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**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
*SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING*

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**Rainwater harvesting for Addis Ababa city; a Case of Jemo  
Condominium site**

By

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## Abstract

*The main objective of this thesis is to assess the potential of rain water harvesting practice to solve problems of both increasing water demand and storm water in Addis Ababa city. The research is carried out based on case-study of Jemo condominium site, from November 2014 to May 2015 that is found in the south western part of Addis Ababa city. The site has about 337 residential blocks with an average roof area of 286m<sup>2</sup> and 50 communal blocks with an average roof area of 216m<sup>2</sup> roof area and serves for about 9,800 households in which they serve for about 42,140 population.*

*A descriptive quantitative study was carried out in order to achieve the objectives of the study. A monthly rainfall data, catchment characteristics, roof material, population data, water consumption and water demand data were collected from primary and secondary sources. People's attitude and practice towards rainwater was also assessed. The collected data was analyzed using different tools including samsamwater RWH model, Google earth, rainwater harvester, AutoCAD, MS Excel spread sheets and etc. Calibration and validation of the finding was carried out using appropriate instruments.*

*Based on the findings the total annual rainfall in an average year is 1219mm. A 6 months of water consumption data of Jemo I collected from AAWSA Mekanisa branch shows that only 30% of the demand is supplied to residents by the municipality at private water pipes. The average annual RWH potential at Jemo I condominium site is not enough to fulfill the total water demand at this site. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 113400 litres (113.4 m<sup>3</sup>) for a single building a rainwater harvesting system could provide about 36% of non-potable demand and RWH can reduce water demand problems by 36% for only non-potable demands and 10% for all domestic demands based on the current AAWSA standard. The total cumulative runoff generation from this site throughout the year is 723,450m<sup>3</sup> and the amount of water that RWH system only from roof tops can harvest could be 90,290.2m<sup>3</sup>. With this estimation RWH from roof tops at Jemo condominium site can reduce runoff by 12%. This contributes for sustainable storm water management and best management practices. Therefore RWH has many benefits once it is applied for any building for sustainable alternative water supply and sustainable storm water management. The big problem here will be the size of storage tank should be big enough since the rainfall is concentrated for limited months which will not be cost effective but related to other interventions RWH is more cost effective and sustainable than other options.*

*Key words: Rainwater, Harvesting, water demand, Stormwater, Alternative source, Non potable, Jemo, Domestic, Urbanization, Condominium, Addis Ababa, Ethiopia*

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## **Acronym**

AAIT-Addis Ababa Institute of technology

AAU-Addis Ababa University

AAWSA-Addis Ababa Water and Sewerage Authority

CRF-Critical Rainfall

FDRE-Federal Democratic Republic of Ethiopia

IHDP-Integrated Housing Development Programme

IWRM-Integration of Rainwater Resource Management

RCC-Reinforced Cement Concrete

ROF-Runoff Factor

RWH-Rain Water Harvesting

WDM-Water Demand Management

WHO-World Health Organization

WSS- Water Supply and Sanitation

UNEP-United Nations Environmental Proclamation

USA- United States of America

## **Operational definitions**

### **Alternative Technology:**

Alternative technology refers to technologies that are more environmentally friendly than the functionally equivalent technologies dominant in current practice, aims to utilize resources sparingly, with minimum damage to the environment, at affordable cost and with a possible degree of control over the processes. (Choudhury, 2003)

### **Catchment Area:**

Catchment area is the net roof surface, in square feet/square meters, from which rainwater is, collected (Choudhury, 2003)

### **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 (Pacey, 1989).

### **Filtration:**

Filtration is the method of separating solid and suspended contaminants in rainwater achieved by the interaction between the rainwater and a porous interface i.e. the filter (Pacey, 1989)

### **Potable Water:**

The water of sufficient quality which is fit for human consumption is called potable water (Choudhury, 2003)

### **Run-off:**

Runoff is the term applied to the water that flows away from a catchment after falling on its surface in the form of rain. Runoff can be generated from both paved and unpaved catchment areas of buildings. The nature of the catchment determines the quantity of runoff that occurs from the area. (Choudhury, 2003)

### **Runoff Coefficient:**

Runoff coefficient is the factor which accounts for the fact that all the rainfall falling on a catchment cannot be collected. Some rainfall will be lost from the catchment by evaporation and retention on the surface itself. (Choudhury, 2003)

**Storm water:**

Water produced by the interaction of precipitation event and the physical environment (buildings, pavement, and ground surface) [www.stoller-eser.com/Annuals/2003/AppendixE.htm](http://www.stoller-eser.com/Annuals/2003/AppendixE.htm)

**Sustainability:**

Meeting the needs of the present without compromising the ability of future generations to meet their own needs [www.afsc.org/trade-matters/learn-about/glossary.htm](http://www.afsc.org/trade-matters/learn-about/glossary.htm)

**Urban runoff:**

Stormwater from urban areas which tends to contain heavy concentrations of pollutants from urban activities [http://www.stormh2o.com/sw\\_glossary.html#u](http://www.stormh2o.com/sw_glossary.html#u)

**Water supply system:**

All the components of water supply structure that enable to convey water from the source to the users.

**Water supply Shortage:**

It is used to describe a shortage where levels of water supply do not meet certain defined minimum requirements. The actual quantity that determines a per capita minimum may differ from place to place

**Rise in life standard:**

It is the change in the status of living due to economic step up.

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# 1 CHAPTER ONE-INTRODUCTION

## 1.1 Background

Water is an important element for all human beings in the world. We need water for drinking, cooking, washing, agriculture and to run our industries. We usually take it for granted because of its availability; but when in scarcity it becomes our most precious resource. Every raindrop that fall from the cloud is very soft and the cleanest water sources in this world (TWDB, 2005). Rainwater is a part of hydrologic cycle; the never-ending exchange of water from the atmosphere to the ocean and back again as rainwater. The precipitation like hail, rain, sleet, snow and all the consequently movement of water in nature forms are from part of this cycle (Hatibu, 2003).

Rainwater quality always exceeds the quality of surface water and is comparable to ground water because of it does not come in contact with soil and rocks where it can dissolve salts and mineral which are harmful for potable and non-portable uses. The rainwater quality usually can be influenced by geographic location, activity in the area and storage tank (TWDB, 2005). However, with minimal treatment and adequate care of the system, rainwater can be used as potable water, for sanitation as well as for irrigation. Rainwater can provide clean, safe and reliable water for drinking so long as the collection system is properly constructed and maintained and treated appropriately for its intended use (Jamaluddin & Huang, 2007). Rainwater harvesting means capturing rain where it falls or capturing the runoff in a village or town and taking all precautions to keep it unpolluted. For century's world has relied upon rainwater harvesting to supply water. Rainwater harvesting promotes self-sufficiency and fosters an appreciation for water as a resource. It saves money, saves other resources of water, reduces erosion and storm water runoff and increases water quality (Thamer et al, 2007)

The growth of population and expansion in urbanization, industrialization and irrigated agricultural is imposing growing demand and pressure on water resource. The existing water resources nowadays were facing the pollution because of this phenomenon. One third of world's population will experience severe water scarcity by the end of this century. In urban areas, water demand and surface runoff increases due to increase in the population and change in land use (Maggie A. et al, 2007).

When vegetation and soils are replaced with roads and buildings, less rainfall infiltrates into the ground, less gets taken up by vegetation and more becomes surface runoff. Until recently, the traditional approach to drainage has been to remove runoff as quickly as possible from developed areas. Storm water runoff from urbanized areas is generated from a number of sources including residential areas, commercial and industrial areas, roads, highways and bridges. Essentially, any surface which does not have the capability to pond and infiltrate water will produce runoff during storm events (Thamer et al, 2007).

When a land area is altered from a natural forested ecosystem to an urbanized land use as in Addis Ababa city consisting of rooftops, streets and parking lots, the hydrology of the system is significantly altered. Water which was previously ponded on the forest floor, infiltrated into the soil and converted to groundwater, utilized by plants and evaporated or transpired into the atmosphere is now converted directly into surface runoff (Maggie A. et al, 2007).

Hence, the most effective way to obtain fresh water and manage storm water is to harvest rainwater. Rainwater harvesting system is inherently simple in form, and can often be assembled with readily available materials by owners, builders with a basic understanding of the plumbing and construction skills (Hatibu, 2003).

Addis Ababa city, the capital city of Ethiopia, is one of the largest urban center in sub Saharan Africa. It is located between 8° 49' 55.929" and 9° 5' 53.853" North latitude and between 38° 38' 16.555" and 38° 54' 19.547" East Longitudes. The city covers an area of 51948.85 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). According to the 2007 census, Addis Ababa city administration has a total population of 2,738,248, which is about 60% of the total urban population of Ethiopia (CSA, 2007). Such a huge population has put a tremendous pressure of the demand for municipal services. There is a massive demand for serviced, healthy and affordable housing in urban areas particularly in Addis Ababa. In order to resolve the chronic housing problem Addis Ababa city administration prepared the Integrated Housing Development Programme (IHDP). It has built more than 140,000 housing units to date.

Nifas Silk Lafto is one of the 10 sub cities in Addis Ababa city Administration. It covers an area of 5876.02 hectares. It is situated in the south western part of Addis Ababa, bounded from south by Oromia special zone, from North West by Kolfe Keranio, from East by Bole and Akaki Kality and from North by Lideta and Kirkos. Jemo I condominium site that is found in the south western part of Addis Ababa city which is in Nifas Silk Lafto sub-city and it is among the big sites in which water demand and surface runoff problems are reflected from residents. The site has about 337 residential blocks and 50 communal blocks and serves for 9,800 houses in which they serve for about 42,140 population. (AALIC, 2014)

Provision of water supply to the people of Addis Ababa is the responsibility of Addis Ababa Water and Sewerage Authority (AAWSA). AAWSA is a public authority and organized into eight branch offices, namely Arada, Addis Ketema, Nifas Silik, Mekenisa, Gulele, Megenagna, Gured Shola and Akaki which provide services to all parts of the city.

In order to address both issues of increasing water demand and surface runoff which limits the sustainable development of cities in Ethiopia, such as Addis Ababa, Rainwater Harvesting is one alternative solution for the problem.

## 1.2 Statement of the problem

Addressing the increasing water demand and surface runoff for urban areas with a centralized water supply and using constructed drainage lines respectively are the most challenging and difficult problems in developing cities. As Ethiopian development goes through different socioeconomic and physical changes the population in which that seeks shelter, water supply and infrastructure also increasing dramatically. Addis Ababa city in which the urban population is increasing dramatically is constructing condominium houses to address demands for shelter in which all the sites constructed demand water supply and other sanitary infrastructures.

Currently the city's centralized water supply system of Addis Ababa is supplying pure water to address the increasing water demand. But insufficiency and poor management of the available water resource is posing problems especially in newly constructed condominium sites. Currently Addis Ababa Water and Sewerage Authority(AAWSA) addressed about 54% of the total water demand of the city. But the city administration also currently undertaking different projects in order to solve the problem. In addition to shortage from the supply side about 39% of the produced water by the authority is registered as Non Revenue water in which about 25% is a direct loss. As the urban population rises the water demand is also increasing. Therefore a sustainable water supply alternative is significant (AAWSA, 2014).

The land cover in Addis Ababa is dramatically changing from pervious to impervious due to urbanization and the expansion of the urban area at the sides of the city. At the study site about 80% of the land became impervious. The increase in the impervious layer of a land poses runoff problems in which most of the rainfall will be changed to runoff. In those regards addressing water demand and storm water runoff from lands that are undergoing urban development and from lands which already developed causes significant problems for landowners in its path, for local governments and for the water bodies which ultimately receive it (Malesu M.M., etal, 2006).

