5.35	5.44	6.41	7.59	6.69	8.31	7.46

E. The daily per capital non-domestic water demand will be assumed.

F.Gutter width and downpipe sizes will be designed from standard tables.

G.Then finally Analyze the system.

3.4 Software's Used

- AutoCAD
- Arc GIS-for delineating the area to be harvested
- Microsoft office excel-for data tabulation and graphical calculations

3.5 The Research Process

In order to determine whether rainwater catchment is an option worth considering for the water scarcity issue in Addis Ababa, particularly Jemo-1 condominium site, water quality, water availability, economic benefit and overall advantages had to be considered. But for this project only the water availability issues and advantages of rainwater harvesting are discussed. When analyzing the feasibility of rainwater catchment projects, Rainwater harvesting becomes viable when the following factors become acceptable together and also separately: 3 factors must be considered: technical aspects which in this case include water availability, precipitation, demand and water quality; economics including a comparison of the costs of implementing this system with the costs of

Obtaining water through other means; finally, the social factor which include the community's response to the project, their involvement and interest.

But this study aims to analyze only the technical aspects, to determine the viability of implementing the project in Jemo-1 condominium site.

For designing rainwater harvesting system rainfall data is required. Preferably data for a minimum of 30 years will be useful. But for this project average monthly rainfall data of 40 years is available and used. The more reliable and specific the data is for the location, the design will be better.

3.6 RWH System Components

Guided by the literature review, rainwater harvesting system in urban environment consists of:

- Roof Catchment
- Gutters and Downpipes
- First flush device
- Filter chamber
- Chlorination chamber
- Storage tank (underground /overhead)
- Water Pump/Supply system

This component requires detail design and analysis for the proper installation of rainwater harvesting system. But for this project only the design of roof catchments, Gutter size, Downpipe size and Storage tank size (above ground) are analyzed in the next chapter.

3.7 Research Flow Chart

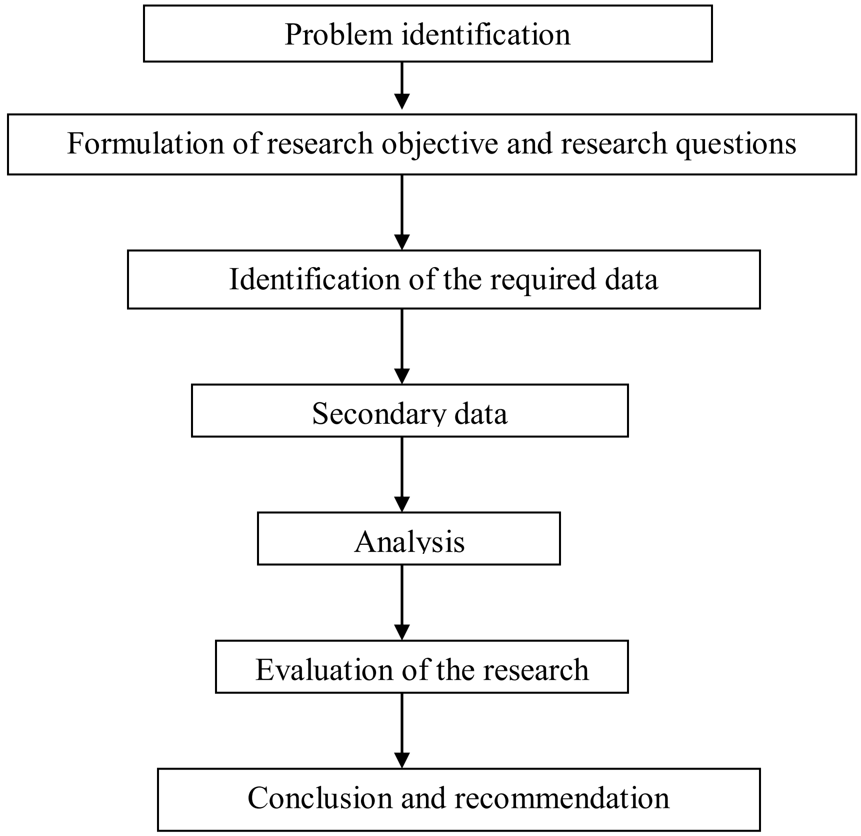

Figure 8: Chart showing the research flow

3.8 Data Interpretation and Presentation

The analyzed data was interpreted in accordance with the relevant correlation to the main aim of the study. The analyzed data was presented in graphs, descriptive statistic, percentage, charts, and tables and so on.

4. RESULTS AND DISCUSSIONS

4.1 Precipitation Results

The success of a rainwater harvesting system depends on many factors. Water demand in the area, cost feasibility, and precipitation are some of the most important issues to be considered when analyzing the viability of implementing such systems. Precipitation data is needed to determine the volume of water that can be captured, with rain depth and roof area, and then use that information to compare with the average monthly demand in an average urban household.

Due to the scarcity of rainfall data near the project area (Ayertena station, Jemo station (if there is), etc.). It is not possible to do the areal depth of precipitation and compute the results of different stations. For this project 40 years of rainfall data at observatory station was collected from the National Meteorological Agency from 1974 to 2013 and do the results only by this point rainfall data.

Table 5: Summary of Average Monthly Precipitation (mm/month), Year 1974-2013(NMA)

Month	Average Monthly Precipitation (mm)
Jan	16.7
Feb	35
Mar	60.2
Apr	85.8
May	84.3
Jun	136
Jul	271
Aug	290.1
Sep	174
Oct	38.2
Nov	9.7
Dec	8.6
TOTAL	1209.6

From the rainfall data of the stations high rainy seasons are observed in July and August. The minimum rainfall is recorded in November and December. During this period the maximum monthly average was 290.1 mm for the month of August and the minimum was 8.6 mm for December.

The main cause of the rainfall in this region is the southward migrating Inter Tropical Convergence Zone (ITCZ) and westward propagating disturbance from the Indian Ocean (Zenaw et al., 2000).

The ITCZ lies in the equatorial trough, a permanent low pressure feature that marks the meteorological equator where surface trade winds, laden with heat and moisture from surface evaporation and sensible heating, converge to form a zone of increased mean convection, cloudiness, and precipitation. The latent heat released in the convective cloud systems of the ITCZ is a critical component of the atmospheric energy balance, and the enhanced cloudiness associated with these cloud systems provides an important contribution to the planetary albedo. The fluxes of heat, moisture, momentum, and radiation between the atmosphere and the surface differ dramatically between the ITCZ region and the regions to the north and south of the ITCZ. Thus, the position, structure, and migration of the ITCZ play an important role in determining the characteristics of ocean–atmosphere and land atmosphere interactions on a local scale, the circulation of the tropical oceans on a basin scale, and a number of features of the Earth's climate on a global scale.

4.2Water Demand

AAWSA standardized that the per capita daily demand is 110 l/c/day considering population equivalents to include non-domestic water demands. Therefore, for rainwater harvesting for a single building with 120 people 40 l/c/day is assumed to be used for non-domestic purposes, by considering toilet flushing, clothes' washing, floor cleaning, car washing, cleaning of pit animals, watering the green areas and for other uses. So it's is assumed to be that the average homes accommodates about 4 peoples and also calculated that a single condominium block, has an area of 290 m^2. This is the size used in the study as basis for calculation. Based on these numbers, the average daily non-domestic water demand in a single house is 160 liters/day as shown in table4.

Table 6: Daily Water Demand

WATER DEMAND	
Daily Non-domestic water demand	40 l/c/d (liters per capita per day)
Basic roof area(residential building)	290 m^2
Basic roof area(communal)	266 m^2
Average No of people/building	120 peoples
Daily Non-domestic water demand per building	4800 liters /day

4.3 User Behavior Patterns with Domestic RWH

Rainwater that has been harvested is used in many different ways. In some parts of the world it is used merely to capture enough water during a storm to save a trip or two to the main water source. Here, only small storage capacity is required, maybe just a few small pots to store enough water for a day or half a day. At the other end of the spectrum we see, in arid areas of the world, systems which have sufficient collection surface area and storage capacity to provide enough water to meet the full needs of the user. Between these two extremes exists a wide variety of different user patterns or regimes. There are many variables that determine these patterns of usage for RWH. Some of these are listed below:

- Rainfall quantity (mm/year)
- Rainfall pattern - The type of rainfall pattern, as well as the total rainfall, which prevails will often determine the feasibility of a RWHS. A climate where rain falls regularly throughout the year will mean that the storage requirement is low and hence the system cost will be correspondingly low and vice versa. More detailed rainfall data is required to ascertain the rainfall pattern. The more detailed the data available, the more accurately the system parameters can be defined.
- Collection surface area (m^2)

- Available storage capacity (m^3)
- Daily consumption rate (liters/capita/day or lpcd)
- Number of users - again this will greatly influence the requirements.
- Cost – a major factor in any scheme.
- Alternative water sources – where alternative water sources are available, this can make a significant difference to the usage pattern. If there is a groundwater source within walking distance of the dwelling (say within a kilometer or so), then a RWHS that can provide a reliable supply of water at the homestead for the majority of the year, will have a significant impact to lifestyle of the user. Obviously, the user will still have to cart water for the remainder of the year, but for the months when water is available at the dwelling there is a great saving in time and energy.
- Water management strategy – whatever the conditions, a careful water management strategy is always a prudent measure. In situations where there is a strong reliance on stored rainwater, there is a need to control or manage the amount of water being used so that it does not dry up before expected.

Table 7: Estimated Per Capita Water Requirement

Uses	Amount(liters per person per day)
Toilet flushing	8-10
Cloth washing	7-9
Floor washing	6-8
Car washing	2-4
Pit animals cleaning	1-3
Green areas	1-3
Other uses	8-10
total	40

4.4Volume of Water that can be captured By a Roof Catchment

To calculate the amount of rain that can be captured off a roof surface per year, a procedure known as the ‘Rational Method’ can be applied. All we need to know is the average annual rainfall for the location, the size or area of the roof and the type of roof surface. The average annual rainfall should be available from National Meteorological Agency.

Supply (litters per year) = rainfall (mm/year) x area (m^2)*runoff coefficient

Roof surface area of a residential building (m^2) =roof length (m) x roof width (m)

=29m*10m

=290m^2

Roof surface area of a communal building (m^2) =roof length (m) x roof width (m)

= (23m*11m) + (13m*1m) =266m^2

The potential volume of water that can be harvested from the residential building roof:

Volume captured (liters) =rainfall (mm)*roof area (m^2)*runoff coefficient

Volume captured in January (m^3) =0.0167 m*290 m^2*0.8(Corrugated metal sheets) =3.87 m^3

Table 8: Volume of Water that can be harvested From a Single block (m^3)

Month	Average monthly Precipitation (mm)	Volume captured per month (m^3)
Jan	16.7	3.87
Feb	35	8.12
Mar	60.2	13.97
Apr	85.8	19.91
May	84.3	19.56
Jun	136	31.55
Jul	271	62.87
Aug	290.1	67.30
Sep	174	40.37
Oct	38.2	8.86

Nov	9.7	2.25
Dec	8.6	2.00
TOTAL	1209.6	280.63

The potential volume of water that can be harvested from a communal building roof:

Volume captured (liters) =rainfall (mm)*roof area (m^2)*runoff coefficient

Volume captured in January (m^3) =0.0167 m*266 m^2*0.8(Corrugated metal sheets) =3.55 m^3

Table 9: Volume of Water that can be harvested From a Single Communal Building (m^3)

Month	Average monthly Precipitation (mm)	Volume captured per month (m^3)
Jan	16.7	3.55
Feb	35	7.45
Mar	60.2	12.81
Apr	85.8	18.26
May	84.3	17.94
Jun	136	28.94
Jul	271	57.67
Aug	290.1	61.73
Sep	174	37.03
Oct	38.2	8.13
Nov	9.7	2.06
Dec	8.6	1.83
TOTAL	1209.6	257.40

Table 10: Monthly water demand from RWH (m^3)

Month	Monthly demand from RWH (m^3)
Jan	48528
Feb	48528
Mar	48528
Apr	48528
May	48528
Jun	48528
Jul	48528
Aug	48528
Sep	48528
Oct	48528
Nov	48528
Dec	48528
TOTAL	**582, 336**

Monthly demand=total population*estimated per capita water requirement

For January:-

Monthly demand (m^3) = (337 blocks*120 peoples/blocks*40 l/c/d*30 days)

= **48, 528 m^3**

Total volume of water captured in a year per a residential block =280.63 m^3

Total volume of water captured in a year per a communal block =257.4 m^3

There are a total of 337 condominium blocks and 50 communal blocks at the site, so total volume of water

= (280.63 m^3per year/block*337 blocks) + (257.4 m^3per year/block*50 blocks) =**107, 442 m^3 per year**

Figure 6 serves as a general estimation of the efficiency of a rainwater harvesting system based on monthly precipitation and monthly demands in the city. The graph is a comparison of the monthly demand and the percentage of it that could be satisfied by rainwater collected from both residential and communal rooftops.

This was analyzed by using average Monthly precipitation records from 1974-2013. Monthly precipitation depths were multiplied by rooftop area to calculate the volume of water available to supply the Monthly demand of a building.