Due to the above mentioned several problems, i.e. topography, pressure and water demand fluctuations and management issues the city is facing challenges to address the increasing water demand. As a result of storm water, sediment fills drainage ditches and channels, causing flooding. The sediment fills rivers, lakes and estuaries, destroying wildlife habitat, degrading water quality, and requiring extensive restoration. High stream velocity causes bank erosion. In addition, the process removes natural vegetation and compact the soil. The land's surface becomes more impervious (Thamer et al, 2007).

Therefore looking for alternative ways of supporting the municipal water supply as well as solving the problem of storm water management in Addis Ababa city Rainwater Harvesting can be essential alternative. The need for alternative, affordable and safe water supplies is critical if poverty is to be reduced and an environment conducive to progress and economic development fostered.

## 1.3 Objective of the study

### 1.3.1 General Objective

To assess the potential of rain water harvesting practice to solve problems of both increasing water demand and stormwater in Addis Ababa city Jemo condominium site

### 1.3.2 Specific Objectives

- To determine the actual water demand of the study area
- To assess the stormwater problems of the study area at times of peak runoff
- To determine the amount of rainfall that can be harvested from roof tops during rain periods and determine storage capacity needed
- To introduce the possible rainwater harvesting technologies available for the study area based on the result of the study

## 1.4 Research Questions

1. What is the real water demand and how much of the demand could be satisfied with the municipal water supply?
2. How much rainwater can be harvested on catchment surface of the roof and how much of water demand can be supported?
3. How much of the runoff that pose problems could be reduced?
4. What conditions can be required to implement/introduce rainwater harvesting technologies to the study area and which type is appropriate?

## 1.5 Scope and Limitations of the study

This study focused only condominium houses with domestic demands due to time and financial limitations. The study also did not considered the qualitative aspects of rainwater harvesting since the plan was to support on the non potable purposes of the water. As far as my knowledge concerns there was no study available in this study area and lack of available studies also limited the study in some areas. The rainwater harvesting in this thesis scenario focused only on roof water harvesting

## 2 CHAPTER TWO-LITERATURE REVIEW

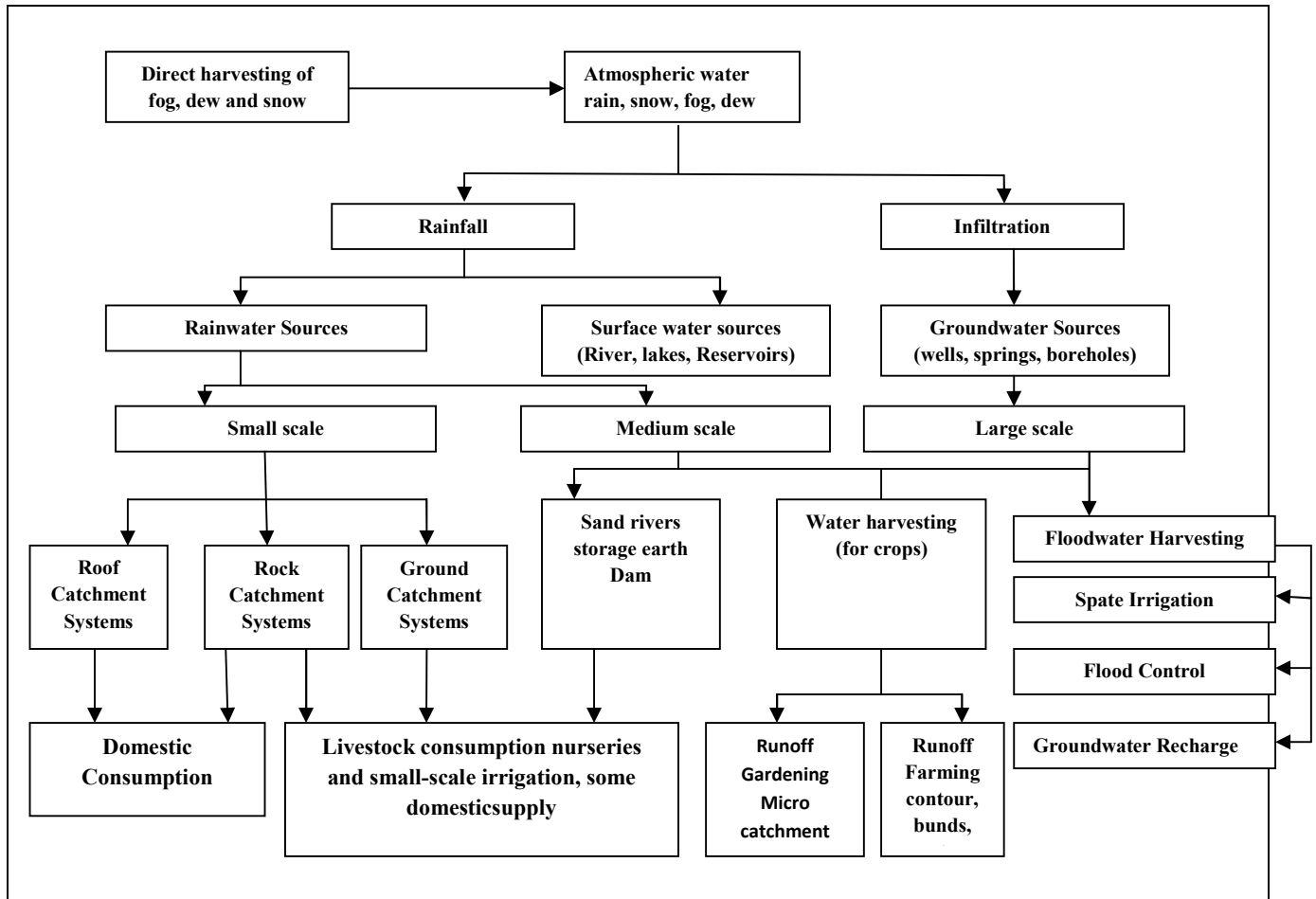
Demand on water resources has increase day to day due to the population growth and expansion in urbanization, industrialization and irrigated agricultural. Adopting the concept of sustainability and conservation of water resources can help to cope with the global water shortage. Rainwater harvesting system is one of the concepts that can be implemented to meet the water shortage problem. Furthermore, rainwater has a lot of potential as an alternative water resource for the future because of its high quality.

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. (Boers, et al., 1982) 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 region. Among other available alternative sources for water supply, rainwater harvesting has become the most economical solution for the water crisis (Boers et al, 1982).

Rainwater harvesting has been practiced for more than 4, 000 years, and, in most developing countries, is becoming essential owing to the temporal and spatial variability of rainfall. Rainwater harvesting is necessary in all areas as it brings water closer to the houses more than what even a stream could do. It is also important in areas having enough rainfall but lacking any kind of conventional, centralized government supply system, and also in areas where good quality fresh surface water or groundwater is lacking. Critchley and Reij, (1989) argue that the application of an appropriate rainwater harvesting technology can make possible utilization of rainwater as a valuable and necessary water resource (Critchley et al, 1989).

### 2.1 Rainwater Harvesting System

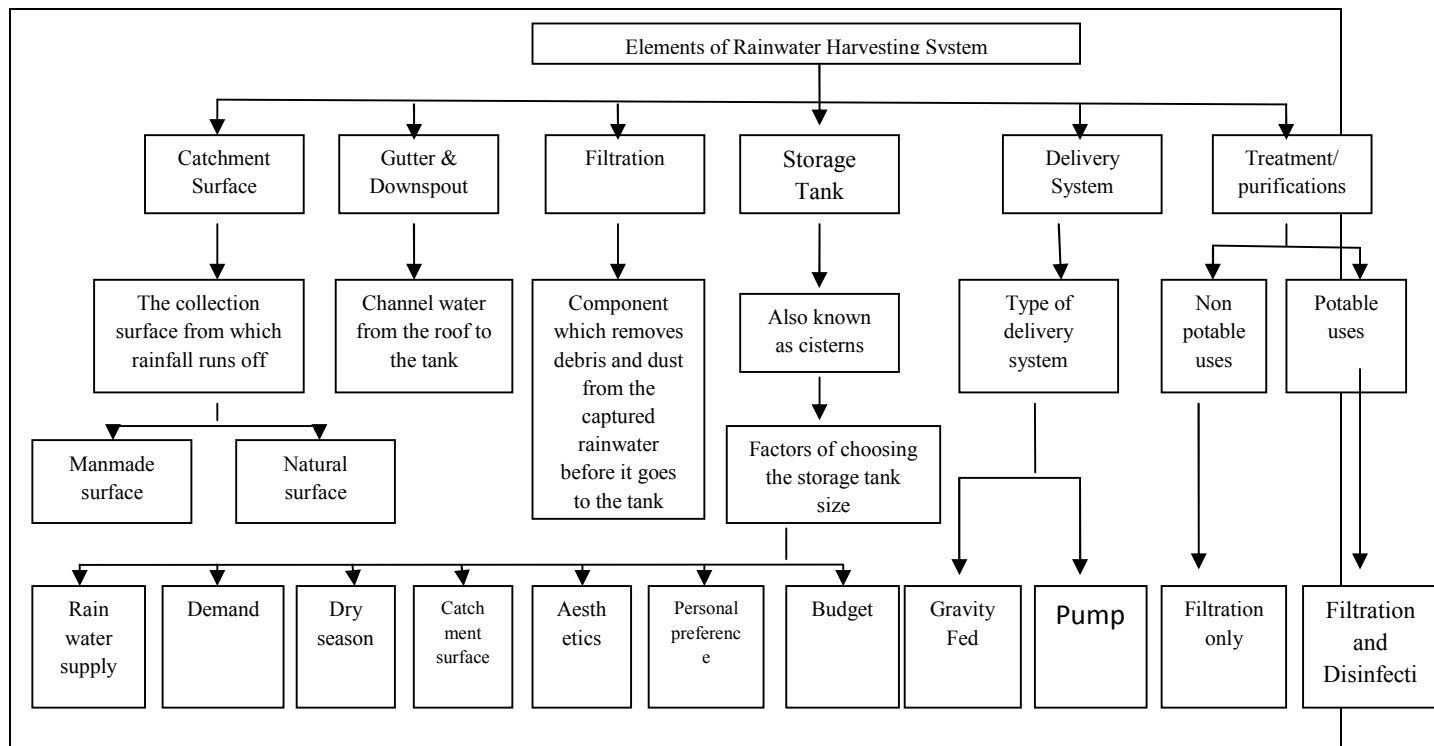
Rainwater can be captured by using the rainwater harvesting system. Generally, rainwater harvesting system is the direct collection of rainwater from roofs and other purpose built catchments, the collection of sheet runoff from man-made ground or natural surface catchments and rock catchments for domestic, industry, agriculture and environment use. The systems can be categorized as small, medium and large scale. Normally, the size of rainwater harvesting was based on the size of catchment area (Thamer et al, 2007). In scientific term, rainwater harvesting refers to collection and storage of rainwater and also other activities aimed at harvesting surface and groundwater, prevention of losses through evaporation and seepage and all other hydrological studies and engineering interventions, aimed at conservation and efficient utilization of the limited water endowment of physiographic unit as a watershed (Jamaluddin & Huang, 2007). The category of rainwater harvesting is depicted in Figure 1.