% of monthly demand satisfied = (volume of water that can be harvested/volume of Monthly demand)*100

For January

% of monthly demand satisfied= (1483.36m^3/48528m^3)*100 = 3.06%

Table 11: Percentage of Monthly Demand Satisfied By RWH for a single building

Month	Average monthly precipitation (mm)	Volume of water that can be harvested from single building (m^3)	Volume of water that can be harvested from one communal (m^3)	Total Volume of water available for a single building (m^3)	Monthly non-domestic water demand from one building(m3)	% of monthly demand satisfied by RWH for a single building
Jan	16.7	3.87	3.55	4.40	144	3.06
Feb	35	8.12	7.45	9.23	144	6.41
Mar	60.2	13.97	12.81	15.87	144	11.02
Apr	85.8	19.91	18.26	22.61	144	15.70
May	84.3	19.56	17.94	22.22	144	15.43
Jun	136	31.55	28.94	35.85	144	24.89
Jul	271	62.87	57.67	71.43	144	49.60
Aug	290.1	67.30	61.73	76.46	144	53.10
Sep	174	40.37	37.03	45.86	144	31.85
Oct	38.2	8.86	8.13	10.07	144	6.99
Nov	9.7	2.25	2.06	2.56	144	1.78
Dec	8.6	2.00	1.83	2.27	144	1.57
TOTAL	1209.6	280.63	257.40288	318.82	1728	18.45

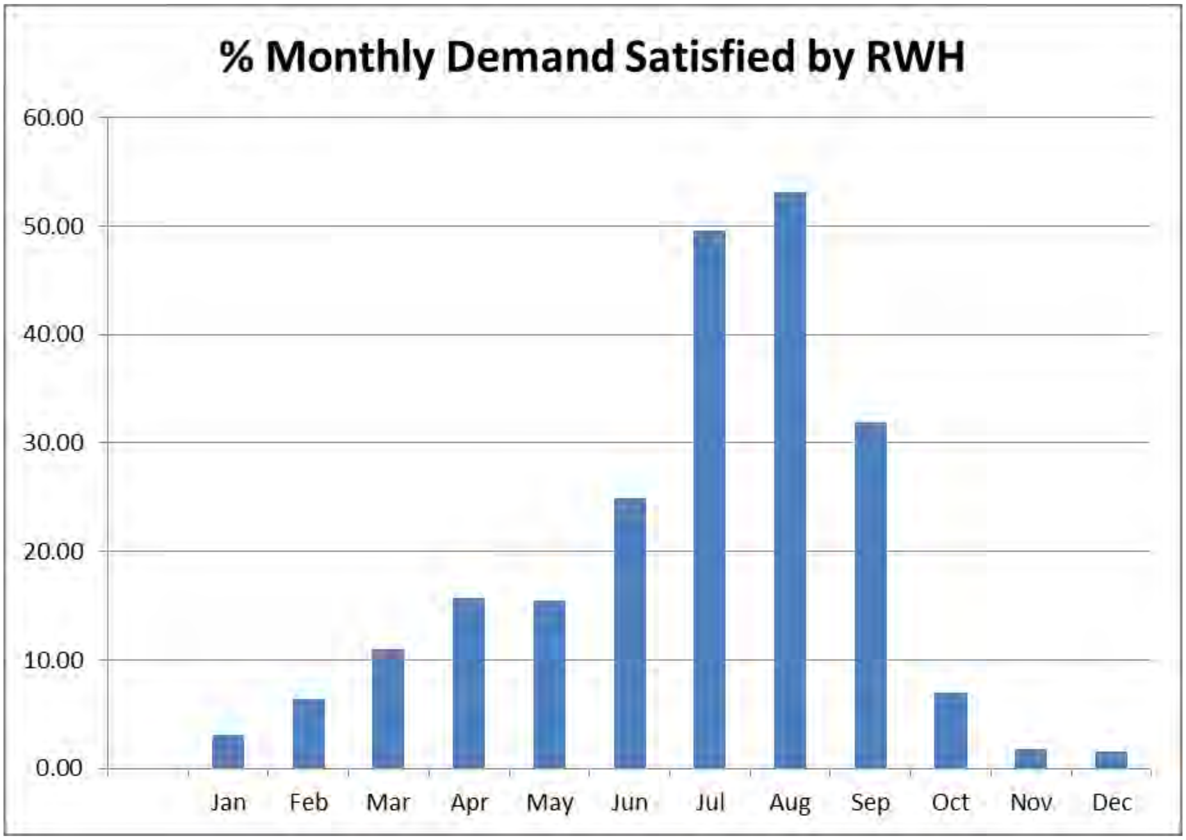

Figure 9: Percentage of Monthly Demand that can be satisfied by RWH

4.5 Sizing of Gutters and Downpipes

Gutters are an almost essential but relatively cheap part of a Rain-water harvesting (RWH) system. It is possible to collect roof water without them by using instead glides or ground level troughs (Gould & Nissen-Petersen, 1999).

The size (width) of the gutters should be chosen based on the roof section area. The South Pacific Applied Geosciences Commission (SOPAC) Handbook rainwater harvesting (2004) provides guidance to sizing of the gutters and the downpipes appropriate to handle rainstorms in tropical regions.

Table 12: Gutter Width and Down Pipe Size (SOPAC, 2004)

Roof Area m2	Gutter Width, mm	Down Pipe, mm
17	60	40
25	70	50
34	80	50
46	90	63
66	100	63
128	125	75
208	150	90

The catchment area for the residential blocks has 4 sides, two of the sides are the same (118 m^2 each) and the other two sides are the same (27 m^2 each).

And for the communal block two of the sides are 100 m^2 area each and the other two sides are 30 m^2 each.

For the residential blocks:

Using the above table providing 125 mm gutters width with 75 mm down pipes and 75 mm gutter width with 50 mm down pipes respectively.

For communal:

Using the above table providing 125 mm gutters width with 75 mm down pipes and 75 mm gutter width with 50 mm down pipes respectively.

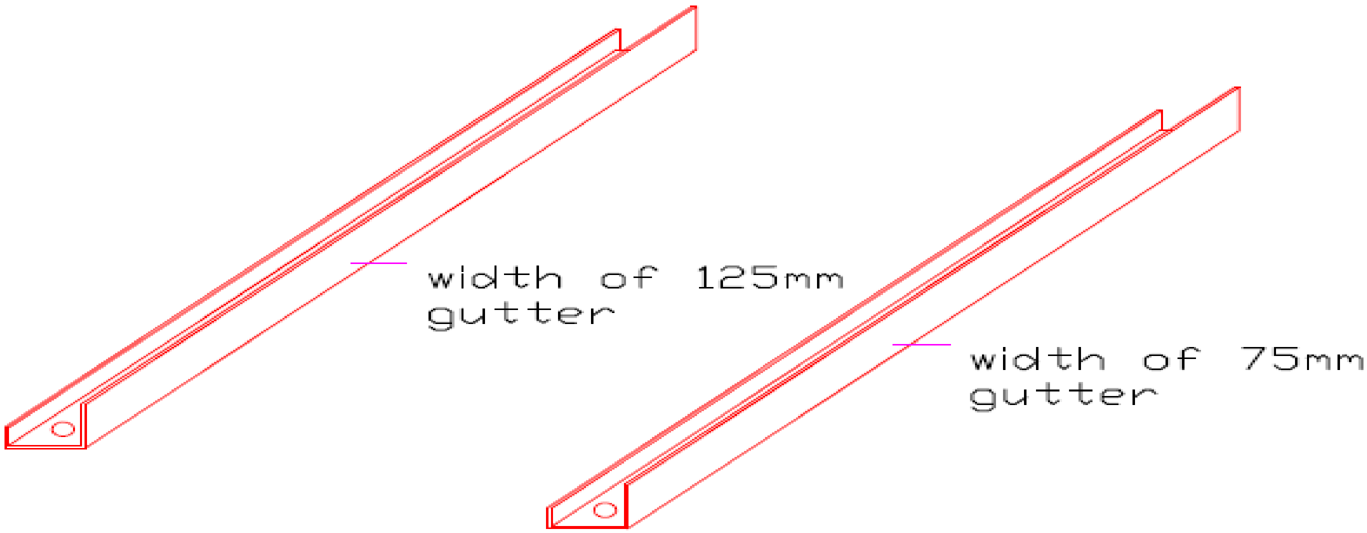

Figure 10: Typical Design of 125 mm and 75mm Gutters

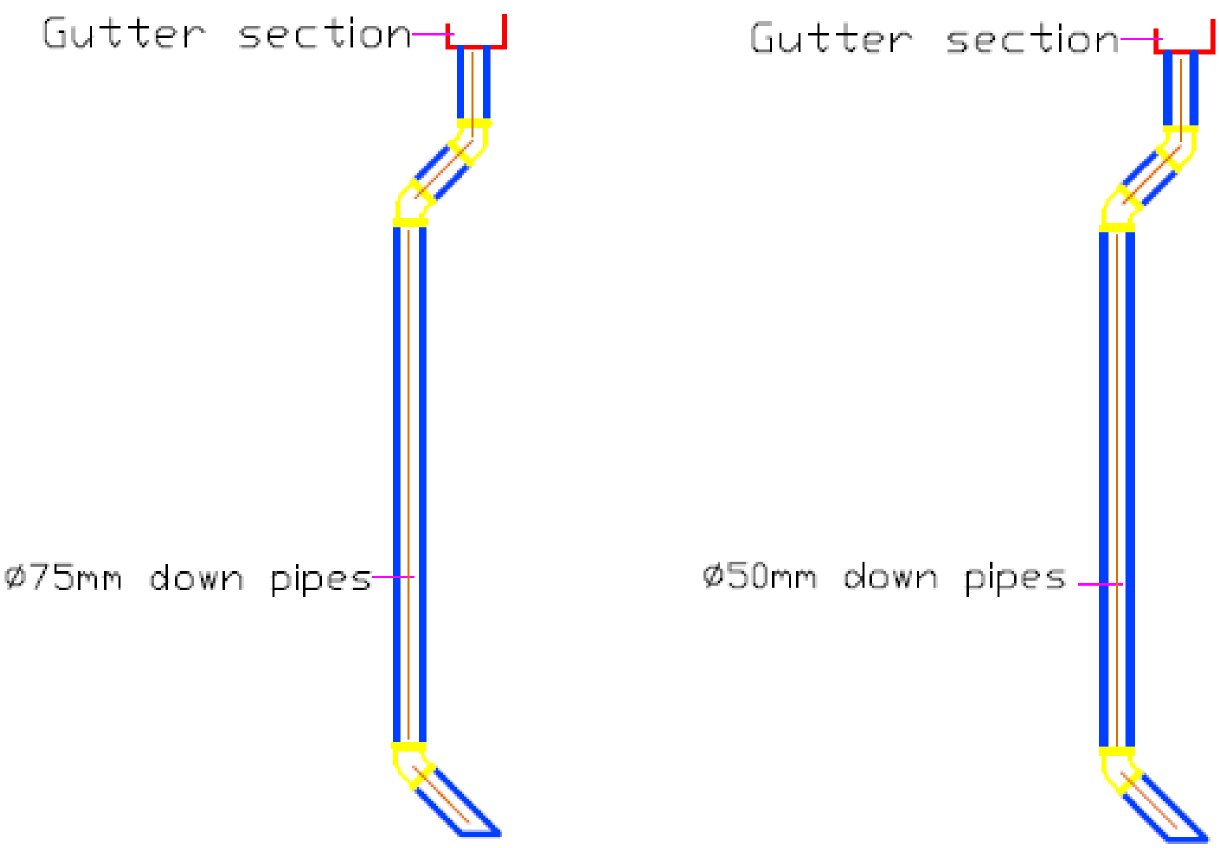

Figure 11: Typical Design of 75 mm and 50 mm diameter Downpipes

4.6Volume of Diverted Water by the First Flush

To calculate the volume of water diverted by the first flush system, it is generally assumed that a depth of rainfall on the roof equivalent to 0.5 mm is required to wash off the accumulated contaminants. First we need to determine the area of the roof and simply multiply by 0.5 mm.

Volume of diverted water (liters) = house length (m) x house width (m) x 0.5 (mm)

= 29 m*10 m*0.5 mm

=0.145 m^3 of water being diverted

4.7. Design of Storage Tanks:

4.7.1 Introduction

It is clear that as roof areas increase, the volume of precipitation that could potentially be stored increases, and so the tank size required capturing the total amount of precipitation is larger.

The graph's behavior illustrates how as rooftop areas are larger, the percentage of days when all daily precipitation can be captured by the proposed tank volumes, decreases. It is also evident that there is a point at which, tank sizes can get larger, but there will be a small or no benefit from that increase. This information provides a clear view for determining appropriate tank volumes that can be installed for rainwater harvesting system. Precipitation analysis was also used to determine how much supply could be provided to users, whether this technology could be implemented as a sole solution or if its application should be considered as a complementary supply to other systems.

The analysis of precipitation records was useful in determining which tank volume presented the most benefits when compared to its costs, for the amount or rain falling daily in the site.

4.7.2 Tank Requirements and Constraints

Tanks need to be watertight although some leakage (such as <5 % of daily abstraction) might be tolerable if it does not weaken the structure or cause puddles. They also need to hold the required volume and to be adequately durable (say 25 years before they become unserviceable). Beyond these basic requirements we can list many further specific requirements. (Milestone A6: Report A4 (January 2001).

Tanks should:

- be able to handle excess input by overflowing in a convenient and safe manner– preferably without leading water unnecessarily via the tank (such water may drop unwanted sediment in the tank)
- have a means by which the water can be extracted which is convenient for the user and which does not pollute the water left behind (as dipped buckets may)
- exclude vermin and as far as possible mosquitoes
- exclude light (so that algae do not grow and larval growth is inhibited)
- have some form of ventilation, especially if there is not an efficient filter to prevent organic material from entering the tank and decaying there
- be easy to access for cleaning (where cleaning is needed) and be unlikely to be damaged during cleaning
- have a sufficient structural safety factor to withstand wear and tear, some impacts and occasional large natural forces caused by winds and (in places) earthquakes
- not give the water a bad taste

4.7.3. Estimating Storage Requirements

Unlike other domestic storage reservoirs, RWH reservoirs don't permit an over flow. Because if an excess amount of water comes it will damage infrastructures and other flood problems will happen. So, the storage reservoir capacity must be designed well. But, due to an expected rains and other problems if an over flow happens the over flow water will goes to the nearby river.