**Figure 1: Rainwater Harvesting Category (Jamaluddin & Huang, 2007)**

Rainwater harvesting is a traditional practice that dates back hundreds of years. Archeological evidence attests to the capture of rainwater as far as 4,000 years ago and the concept of rainwater harvesting in China may date back 6,000 years (TWDB, 2005). Rainwater has been the main source of water supply for potable and non-potable uses in the old days because the water supply systems were not developing yet. The method of rainwater harvesting at that time was very simple. Usage of the collected water volume from rainwater harvesting was direct and without any treatment. Usually, the rainwater was mostly collected from roofs and some was directly collected (Thamer et al, 2007).

Rainwater harvesting system has been implemented in many countries such as USA, Japan, China, India, Germany and Australia to support the increasing water demand. The integration between rainwater harvesting system and existing conventional water supply systems will help to meet the demand and contribute in the sustainability of the water supply. There are six main elements in rainwater harvesting system as in Figure 2. They are catchment area, gutter and downspout, filtration system, storage system, delivery system and treatment.



**Figure 2 Elements of Rainwater Harvesting System ( Shaari N etal. , 2009)**

Rain water harvesting techniques can be divided into two types depending on source of water collected; namely, the in situ (on site) and the ex situ (off site) types of rainwater harvesting, respectively. In essence, in situ rainwater harvesting technologies are soil management strategies that enhance rainfall infiltration and reduce surface runoff. The in situ systems have a relatively small rainwater harvesting catchment typically not greater than 5-10 m from point of water infiltration into the soil. The rainwater capture area is within the field where the crop is grown (or point of water infiltration). This technology often serves primarily to recharge soil water for crop and other vegetation growth in the landscape (Malesu M.M., etal, 2006). Malesu argues that in situ technique emphasizes on water management and conservation structures which are mostly traditionally considered for soil moisture conservation. This approach aims at maximum infiltration and minimum surface runoff to achieve better yields where soil moisture is a constraint. Hatibu, 2003 defines the ex-situ technique as systems which have rainwater harvesting capture areas external to the point of water storage.

The rainwater capture area varies from being a natural soil surface with a limited infiltration capacity, to an artificial surface with low or no infiltration capacity. Commonly used impermeable surfaces are rooftops can provide the platform to collect substantial amounts of water for different uses. As the storage systems of ex situ systems often are wells, dams, ponds or cisterns, water can be abstracted easily for multiple uses including irrigation or

domestic, public and commercial uses through centralized or decentralized distribution systems.

The storage time of the collected and stored water in cisterns, dams and tanks is more dependent on the size of capture area, size of storage unit and rate of outtake rather than residence time and flow gradient through the soil. Rainwater harvesting systems require few skills and little supervision to operate. The major concerns are preventing of contamination of the tank during construction and replenishing during rainfall. Contamination of the water supply from contact with certain materials can be avoided by the use of proper materials during construction of the system.

## 2.2 Components of Rainwater Harvesting System

A rainwater harvesting system comprises of components for - transporting rainwater through pipes or drains, filtration, and tanks for storage of harvested water. The common components of a rainwater harvesting system are: -

1. **Catchments:** The surface which directly receives the rainfall and provides water to the system is called catchment area. It can be a paved area like a terrace or courtyard of a building, or an unpaved area like a lawn or open ground. A roof made of reinforced cement concrete (RCC), galvanized iron or corrugated sheets can also be used for water harvesting.
2. **Coarse Mesh:** It prevents the passage of debris, provided in the roof.
3. **Gutters:** Channels which surrounds edge of a sloping roof to collect and transport rainwater to the storage tank. Gutters can be semi-circular or rectangular and mostly made locally from plain galvanized iron sheet. Gutters need to be supported so they do not sag or fall off when loaded with water. The way in which gutters are fixed mainly depends on the construction of the house, mostly iron or timber brackets are fixed into the walls.

Gutters and down pipes of different materials like PVC pipes, G.I pipes, fibrocement pipes, wooden pipes can be used for gutters. Depending on the intensity of the rainfall (inch/hr), the sizes of the pipes are determined. Table 1 illustrates the dimensions depending on rainfall intensity. It is recommended to keep the dimension 10-15% more than the required one (MHWD, 2002)

Table 1 Piping dimensions for designing of gutters, 2000 (Stein, 2000)

*Piping dimensions (Stein & Reynolds, 2000)*

Pipe diameter	Highest rainfall (inch/hr)					
	1	2	3	4	5	6
2	2176	1088	725	544	435	363
3	6440	3220	2147	1610	1288	1073
4	13840	6920	4613	3460	2768	2307
5	25120	12560	8373	6280	5024	4187
6	40800	20400	13600	10200	8160	6800
8	88000	44000	29333	22000	17600	14667

4. **Conduits:** Conduits are pipelines or drains that carry rainwater from the catchment or rooftop area to the harvesting system. Commonly available conduits are made up of material like polyvinyl chloride (PVC) or galvanized iron (GI).

5. **First-flushing:** A first flush device is a valve which ensures flushing out of first spell of rain away from the storage tank that carries a relatively larger amount of pollutants from the air and catchment surface.

6. **Filters:** The filter is used to remove suspended pollutants from rainwater collected from rooftop water. The Various types of filters generally used for commercial purpose are Charcoal water filter, Sand filters, Horizontal roughing filter and slow sand filter.

A filter is an important part of the inflow structure of a RWH System. Once screens and roof washers remove large debris, other filters are available which help improve rainwater quality. Keep in mind that most filters available in the market are designed to treat municipal water or well water. Therefore, filter selection requires careful consideration. Screening, sedimentation, and pre-filtering occur between catchment and storage or within the tank. A cartridge sediment filter, which traps and removes particles of five microns or larger is the most common filter used for rainwater harvesting. Sediment filters used in series, referred to as multi-cartridge or inline filters, sieve the particles from increasing to decreasing size. These sediment filters are often used as a pre-filters for other treatment techniques such as ultra-violet light or reverse osmosis filters which can become clogged with large particles. Unless something is added to rainwater, there is no need to filter out something that is not present. When a disinfectant such as chlorine is added to rainwater, an activated carbon filter at the tap may be used to remove the chlorine prior to use. It should be remembered that activated carbon filters are subject to becoming sites of bacterial growth. Chemical disinfectants such as chlorine or iodine must be added to the water prior to the activated carbon filter. If ultraviolet light or ozone is used for disinfection, the system

should be placed after the activated carbon filter. Many water treatment standards require some type of disinfection after filtration with activated carbon. Ultraviolet light disinfection is often the method of choice (UN-HABITAT, 2005).

Table 2 Rainwater treatment options and expected results, 2015

Method	Location	Result
<b>Screening</b>		
Strainers and Leaf Screens	Gutters and Leaders	Prevent leaves and other debris from entering tank
<b>Settling</b>		
Sedimentation	Within Tank	Settles particulate matter
<b>Filtering</b>		
In-line/Multi Cartridge	After Pump	Sieves sediment
Activated Carbon*	At Tap	Removes chlorine
Reverse Osmosis	At Tap	Removes contaminants
Mixed Media	Separate Tank	Traps particulate matter
Slow Sand	Separate Tank	Traps particulate matter
<b>Disinfecting</b>		
Boiling/Distilling	Before Use	Kills microorganisms
Chemical Treatments (Chlorine or Iodine)	Within Tank or Pump	Kills microorganisms (liquid, tablet or granule)
Ultraviolet Light	Should be located after the activated carbon filter before trap	Kills microorganisms
Ozonation	Before Tap	Kills microorganisms

Source: (UN-HABITAT, 2005)

7. **Storage facility:** There are various options available for the construction of these tanks with respect to the shape, size, material of construction and the position of tank and they are:-  
 Shape: Cylindrical, square and rectangular. Material of construction: Reinforced cement concrete (RCC), masonry, Ferro cement etc.

Position of tank: Depending on land space availability these tanks could be constructed above ground, partly underground or fully underground. Some maintenance measures like disinfection and cleaning are required to ensure the quality of water stored in the container. If harvested water is decided to recharge the underground aquifer/reservoir, then some of the structures mentioned below are used.

The quantity of water stored in a water harvesting system depends on the size of the catchment area and the size of the storage tank. The storage tank has to be designed according to the water requirements, rainfall and catchment availability. The following table shows tank capacities of different countries.

Table 3 Tank capacities for different rainfall countries, 2015

Region	Average Annual Rainfall * (mm)	Sample Roof Area * (m <sup>2</sup> )	Recommended Tank Capacity (m <sup>3</sup> )	Estimated Daily Supply (litres)
<b>AFRICA</b>				
Ghana, N.E.region	800 in two wet seasons	30	7.5	66
Swaziland, Lowveld	635 with 6 dry months	30	5.0	37
Botswana Francistown	470 with 7-9 dry months	30	4.5	31
			4.5	66
			8.0	31
<b>INDONESIA</b>				
Java, Jakarta area	1800, no really dry months	30	1.2	30
			5.5	60
			3.6	30
			7.8	60
Madura	1500 with 5 dry months	30	5.1	30
Java, Yogyakarta	1800 with 6 dry months	30	5.0	30
<b>THAILAND</b>				
Khon Kaen area	1300 with 4 dry months	60	11.5	90
			30	45
<b>AUSTRALIA</b>				
Sydney	1210 no dry months	320	126	800
			30	74
Griffith, New South Wales	390 with no defined wet season	965	336	800
			30	25
<b>BERMUDA</b>				
	1500 no dry months	30	11.7	-

Source: (UN-HABITAT, 2005)

8. **Recharge structures:** Rainwater Harvested can also be used for charging the groundwater aquifers through suitable structures like dug wells, bore wells, recharge trenches and recharge pits. Various recharge structures are possible - some which promote the percolation of water through soil strata at shallower depth (e.g., recharge trenches, permeable pavements) whereas others conduct water to greater depths from where it joins the groundwater (e.g. recharge wells). At many locations, existing structures like wells, pits and tanks can be modified as recharge structures, eliminating the need to construct any fresh structures. Some of the few commonly used recharging methods are recharging of dug wells and abandoned tube wells, Settlement tank, Recharging of service tube wells, Recharge pits, Soak ways /Percolation pit, Recharge troughs, Recharge trenches, Modified injection well.

### 2.3 Rainwater Harvesting Potential

The total amount of water that is received in the form of rainfall over an area is called the rainwater endowment of that area. Out of this, the amount that can be effectively harvested is called the water harvesting potential. Among the several factors that influence the rainwater harvesting potential of a site, climatic conditions specially rainfall and the catchment characteristics are considered to be the most important (UN-HABITAT, 2005).

The annual yield of water which is probably measured in unit of liters is the product of roof type and annual average rainfall of an area. Rain water yield varies with the size and texture of the catchment area. A smoother, cleaner and impervious roofing material contributes to better water quality and greater quantity. Potential of roof rainwater harvesting in a study area has evaluated by using following formula (Gould J. a.-P., 1999)

$$S = R * A * Cr$$

Where, S = Potential of roof rainwater harvesting (In cu. m.)

R = Average annual rain fall in m.

A = Roof area in Sq. m.

Cr = Coefficient of Runoff.

**Rainfall Quantity:** Rainfall is the most unpredictable variable in the calculation and hence, to determine the potential rainwater supply for a given catchment, reliable rainfall data are required, preferably for a period of at least 10 years. Also, it would be far better to use rainfall data from the nearest station with comparable conditions (UN-HABITAT, 2005).

**Pattern:** The number of annual rainy days also influences the need and design for rainwater harvesting. The fewer the annual rainy days or the longer the dry period, the more the need for rainwater collection in the region. However, if the dry period was too long, big storage tanks would be needed to store rainwater. Hence in such regions, it is more feasible to use rainwater to recharge ground water aquifers rather than for storage (UN-HABITAT, 2005).