From last 10 years of daily rainfall data it is assumes that the maximum daily precipitation for the area is about 40mm (from daily rainfall data of observatory station).

Therefore, for a single Block the storage requirement will be

$=0.004m*290m^2*0.8*1.5$(peak factor)

$=13.92m^3$

And for the communal building the storage requirement will be

=0.004m*266*0.8*1.5(peak factor)

$=12.77m^3$

So, an average $13.8m^3$ reservoir is required for a single building.

Therefore, for 337 residential buildings and 50communal buildings

= (337+50)*13.8m3=$5341m^3$ reservoir is required.

Therefore, providing 10 collecting Ground storage reservoirs of $535m^3$ near the communal buildings and 2 distributing reservoirs of $2670m^3$ is recommended.

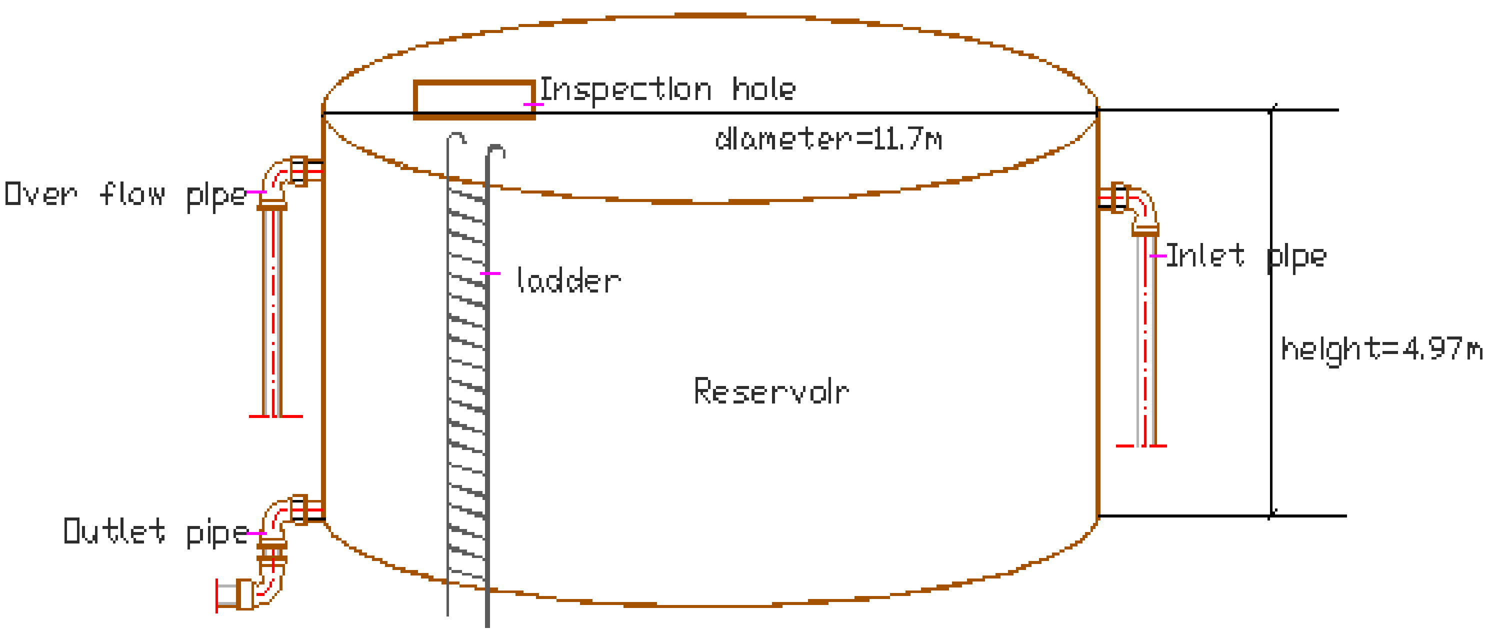

Figure 12: Typical Design of 535m³ Reservoirs

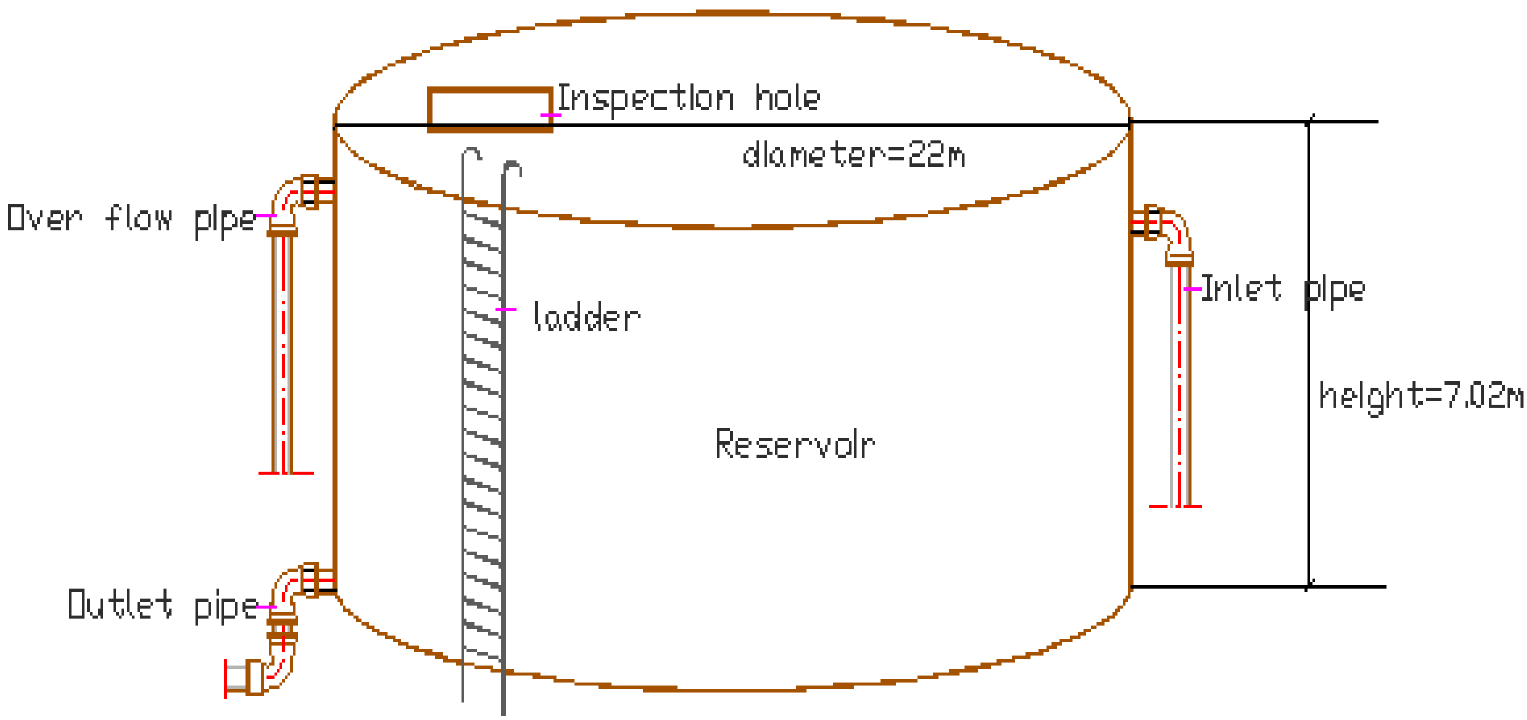

Figure 13: Typical Design of 2670m³ Reservoirs

From the 10 collecting reservoirs the water is directly pumped to the nearby elevated area then distributed to each building by gravity.

4.7.4 Residual Pressure

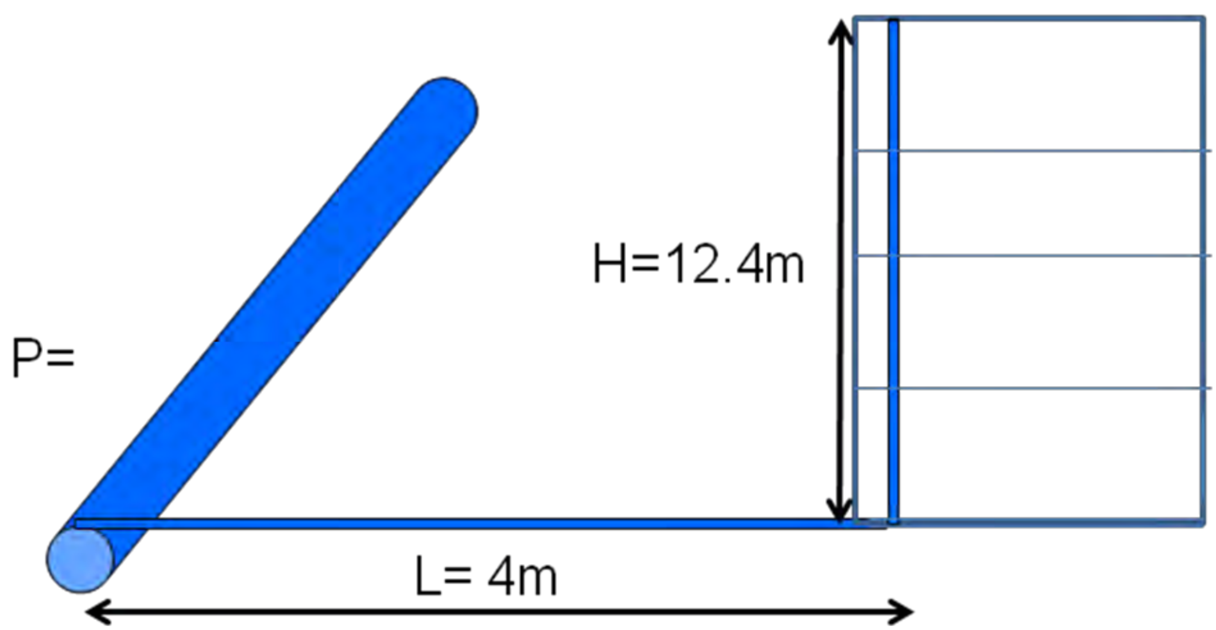

Figure 14: non-domestic water supply pipe line

- riser height =12.4m
- length of 25mm pipe line=4m
- Friction head loss of pipe(Assume I=800)

H = I・L/1000 = 800*16.4/1000 = 13.12m

- Head loss of valve, meter Corporation Stop (Staffa) and different fittings assumed to be 6m

Total head loss=13.12m+6m=19.12m

P=0.196Mpa (20m) is enough to reach the water to 4^{th} floor house.

5. CONCLUSIONS AND RECOMMENDATIONS

5. 1. Conclusions

- Water scarcity in Jemo-1 condominium site is so severe in part because of the growing population around the site and the construction of other condominium sites (Jemo 2 and Jemo 3). Due to this and other problems, the main source of water for area that founds near the site did not satisfy the water demand of the residents. The Addis Ababa water and sewerage authority have been aimed for improvement of connection systems by connecting additional water from Akaki water wells. However, nothing is being done, users receive water for a few hours only some each week in the best cases and the resident above the second floor did not get the water at day times.
- Rainwater harvesting has great potential in freshwater-starved urban areas to be environmentally, socially and economically sustainable. In Addis Ababa the rainfall is not the same throughout the year. But the amount of annual rainfall is big enough for utilization.
- According to the average previous 3 years of water consumption data from AAWSA mekanisa branch office, it will show that the water that will harvest from rainwater is more than the water that is provided to the project area by AAWSA. but the estimated design of the per capital water demand for non-domestic purposes 40l/c/d, RWH from roof tops at Jemo condominium 1 site can reduce the Non-Domestic water demands by approximately18.45%. And also RWH can reduce runoff by significant amount; this contributes for sustainable storm water management and best management practices. Therefore RWH can be an alternative solution to support the increasing water demand and reduce the surface runoff as a best management practice which helps to satisfy the Environmental sustainability which is one of the millennium development goals.
- From chapter 4 results and discussion part it is clear to show that the storage tank will only require a diameter of 11.7m space to install on the ground and it will not take any space above ground and also the wall of storage tanks will give structural support to the buildings.
- Along with this, AAWSA can use this research as a guideline to calculate the possible amount of supply water conserved by the rainwater harvesting as well as the decrease in load on the ground water.