The amount of water harvested depends on the frequency and intensity of rainfall, catchment characteristics, water demands, how much runoff occurs and how quickly or how easy it is for the water to infiltrate through the subsoil and percolate down to recharge the aquifers. In urban areas, where adequate space for surface storage is not available and water levels are deep enough to accommodate additional rainwater to recharge the aquifers, roof top rainwater harvesting is the ideal solution to solve the water supply problems. The urban housing complexes or institutional buildings have large roof area and can be utilized for harvesting roof top rainwater to recharge aquifer in urban areas. The following table shows availability of rainwater through roof top rainwater harvesting. (UN-HABITAT, 2005)

Table 4 Availability of Rainwater through rooftop Rainwater Harvesting

Rainfall mm	100	200	300	400	500	600	800	1000	1200	1400	1600	1800	2000
Roof Top Area (sq.m.)	Harvested Water from Roof Top (m <sup>3</sup> )												
20	1.6	3.2	4.8	6.4	8.0	9.6	12.8	16	19.2	22.4	25.6	28.8	32
30	2.4	4.8	7.2	9.6	12	14.4	19.2	24	28.8	33.6	38.4	43.2	48
40	3.2	6.4	9.6	12.8	16	19.2	25.6	32	38.4	44.8	51.2	57.6	64
50	4.0	8.0	12	16	20	24	32	40	48	56	64	72	80
60	4.8	9.6	14.4	19.2	24	28.8	38.4	48	57.6	67.2	76.8	86.4	96
70	5.6	11.2	16.8	22.4	28	33.6	44.8	56	67.2	78.4	89.6	100.8	112
80	6.4	12.8	19.2	25.6	32	38.4	51.2	64	76.8	89.6	102.4	115.2	128
90	7.2	14.4	21.6	28.8	36	43.2	57.6	72	86.4	100.8	115.2	129.6	144
100	8.0	16	24	32	40	48	64	80	96	112	128	144	160
150	12	24	36	48	60	72	96	120	144	168	192	216	240
200	16	32	48	64	80	96	128	160	192	224	256	288	320
250	20	40	60	80	100	120	160	200	240	280	320	360	400
300	24	48	72	96	120	144	192	240	288	336	384	432	480
400	32	64	96	128	160	192	256	320	384	448	512	576	640
500	40	80	120	160	200	240	320	400	480	560	640	720	800
1000	80	160	240	320	400	480	640	800	960	1120	1280	1440	1600
2000	160	320	480	640	800	960	1280	1600	1920	2240	2560	2880	3200
3000	240	480	720	960	1200	1440	1920	2400	2880	3360	3840	4320	4800

Source: (UN-HABITAT, 2005)

## 2.4 Catchment Area Characteristics

The characteristics of the catchment area determine the storage conditions. All calculations relating to the performance of rainwater catchment systems involve the use of runoff coefficient to account for losses due to spillage, leakage, infiltration, catchment surface wetting and evaporation, which will all, contribute to reducing the amount of runoff. (Runoff coefficient for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface).

**Water harvesting potential = Rainfall (mm) x Area of catchment x Runoff coefficient or**

**Water harvesting potential = Rainfall (mm) x Collection efficiency**

Source: (UN-HABITAT, 2005)

The collection efficiency accounts for the fact that all the rainwater falling over an area cannot be effectively harvested, because of evaporation, spillage etc. Factors like runoff coefficient: Runoff coefficients for various catchment surfaces) and the first-flush wastage are taken into account when estimating the collection efficiency.

### Runoff

Runoff is the term applied to the water that flows away from a catchment after falling on its surface in the form of rain. Runoff can be generated from both paved and unpaved catchment areas of buildings. The nature of the catchment determines the quantity of runoff that occurs from the area. For example, about 70 per cent of the rainfall that occurs over the tiled surface of a terrace would flow as runoff while only 10 per cent of the rainfall on a wooded or grassy area would flow, the rest being retained on the surface and getting percolated into the ground. From the point of view of quality, runoff can be divided into two types: runoff from paved surfaces (e.g., roofs and courtyards) and runoff from unpaved surfaces (e.g., lawns and playgrounds). Quality of runoff from paved surfaces is better since runoff from unpaved surfaces may have bacterial or other contamination. If water is to be stored for drinking purposes, it is advisable that only runoff from paved surfaces is used for the purpose (Pacey et al, 1989).

### Runoff coefficient

Runoff coefficient is the factor which accounts for the fact that all the rainfall falling on a catchment cannot be collected. Some rainfall will be lost from the catchment by evaporation and retention on the surface itself. (Refer Table 2.1 for runoff coefficient). Rainwater yield varies with the size and texture of the catchment area. A smoother, cleaner, and more impervious roofing material contributes to better water quality and greater quantity. While loss is negligible for pitched metal roofs, concrete or asphalt roofs average less than 10 per cent loss, and built up tar and gravel roofs average a maximum of 15 per cent loss. Losses can also occur in the gutters and in storage. Regardless of roofing material, many designers assume loss on annual rainfall up

to 25 per cent. These losses are due to several factors: the roofing material texture which slows down the flow; evaporation; and inefficiencies in the collection process (Pacey et al, 1989).

**Table 5: Runoff Coefficients for various Catchment Surfaces**

Type of catchment	Coefficient
Roof Catchments	
Tiles	0.8 - 0.9
Corrugated metal sheets	0.7 – 0.9
Ground Surface Coverings	
Concrete	0.6 – 0.8
Brick pavement	0.5 - 0.6
Untreated Ground Catchments	
Soil on slopes less than 10 per cent	0.0 – 0.3
Rocky natural catchments	0.2 – 0.5
Green area	0.05 – 0.10

Source: (Pacey et al, 1989)

## 2.5 Rainwater and Community

Domestic Rainwater Harvesting (DRWH) is a sub set of rainwater harvesting whereas policies and legislation mostly refer to the generality. The popular means of water harvesting is surface run-off providing water in large quantity, of low quality mainly for agriculture. In water policies of the African countries, such as Kenya, RWH as a means of poverty alleviation refers to harnessing water by constructing appropriate dams and pans for collection of water for small-scale agriculture and livestock. In Kenya, DRWH can mean both surface run off and roof water harvesting while in Sri Lanka and Thailand it means only roof water harvesting. Due to recent rapid development of roof water harvesting in some countries, some policy documents now distinguish between roof water harvesting and rainwater harvesting. Although the one of the largest development of roof water harvesting took place in Thailand in the 1980's, neither rainwater harvesting nor roof water harvesting are mentioned in the local Water Act (Ariyabandu, 2003). Therefore, interpretation is crucial for the implementation of policies, depending on the need of the hour. As shown in table 4, most countries of the world, state owns the water resources, while the current debate in the water sector reforms is the Community Verses State Ownership in Water Resources Development. Although the presumption of most activists is that water resources development should be transferred to community ownership for it to serve the communities and attain sustainable development, all water policies (contributing to this view) are still engrossed in the conventional state ownership of water resources.

Table 6 Ownership of water at different countries, 2013

*Ownership of water and its impact. (Ariyabandu, 2003)*

Country	Status	Description
Sri Lanka	Public Ownership	No restriction on development of DRWH
India	Not specified	Water is a state object. No potential threat to development of DRWH
Bangladesh	State ownership	No constraints on development of DRWH
Thailand	State ownership including atmospheric water	Storage of water requires a license as decided by the river basin committees
Kenya	State ownership	Requires a permit to construct water works. Not clear whether this includes DRWH. No restriction on water for domestic use.
Uganda	State ownership	Requires a permit to construct water works. Not clear whether this includes DRWH. No restriction on water for domestic use.
Ethiopia	Public Ownership	No permit is required. But large scale water development is practiced without permission. Status of DRWH is not clear. No restriction on water for domestic use.

Community operation and maintenance, along with community participation and control, is essential to the successful implementation, operation and maintenance of any rainwater project, eventually which encourages demand management. Demand management strategies are unlikely to succeed without strict individual self-discipline and community control / recommendations agreed by the community themselves regarding efforts to promote water conservation. Evidences show that combined public private sector approaches for rainwater harvesting initiatives can work effectively in certain circumstances (Gould J. , 2007).

## 2.6 Water Shortage in Ethiopia

The Ethiopian economy has gone through rapid structural change for the last 3 decades. In global arena, Ethiopia is often considered as a ‘developing’ country. The urban growth is dynamic in accordance with the rapid economic growth and industrialization. The infrastructure has been strained by rapid urban growth and there are high needs of improvement of amenities such as water supply, electricity, transportation, environment and drainage. The impacts of the growth have put excessive demands on water supply and water resources. Besides economy and industrialization, the number of population also has an increase.

A number of factors for urban water supply shortage are indicated in different literatures. Those which focus on the problem in developing countries point out the common factors like weak actions to reduce environmental degradation, economic development, distribution inefficiency of the water supply system, inconsistency of the system, climatic changes (temperature and rainfall variability), topography of the area, population growth and urbanization, water loss in the system, capacity of towns to manage the water system.

Environmental degradation affects both the quantity and quality of water resources. (WSP, 2009) World Water Week synthesis report 2009 indicated that many of the actions for reducing environmental degradation are focused at the local level and scaling-up these to the river basin

and regional levels, and the ability to tailor solutions are major challenges. The report also showed that primary threats to water resources and ecosystems emerge from greater wealth and consumption and increasing populations. These threats will be exacerbated by climate change and must be addressed together. Developing large water schemes for urban areas require relatively huge investments. Governments of developing countries fail to finance these investments (Maggie A. et al, 2007). Montgomery (2007) pointed out that in many developing countries lack of financial resources and low prioritization of water and sanitation constrain both the maintenance and expansion of water and sanitation services. However, using efficiently the available finance is another challenge.

Institutional issues of urban water supply are raised by WSP (2009) in such a way that the poor performance of water supply and sanitation (WSS) services is often due to an inappropriate institutional framework, lack of regulatory mechanisms, an absence of appropriate attitudes and skills, and a lack of explicit directives and incentives to serve the poor.

Water governance in Addis Ababa, the capital city of Ethiopia, is very poor. According to the World Bank, the Addis Ababa population has grown from 2 million to about 4 million in the last fifteen years, but capital investment in water supply and sanitation services, did not follow. During the same period, the administrative area had expanded from 24,000 hectare to 51,949 hectare. As a result, there is heavy pressure on the Addis Ababa City Administration and the Addis Ababa Water and Sewerage Authority to extend public services that include safe drinking water supply and sanitation services.

## **2.7 Rainwater Harvesting Context in Ethiopia**

Ethiopia is a country endowed with a reasonable level of fresh water resources. The long term average annual rainfall as reported in the 1996 Food Security Strategy of FDRE was 913 mm. This represents more than a thousand billion m<sup>3</sup> rainwater a year precipitating onto the 1.13 million Km<sup>2</sup> land area of the country. This claim on the potentials of the rainwater resource had been confirmed by a 2006 UNEP report. A UNEP report released in 2006 acknowledged the fact that Ethiopia has a potential rainwater harvest equivalent to 11,800 m<sup>3</sup> per capita of the 2006 population. Which reportedly is capable of meeting the needs of over 520 million people. The annual surface runoff flowing in the 12 major river basins of the country is estimated to comprise 122 billion m<sup>3</sup> (MoWR, 1999), with a further 185 billion m<sup>3</sup> groundwater stored in the aquifers (ALEMAYEHU, 2006). Rainwater is known to be the mother of surface and ground water sources; nevertheless, both global and local experiences indicate that its effective utilization has by and large been overlooked. During the past few decades however, there have been encouraging developments that has been well recognized in many countries including Ethiopia. This is reflected by the fact that there are efforts being made by the Ethiopian government to promote ponds for supplementary irrigation, and the introduction of various RWH harvesting technologies for domestic water supply by NGOs. The effective promotion of the rainwater alternative, nevertheless, requires facilitation for a wider involvement of the public and decision-

makers towards conscientious actions. This among other things, includes strengthening the RWH capacity of experts, technicians and artisans, working in the field, building the awareness of end-users, persistent emphasis on information availability, accessibility and dissemination as well as the integration of rainwater resource management (IWRM), and as a cross-cutting issues for other sector development initiatives (ERWHA, 2009).

## 2.8 Benefits of Rainwater Harvesting System

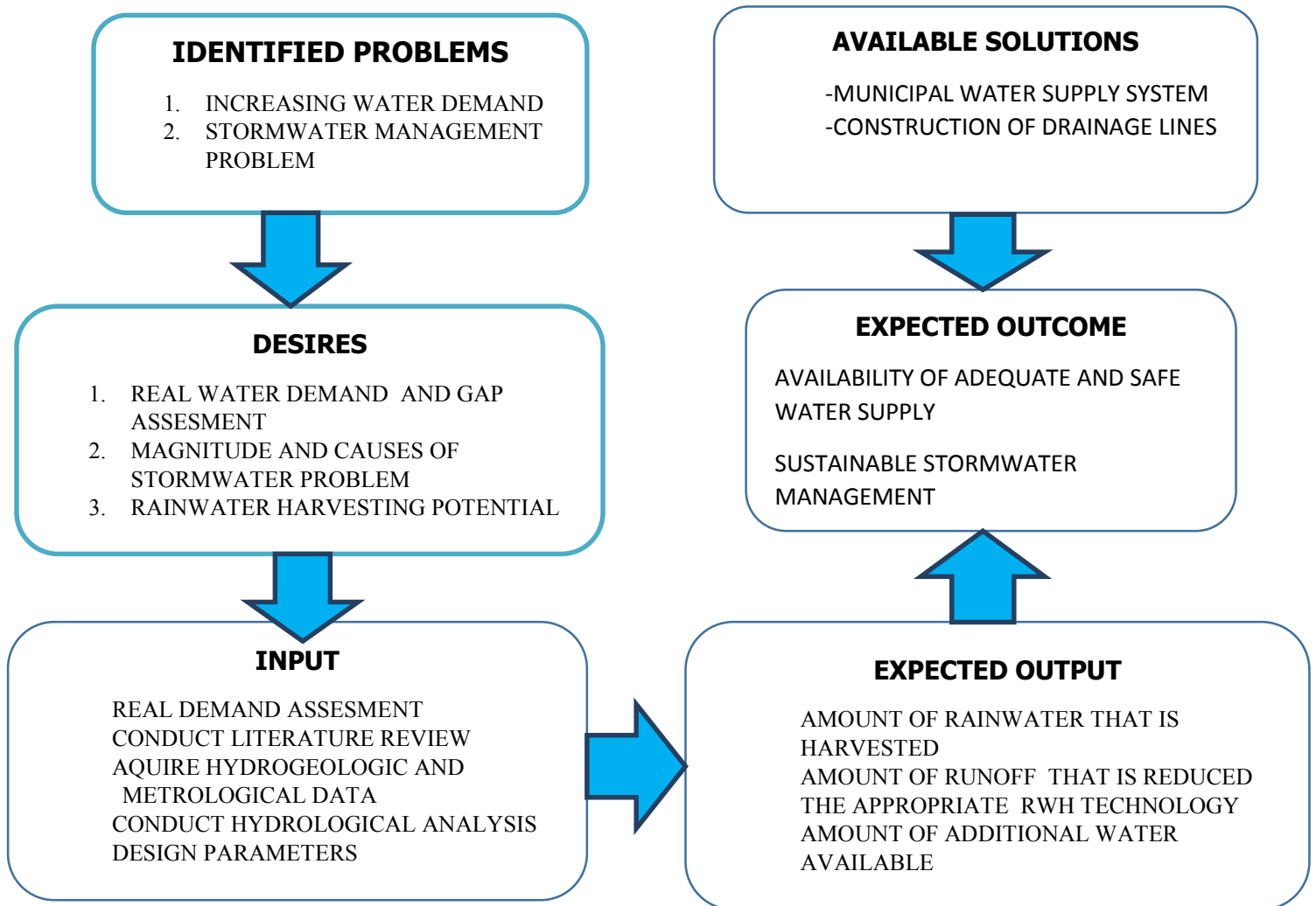
Rainwater harvesting is part of sustainable architecture and it is bring a lot of advantages; not just for users but also to environment and government. In short, Table 6 shows some of the benefits of rainwater harvesting.

Table 7: Benefits of Rainwater Harvesting To Users, Environment and Government ( Shaari N etal. , 2009)

<b>Users</b>	<b>Government</b>	<b>Environment</b>
Rainwater is a relatively clean, independent and ample water supply	Reduce the burden for new investment to replace the ageing systems and adding the water supply Infrastructures	By capturing rainwater, we reduce the abundant amount of rainwater that goes to the drainage and avoiding the floods phenomena
Rainwater Harvesting system uses simple technologies that are inexpensive and easy to maintain		
Rainwater harvesting system is very easy to handle and flexible. It can be modular in nature, allowing expansion, Reconfiguration/ relocation.	Potentially avoid the cost of accessing public water systems when it is not economically feasible	We can significantly reduce our reliance on water storage dam. This will avoids ecological damage to the area which has to be submerged to build the dam
Save money by reducing the volume of water purchased from public systems	Rainwater harvesting system can reduce construction cost in each development because it can be easily retrofitted to an existing structure or built during new construction	Rainwater is superior for landscape use and plants thrive on rainwater well rather than other sources that might have chemical compounds that polluted them and soils. This is because rainwater forces salts down and away from root zone when it percolates into the soil
Save money by extending the life of plumbing fixtures and appliances		
Avoid interrupted service from centralized water systems or overuse of water from a well		

## 2.9 Conceptual framework

The overall conceptual framework of the study is based on the problems identified in Addis Ababa which are increasing water demand and surface runoff. Areal water demand and supply assessment was conducted, Magnitude of stormwater determined and the rainwater harvesting potential is also determined after the inputs of hydrological data. Finally the harvested water potential to reduce surface runoff and to support water demand determined as shown in the following figure.

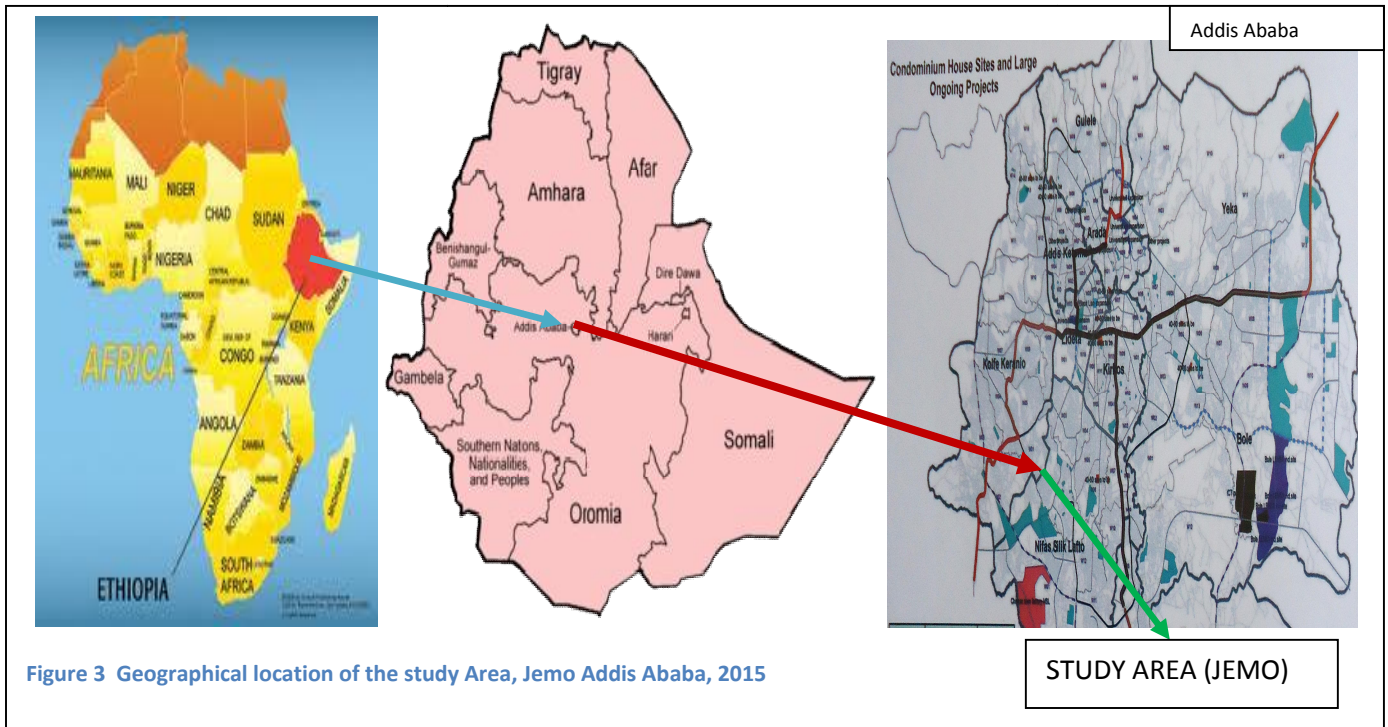


### 3 CHAPTER THREE-RESEARCH METHODS AND MATERIALS

#### 3.1 Study area and period

This study is conducted in Addis Ababa city, the capital city of Ethiopia, which is one of the largest urban center in sub Saharan Africa. The city covers an area of 51948.85 hectare of land.

Nifas Silk Lafto is one of the 10 sub cities in Addis Ababa city Administration in which Jemo condominium site the specific study area exists. The study was conducted from November 2014 to May 2015.



#### 3.2 Study design

A descriptive quantitative study design was used to determine each variable in order to achieve the objectives of the study. Data types, collection and analysis methods was also designed before the study.

#### 3.3 Sample size

For household survey sample was drawn from the total households of 9,800 at the study site. The sample size is determined using statistical software called Epi-info version 7.1. In calculating the sample size the following parameters and assumptions are considered:

- Prevalence (p) of respondents satisfaction value = 0.5 (0.5 is taken to obtain maximum sample size and due to the absence related study in the area).
- Margin of error (d) which is 0.05 (i.e. 5% margin of error)
- Confidence Interval of 95%

The sample size becomes 384, and assuming 10% non-response rate the final sample size becomes 422. A total of 422 households living in Jemo 1 was included in the survey.

### 3.4 Sampling methods

A systematic random sampling technique was applied in order to select the study units starting from the first block at an interval of 23 houses.

### 3.5 Data collection

The data was collected using semi structured questionnaires, reviewing literatures and personal observations with interviewing responsible bodies. Both primary and secondary data were also collected. The collected data are presented as follows.