5.2. Recommendations

- Rainwater harvesting consists of collecting precipitation from rooftops and storing it in tanks. Rooftops can have particles and pathogens that might contaminate water that falls through them. There are basic treatment methods that users can implement at household levels like boiling water and post chlorination on the reservoirs that will be low-cost solutions.
- Rainwater harvesting is a solution that could give some chance for users to use the water they collect for their best interests. However, rainwater-harvesting systems are very dependent on the amount of precipitation falling during the wet season in Addis Ababa, Jemo-1 condominium site. Droughts, climate change, varying precipitation patterns make this system uncertain and that is why it is recommended as a complement to other solutions.
- It is important for users to maintain clean storage tanks, clean filters, gutters, drains and rooftops and it is recommended to let water from the first strong rainfall of the season wash out the roof without collecting it because it will be more contaminated.
- Although data from secondary sources were used for this study to assess the availability of rainwater and the catchment areas are calculated from AutoCAD drawings, so physical measurements should be executed to get the exact area of the roof to be harvested.
- The rain fall data used for this project is monthly precipitation from the observatory station. So for better results the availability of rainfall should be calculated from daily rainfall data's of different stations near the project area and computed by mean areal depth of precipitation.
- Some of the design approach and criteria exercised for this study needs to be reconsidered. For instance tank sizes, which is the most important and expensive facility in the promotion of DRWH system are determined based on an average annual rainfall that does not consider the rainfall patter. The method is used only for preliminary works and gives a size that does not fit with the demand. So the research recommend to use other methods or software.
- For this study the daily per capita water requirement is done by estimation and for the best results it is better to be done by physical measurements and assessing the need of the community.

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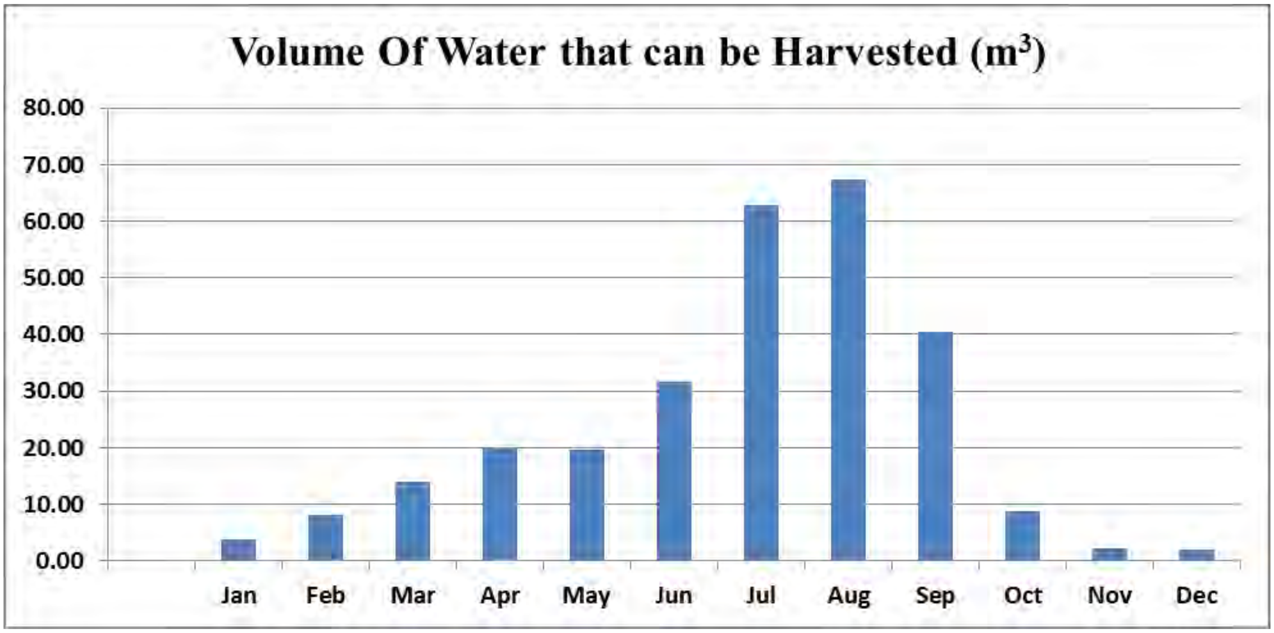
APPENDIX

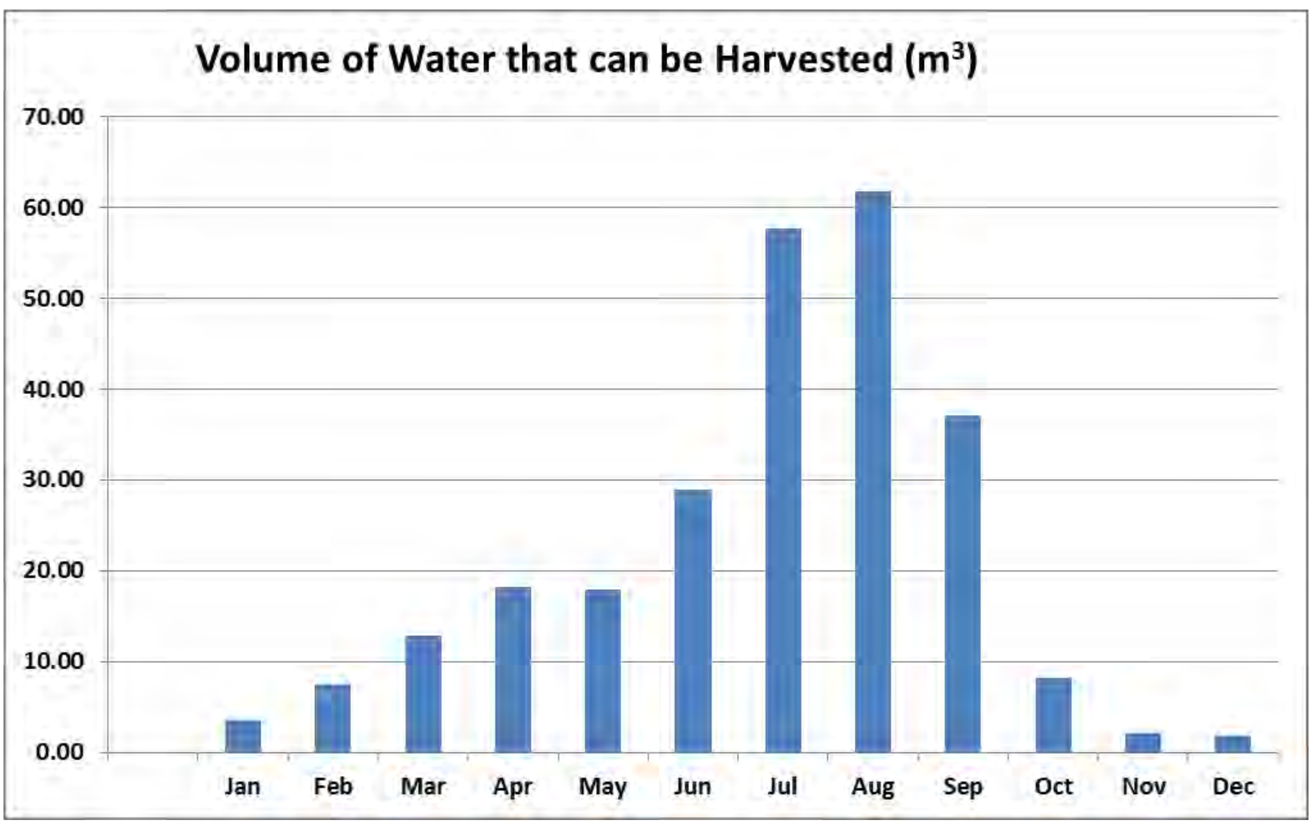
Appendix 1: Monthly Annual Rainfall of Addis Ababa city (Observatory Station)