#### 3.5.1 Primary data collection

Most important characteristics which are crucial for rainwater harvesting designing from Jemo I condominium site was collected using the semi structured questionnaires from the predetermined 422 sample households. These households have a total population of 1596 in which average person in a single house is 4. From the 422 households 183(43.4%) of them are owners of their house and the rest 239(56.6%) are households rented from others. Average monthly income is 5213.5 Birr and average monthly expenditure for water is about 199 Birr. On average of the 199 birr each household expends 27.35Birr (13.7%) for AAWSA and the rest 171.65 Birr (86.3%) for other private sellers. The cost for water from AAWSA is 1.75 birr for 1-7m<sup>3</sup> water, 3.75 birr for 8-20m<sup>3</sup> of water, 4.75 birr for 21-40m<sup>3</sup> of water and 5.75 birr for more than 40 m<sup>3</sup> of water, etc. But at Jemo I condominium site the cost of water when there is no water at pipe lines is 2 birr for a single 20l Jerican without considering labor cost and 12 birr when considering labor cost. All respondents responded that the water from AAWSA is not continuous and sufficient to satisfy their basic needs. The following figure compares cost of water direct from AAWSA and cost of water at private markets when there is no sufficient water at pipelines.

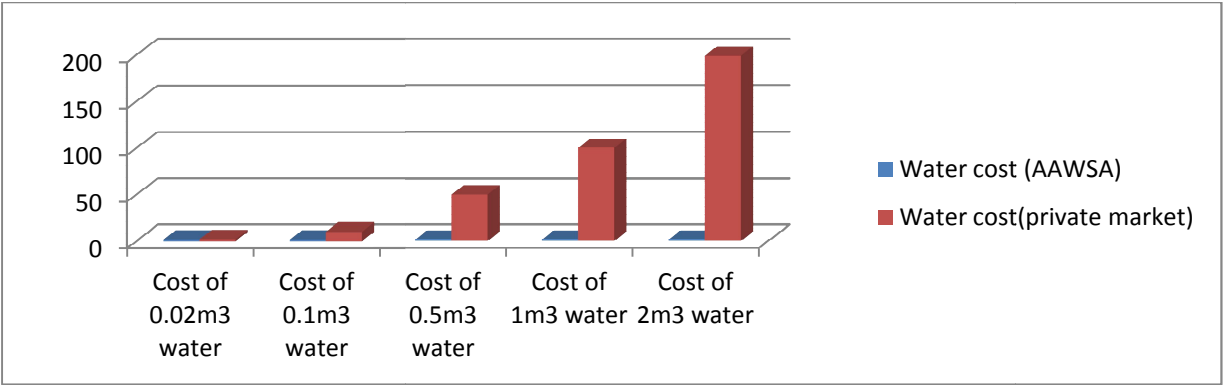


Figure 4 Comparison of water cost of AAWSA and at private sellers, Jemo Addis Ababa, January 2015

Respondents also asked their experience of using rainwater for domestic purposes and their willingness to use it in the future as their water source for non-potable purposes and they responded that 325(77%) of them had experience of using rainwater and the rest 97(23%) does not have experience of using rainwater. All respondents were willing to use rainwater to satisfy their non-potable water demands.

Their different water demands were also assessed during the survey. On average the households demand about 65l/c/d water from water supply services which is near the AAWSA standard set before that is 70l/c/d without considering other demands. The following chart shows the detail breakdown of water demand for different purposes as collected from respondents.

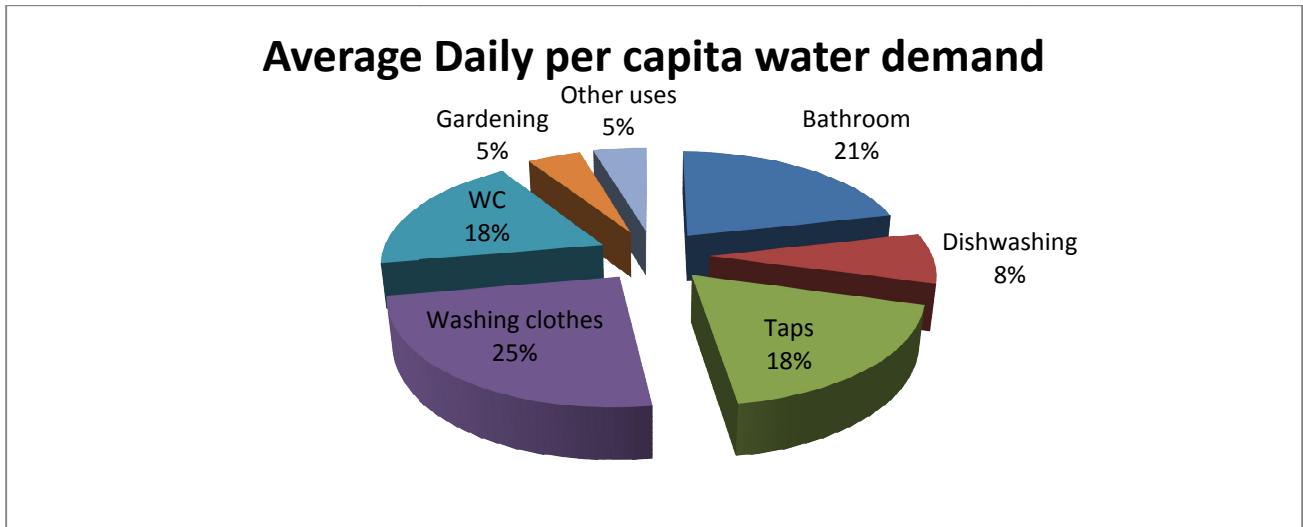


Figure 5 Breakdown of average daily per capita water demand, Jemo I condominium site, Addis Ababa, 2015

### 3.5.2 Secondary data collection

Data required for study such as rainfall intensity, population, runoff coefficient, land use data and water also collected from different sources

### 3.5.2.1 Rainfall Intensity and Runoff Coefficient

#### 3.5.2.1.1 Rainfall Intensity

The rainfall intensity of Addis Ababa city is not uniform throughout the year. That is the rainfall is concentrated to limited number of months. The average rainfall varies between 9.4 mm in the driest month (December) and 294.8mm in the wettest month (August). The total annual rainfall in an average year is 1219mm (NMA, 2014). The following graph shows a 30 year monthly rainfall data for an average year for Addis Ababa city.

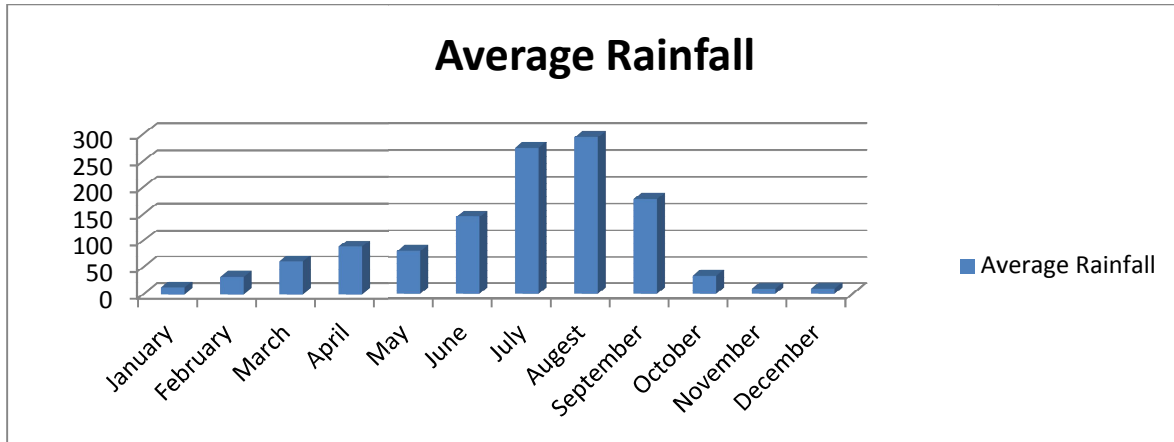


Figure 6 Average monthly rainfall of Addis Ababa city, Observatory station, Addis Ababa,2015

#### 3.5.2.2 Topography

In the sub-city the altitude ranges from 2074 to 2485 meters above sea level which has a range of 411 meters. The highly elevated land exists in the south west while relatively lower elevation exists in south.

#### 3.5.2.3 Slope (Steepness)

In this slope analysis, slope is measured as percentage rise classified into 6 different ranges. Nifas Silk Lafto is relatively flat and gently sloping sub-city in which 77.39% of its land area comprising less than 10% slope.

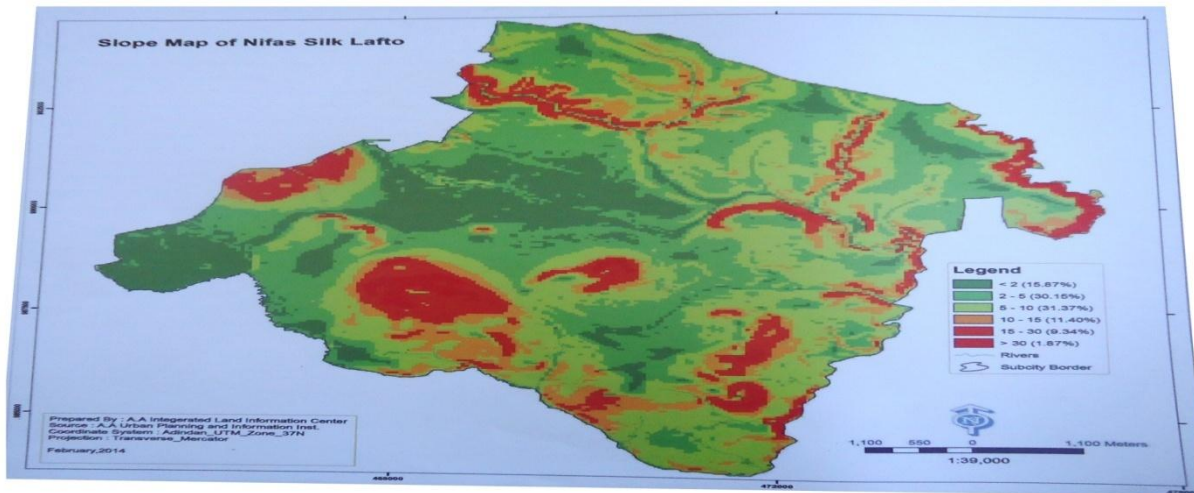


Figure 7 Slope map of Nifas Silk Lafto sub-city, Addis Ababa, 2015(AALITC,2012)

### 3.5.2.4 Land Area in the sub-city

The land area covered by Nifas Silk sub-city is 5876.02 hectares and this constitutes 11.31% of the total land area of the city which makes the sub-city in 5th place in land area covered from the 10 sub-cities. Among the 12 Woredas in the sub-city the largest area is covered by Woreda 01 with 2592.83 hectares that is 44.12% of the sub-city land area.

#### 3.5.2.4.1 Land Use

In the sub-city 28.84% of land is residential area and 14.86% of the area is road network in which much of the land is covered with different constructions. The following figure shows the existing land use map of the sub-city.



Figure 8 Existing land use map of Nifas Silk Lafto sub-city, 2015(AALITC,2012)

### 3.5.2.4.2 Distribution of Condominium Houses

The sub-city has more than 17 condominium sites including the biggest sites like Jemo and Gofa condominium sites. Jemo condominium sites cover about 2,756,700 m<sup>2</sup>. The following figure shows distribution of condominium sites in the sub-city.

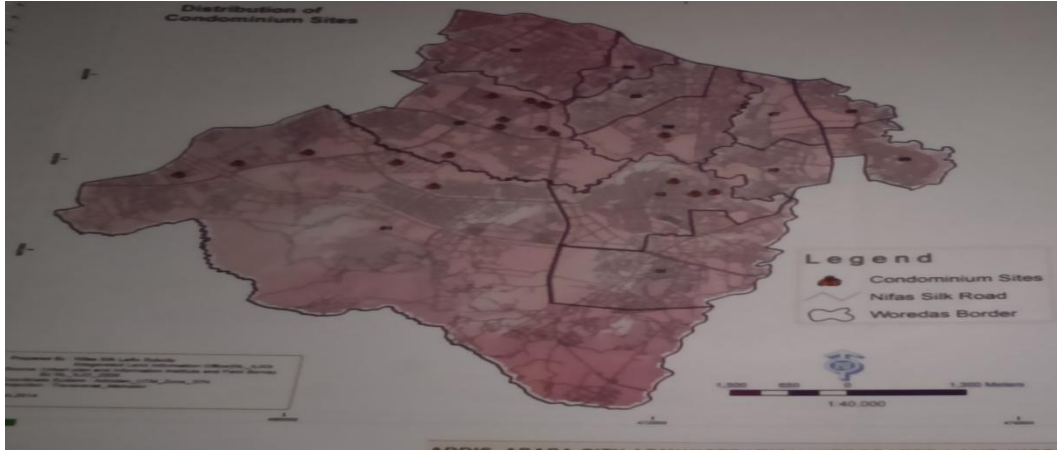


Figure 9 Distribution of Condominium houses in Nifas Silk Lafto sub-city, Addis Ababa 2015 (AALIC,2014)

### 3.5.2.4.3 Jemo I condominium site

Jemo condominium site is one of the biggest condominium sites in Nifas Silk Lafto sub-city as well as in Addis Ababa.



Figure 10 GIS map of Jemo I condominium site, Addis Ababa, 2015

The site has 337 residential and 50 communal buildings/blocks which has about 286m<sup>2</sup> and 216m<sup>2</sup> roof area respectively and the residential area comprises about 44% of the total land area of the site. The distribution of houses at this site is shown in table 8.

Table 8 Distribution of Condominium Houses at Jemo I condominium site, Addis Ababa 2015 (AAHDA, 2014)

Site	No. of buildings	Type of house					Total
		Studio	1 bed	2 bed	3 bed	Business	
Jemo 1	337	2087	3735	2027	1241	710	9800
Jemo 2	163	252	1861	764	832	264	3973
Jemo 3	147	174	1440	945	370	280	3209
<b>Total</b>	<b>647</b>	<b>2513</b>	<b>7036</b>	<b>3736</b>	<b>2443</b>	<b>1254</b>	<b>16982</b>

At Jemo condominium site 87% of land is a built up area in which 44% is residential, 20% commercial, 1% road and 11% green area and sport field.

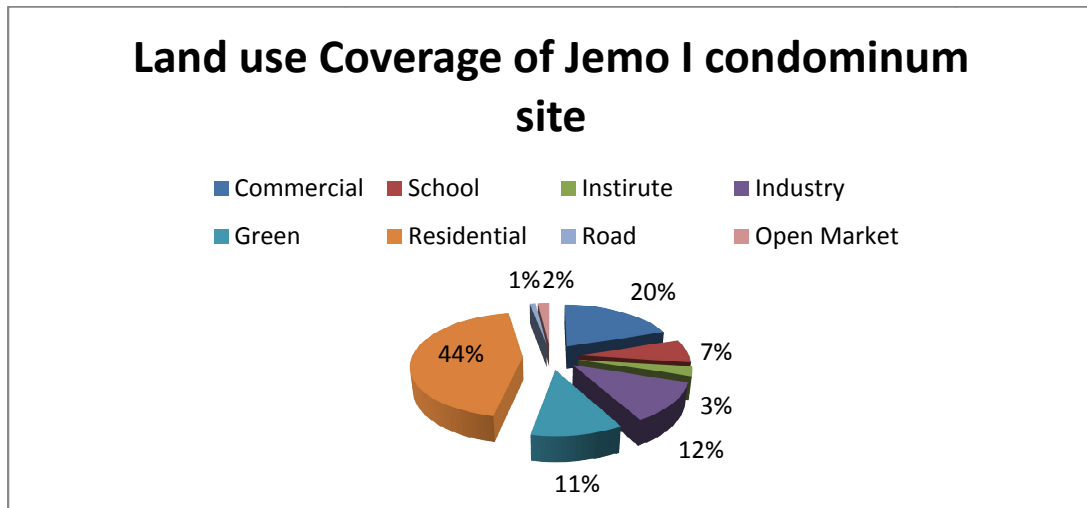


Figure 11 Land use coverage of Jemo I condominium site, Addis Ababa 2015 (AAHDA, 2014)

The average roof area for the residential buildings is about 286 square meter and average roof area for communal buildings is about 216 square meters. The following table shows summary of the total area of roof in the study area.

Table 9 Total average roof area of building at Jemo I condominium site, Addis Ababa 2015

Site	Residential			Communal			Cumulative area
	Number of blocks	Avg. Roof Area(m <sup>2</sup> )	Total Roof Area(m <sup>2</sup> )	Number of blocks	Total Roof Area(m <sup>2</sup> )	Total Roof Area	
Jemo 1	337	286	96382	50	216	10800	107,182
Jemo 2	190	286	54340	31	216	6696	61,036
Jemo 3	120	286	34320	20	216	4320	38,640
<b>Total</b>	<b>647</b>		<b>185,042</b>	<b>101</b>		<b>21816</b>	<b>206,858</b>

### 3.5.3 Population Forecasting

Based on the 2007 census conducted by the Ethiopian national statistics authorities the population of Addis Ababa was 2,739,551 million; all of the population are urban inhabitants.

Using the population growth rate set by CSA which is 2.1%(CSA,2007) for Addis Ababa city the population of Addis Ababa city is forecasted as follows.

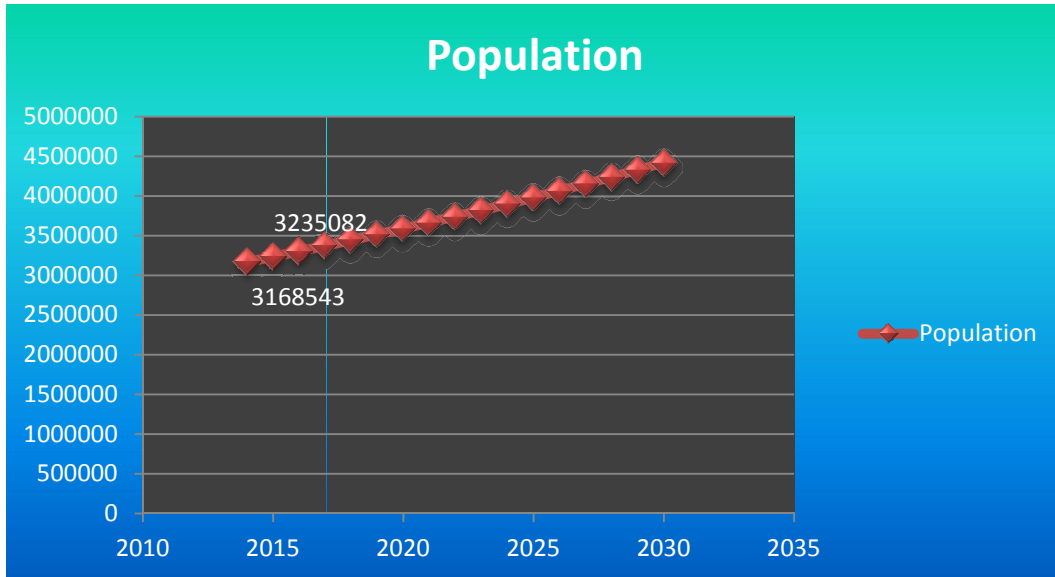


Figure 12 Forecasted population for Addis Ababa city, 2015 (CSA, 2007)

Jemo condominium site is found in Nifas silk Lafto sub-city woreda 1 administration area. It is found in the largest woreda of the sub-city. The population of the site is determined based on the data obtained from Addis Ababa Housing Development office area development plans of residential buildings. The projected population planned to settle at Jemo I site is shown in the following table.

Table 10 Planned population to settle at Jemo I condominium site, Addis Ababa, 2012 (AAHDA, 2012)

Housing Type	Assumed No. of Inhabitants	Total No. of Housing Units	Total population
3 Bed Rooms	6	1241	7446
2 Bed Rooms	5	2027	10,135
One Bed Room	4	3735	14,940
Studio	3	2087	6261
Employee/Shops	2	710	1420
<b>Total</b>		<b>9800</b>	<b>40,202</b>

The following assumptions have been made to estimate the expected number of inhabitants/users per room. The figures are compared with Ethiopian census report 2007 for Addis Ababa and Nifas Silk Lafto Sub city. The average size of population per house hold is 4.3 for Addis Ababa and 4.2 for Nifas Silk Lafto Sub-city. Dividing the total population of Jemo Condominium site to the number of buildings with average number of housing units in which there are 337 residential buildings, the population that lives in each building would be 120.

### 3.5.4 Water Demand

Addis Ababa water and sewerage Authority estimated a Water demand projections for the water supply systems based on population projections and per capita water demand. The following factors are taken into consideration when evaluating the projected water demand:

- Increased demand due to population growth,
- Increased demand due to higher levels of consumption,
- Other demands for commercial, institutional and public purpose,
- Losses of water due to leakage and unauthorized use.

The current demands of each sub-system had been derived from 1994-95 water consumption statistics and from the demand monitoring program carried out in 1995. The water demand projections are shown in the following figure.

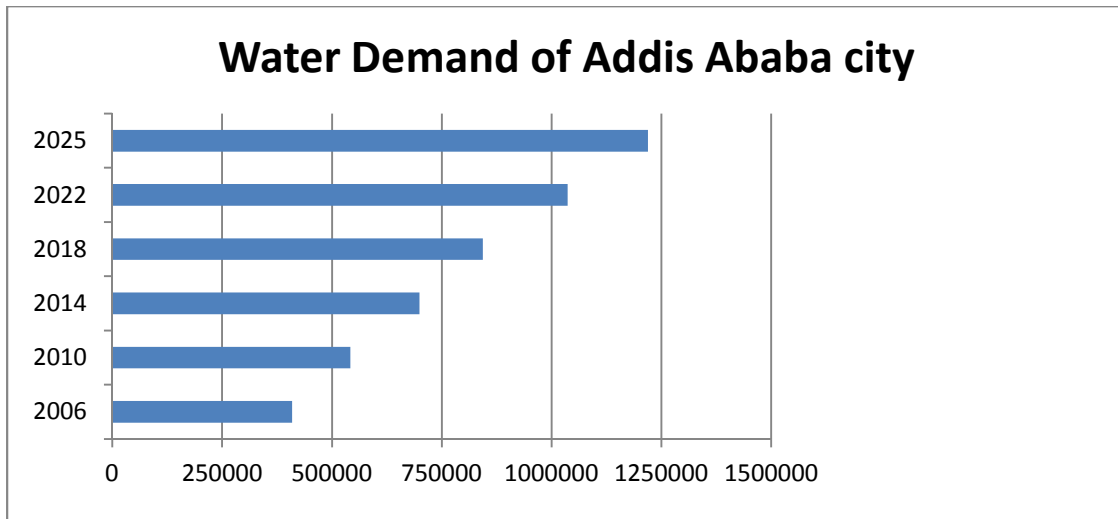


Figure 13 Forecasted water demand for Addis Ababa city, Addis Ababa 2014 (AAWSA, Forecasted Water Demand, 2014)

Water demand for the specific area is also estimated based on the standard set by AAWSA which is 110 l/c/d which includes the population equivalents for domestic, institutional, industrial and losses. Without including the population equivalents it is 70l/c/d. Therefore the water demand of the study area for the projected houses design period could be as follows in the following table.