Year	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANNUAL
1974	0	31.9	21.7	8.9	114.2	135.5	264.9	330.8	229.2	3.5	0	0	1140.6
1975	0	2.7	24.4	60.3	53.5	123.5	271.5	183.6	181.3	17	0	0	917.8
1976	19.3	61.4	44	94.8	113.3	108.7	181.2	277.7	145.5	3	62.3	13.2	1124.4
1977	55.7	40	68	65.9	146	154.6	255.3	278.8	133.6	272.5	1.2	0	1471.6
1978	2.1	63.3	30.8	80.3	30.8	116.7	208.1	361.3	111	39.1	0	3.4	1046.9
1979	127.9	18.2	73.6	84.9	84.1	144.7	316.1	204.5	225.1	0	0	16.2	1295.3
1980	23.2	46.2	45.3	88.5	54.2	126.2	385.1	297.4	111.9	51.5	0	0	1229.5
1981	0	75.5	176	82.9	3.9	50.1	266.5	320.9	182.1	13.3	0	5.2	1176.4
1982	48.7	80.9	57.8	103.7	115.9	31.9	259.3	257.9	133.8	64.4	43.2	12.8	1210.3
1983	18.3	21.7	48.7	117	237	109.3	199.3	244.7	160.9	26.3	0	8.8	1192
1984	0	8	8.8	8.4	127.8	220.8	296.1	295.6	142.4	0	4.4	16.3	1128.6
1985	14.2	0	17.5	96.3	83.7	112.2	270.4	327.7	205.9	58	3.3	1.2	1190.4
1986	0	35.7	88	197.6	125.4	179.5	180.1	291.1	127.8	36.1	0	6.4	1267.7
1987	0.5	63.4	248.9	82.4	241.3	92.9	196.5	254.4	115.2	21.3	0.8	0.3	1317.9
1988	9.7	53.4	5.3	144.6	16.6	106.2	277.9	299.3	229.7	59.9	0	0	1202.6
1989	0.8	75.9	75.7	154.4	0.5	120.9	357.7	325.3	187.7	14.8	0	7.6	1321.3
1990	0.8	155.9	59.2	106.4	20	88.8	218.7	268.6	184	16.2	6	0	1124.6
1991	0	74.5	106.6	34.7	36	98.9	248.9	262.6	126.4	3.4	0	50	1042
1992	20.2	33.7	20.2	41	52	109.1	248.5	294.7	209.4	69.7	0	2.9	1101.4
1993	10.8	67.2	16.1	157.9	97.2	208.3	274	426.5	243.3	62.1	0	4.5	1567.9
1994	0	0	82.4	82.3	63.3	123.4	308.9	225	142	0.5	14.7	0	1042.5
1995	0	69	41.5	174.4	68.2	102.9	190.2	314.9	136.1	0	0	0	1097.2
1996	28.1	5.2	106.8	128.2	122	258.5	266.4	338.7	294.2	0.2	0.2	0	1548.5
1997	39.2	0	24.5	51.3	38.5	104	272.6	194.3	113.8	62.4	50.3	1.5	952.4
1998	55.2	20.5	49	48.5	154.2	124.4	285.4	260	213.6	126.9	0	0	1337.7
1999	2.9	0.3	28.8	16.3	23.8	119.6	265.5	305.3	88.4	75.4	0	0	926.3
2000	0	0	17.6	49.9	110	144.5	244.8	306.2	250.6	46.4	21.1	0	1191.1
2001	0	12.2	210.8	25	168	216.2	428	246.4	131.7	13.7	0	0	1452
2002	14.7	21	90.2	56.3	63.1	172.5	256.9	215.9	108.8	0.2	0	16.5	1016.1
2003	10.5	53.3	62.6	99.3	20.2	151.8	291.8	233.3	193.3	0.8	1.5	54.9	1173.3
2004	24.8	20.3	49.5	139.9	30.1	141.9	238.5	272.6	164	76.9	0	0	1158.5
2005	45.9	51.6	83.2	160.9	133.7	179.8	246	315.2	162.5	18.8	4.4	0	1402
2006	0.7	11.2	60.9	78.9	74.6	150.1	356.3	243.6	239.1	54	0.3	8	1277.7
2007	51.3	19.1	59.8	73.8	120.1	162.8	261.8	381.2	147.6	24.8	0	0	1302.3
2008	0	13	0	49.4	94.3	88.9	277	360.9	256.7	88.2	79.4	22.9	1330.7
2009	21.3	2.7	28.4	80.6	58.9	82.6	349.9	388.3	112.7	45.8	4.4	65	1240.6
2010	2.6	79.8	55.5	97.8	74.4	271.1	313.9	205.8	237.8	1.8	25.7	15	1381.2
2011	14.1	13.1	44.3	22.8	66.1	182	180.9	340.8	146	0	42.3	0	1052.4
2012	0	0	15.8	92.1	50.2	69.4	324.2	298	215.5	2.3	0	9.8	1077.3
2013	4.4	0	62.9	92.3	85	153.2	304.7	353.2	218	58.4	22.3	0	1354.4
MEAN	16.698	35.045	60.2775	85.773	84.3025	135.96	270.995	290.075	173.97	38.24	9.695	8.56	1209.6

Appendix 2: Volume of Water that can be harvested From a Single Residential Block per Month (m^3)



Appendix 3: Volume of Water that can be harvested From a Single Communal Block per Month (m^3)



Appendix 4: Percentage of Monthly Demand Satisfied By RWH from All Buildings

Month	Average monthly precipitation (mm)	Volume of water that can be harvested from building (m^3)	Volume of water that can be harvested from communal (m^3)	Total Volume of water that can be harvested (m^3)	monthly demand from RWH	% of monthly demand satisfied by RWH
Jan	16.7	1305.67	177.69	1483.36	48528	3.06
Feb	35	2736.44	372.40	3108.84	48528	6.41
Mar	60.2	4706.68	640.53	5347.20	48528	11.02
Apr	85.8	6708.19	912.91	7621.10	48528	15.70
May	84.3	6590.91	896.95	7487.86	48528	15.43
Jun	136	10633.02	1447.04	12080.06	48528	24.89
Jul	271	21187.86	2883.44	24071.30	48528	49.60
Aug	290.1	22681.18	3086.66	25767.84	48528	53.10
Sep	174	13604.02	1851.36	15455.38	48528	31.85
Oct	38.2	2986.63	406.45	3393.08	48528	6.99
Nov	9.7	758.38	103.21	861.59	48528	1.78
Dec	8.6	672.38	91.50	763.89	48528	1.57
TOTAL	1209.6	94571.37	12870.14	107442	582336	