Table 11 Water demand of the study area for the study area , Addis Ababa 2015

Housing Unit	Population	Per capita water demand(l/c/d)	Total water demand(l/c/d)	Total water demand(m <sup>3</sup> /d)
Single building	120	70 (Domestic demand)	8400	8.4
All buildings at Jemo I	40,202	70 (Domestic demand)	2,414,140	2814.1
Single building	120	110 (all demand)	13,200	13.2
All buildings at Jemo I	40,202	110 (all demand)	4,422,220	4,422.2

### 3.5.5 Water Consumption

Water consumption in Addis Ababa is dependent on the availability of water in the pipelines in which there is a big gap between the supply and the demand. A 6 months of water consumption data of Jemo I collected from AAWSA Mekanisa branch shows that only 30% of the demand is supplied at private water pipes. The following figure shows this gap.

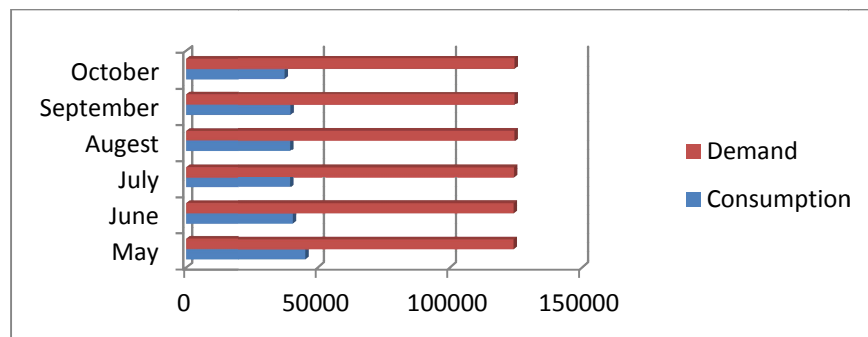


Figure 14 Water consumption rate related to demand at Jemo I condominium site in m<sup>3</sup>, Addis Ababa 2015

### 3.6 Description of variables

The independent variables listed in table 12 determine the results for the dependent variables. Amount of rainfall, roof size, land cover, water demand and type of roof determine the rainwater harvesting potential, runoff reduction potential and demand support potential.

Table 12 Dependent and independent variables, Addis Ababa 2015

Dependent variables	Independent variables
<ul style="list-style-type: none"> <li>➤ Water demand addressed</li> <li>➤ Reduced runoff amount</li> </ul>	<ul style="list-style-type: none"> <li>➤ Roof size</li> <li>➤ Amount of rainfall</li> <li>➤ Land cover</li> <li>➤ Water demand</li> <li>➤ Type of roof</li> <li>➤ Runoff coefficient</li> </ul>

### **3.7 Data management, quality assurance and Ethical considerations**

Before data collection, all tools were checked for completeness in order to answer the given questions and a pretest will be made in order to check feasibility. Calibration and validation of the data was also conducted. All data collection forms was checked for completeness and reliability before analysis and processes carefully. After thoroughly discussing the ultimate purpose and method of the study, a written consent was sought from local authorities and concerned government officials. Additionally, an informed written consent was obtained from the individual to involve in the study and anyone not willing to take parts in the study have full right to do so.

### **3.8 Modeling and Analysis tools**

Even if there were limitations in the selection of appropriate models for analyzing the collected data, it has been tried to use samsamwater rainwater harvesting tool which is simple and which works online, Google Earth, AutoCAD and MS Excel spread sheets were mainly used for analysis.

The samsamwater RWH tool is selected because of its simplicity and the raw data required for analysis. The data inputs for the model are a satellite map of the study area from Google Earth, Population, Per capita water demand, Roof area, Type of roof material and a rainfall data from satellites. The expected results from the model are Rainwater harvesting potential, Water availability, Required storage and Dry and Wet year potentials.

### **3.9 Data Calibration and Validation**

The collected data from secondary sources were calibrated for quality checking. The rainfall data in which the Samsamwater model used during simulation was a satellite data and this data was calibrated using the data taken from National Metrological Agency of Ethiopia which is observed data. And it was assured that there were no significant gaps between the two data. The rainwater harvesting potential also calibrated on the same way.

The study tools and the findings of the study also validated using theoretical standards set by UN-HABITAT and other studies conducted in India, Bangladesh, Brazil and China.

### **3.10 Disseminations of results**

Results of this study is disseminated to Addis Ababa water and sewerage Authority, Addis Ababa municipality, Addis Ababa Housing Development Agency, Ethiopian Rainwater Harvesting Association and other responsible institutions.

## 4 CHAPTER FOUR-DATA ANALYSIS AND RESULTS

### 4.1.1 Rainwater Harvesting Potential

In order to determine the rain water harvesting potential of the study area different primary and secondary data were collected and used in the analysis. Rainwater harvesting is typically carried out by collecting rainwater from rooftops in residential buildings. The rainwater harvesting potential of the study area is analyzed using samsamwater rainwater harvesting model in which a model needs Water demand, Roof area, Location map from Google earth, Type of roof material and per capita water demand as an input and delivers the RWH potential for a single communal residential building and for the study area. The model used a runoff coefficient of 0.9 for the specific study area and roof material given and the tank size is determined using supply side approach.

#### 4.1.1.1 Rainwater harvesting potential for a single building considering all demand

Location: Jemo, Addis Ababa, Ethiopia

Latitude: 8.95914 degrees

Longitude: 38.71082 degrees

Roof size: 286 square metres

Roof type: metal

Runoff coefficient: 0.9

Water demand: 8400 litres per day

The average rainfall at this location varies between 8.7 mm in the driest month (December) and 272.8 mm in the wettest month (August). The total annual rainfall in an average year is 1209mm.

#### Water availability

Metal roof has a runoff coefficient of 0.9, which means that 90% of the rain can be harvested. Based on this runoff coefficient and a roof area of 286 square meters a volume of 2239 litres (8.7 mm x 286 m<sup>2</sup> x 0.9) of water can be collected in the driest month (December) and 70219 litres (272.8 mm x 286m<sup>2</sup> x 0.9) in the wettest month (August). The total yearly amount of water that can be collected from the roof is 311200 litres (311m<sup>3</sup>) in an average year.

#### Water demand

Water demand is 8400 litres per day, which equals to about 252000 litres per month. The total water demand is 3066000 litres (3066 m<sup>3</sup>) per year. The amount of water that can be collected from the roof (311m<sup>3</sup>) is less than the water demand (3066 m<sup>3</sup>). Only a part of the water demand can be fulfilled using a rainwater harvesting system.

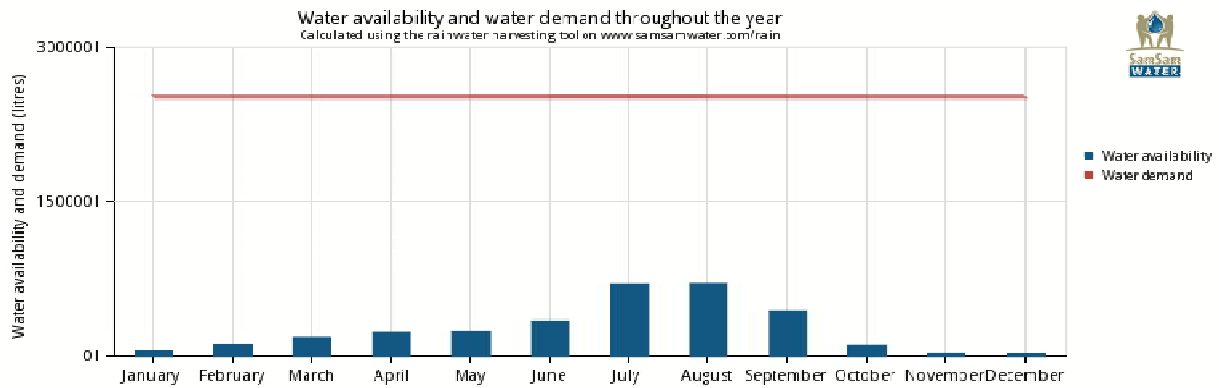


Figure 15 Water availability and water demand throughout the year, Jemo I 2015(samsamwater)

### Required storage

Total amount of water that can be collected from this roof, 311200 litres, is not enough to fulfill the total yearly water demand of 3066000 litres. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 113400 litres (113.4 m<sup>3</sup>) a rainwater harvesting system could provide 853 litres of water per day, which is 10% of the total demand. The storage reservoir will be full in and then slowly drain until it is (almost) empty at the end of May.

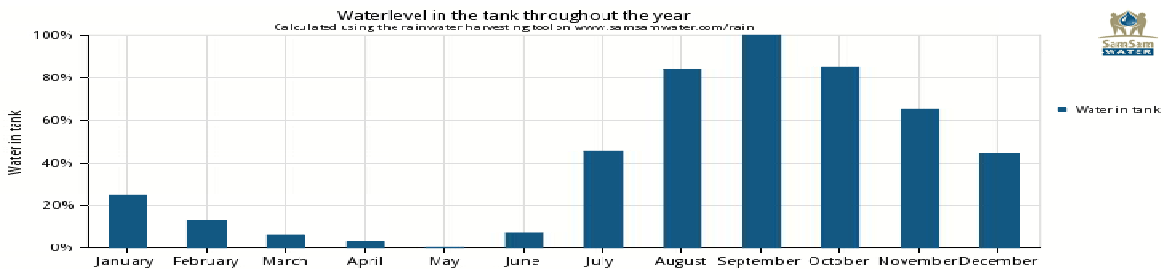


Figure 16 Water level in the tank throughout the year, Jemo I 2015(Samsamwater)

### Dry and wet years

This calculation is based on the average monthly rainfall. The actual rainfall differs from month to month and year to year. The amount of available water and filling of the tank might therefore be different and change from year to year. When constructing a rainwater harvesting system it is important to take this into account. Below is a description of the situation in a dry year (20% chance) and a wet year (20% chance).

**Situation in a dry year:** during a dry year, there is less rain to fill the system. The system can provide a smaller amount of water compared to an average year. All rain is stored, so constructing a larger reservoir won't help.

**Situation in a wet year:** during a wet year there is more water available and constructing a larger tank will increase the water availability in this situation. With a storage reservoir of 130900 litres (130.9 m<sup>3</sup>) a rainwater harvesting system could provide 13% of the total demand.

#### 4.1.1.2 Rainwater harvesting potential for a single building considering non potable demand

Location: Jemo, Addis Ababa, Ethiopia

Latitude: 8.95914 degrees

Longitude: 38.71082 degrees

Roof size: 286 square meters

Roof type: metal

Runoff coefficient: 0.9

Water demand: 2400 litres per day

#### Rainfall

The average rainfall at this location varies between 8.7 mm in the driest month (December) and 272.8 mm in the wettest month (August). The total annual rainfall in an average year is 1209 mm.

#### Water availability

Metal roof has a runoff coefficient of 0.9, which means that 90% of the rain can be harvested. Based on this runoff coefficient and a roof area of 286 square meters a volume of 2239 litres (8.7 mm x 286 m<sup>2</sup> x 0.9) of water can be collected in the driest month (December) and 70219 litres (272.8 mm x 30 m<sup>2</sup> x 0.9) in the wettest month (August). The total yearly amount of water that can be collected from the roof is 311200 litres (311m<sup>3</sup>) in an average year.

#### Water demand

Water demand is 2400 litres per day, which equals to about 72000 litres per month. The total water demand is 876000 litres (876 m<sup>3</sup>) per year. The amount of water that can be collected from the roof (311m<sup>3</sup>) is less than the water demand (876 m<sup>3</sup>). Only a part of the water demand can be fulfilled using a rainwater harvesting system.

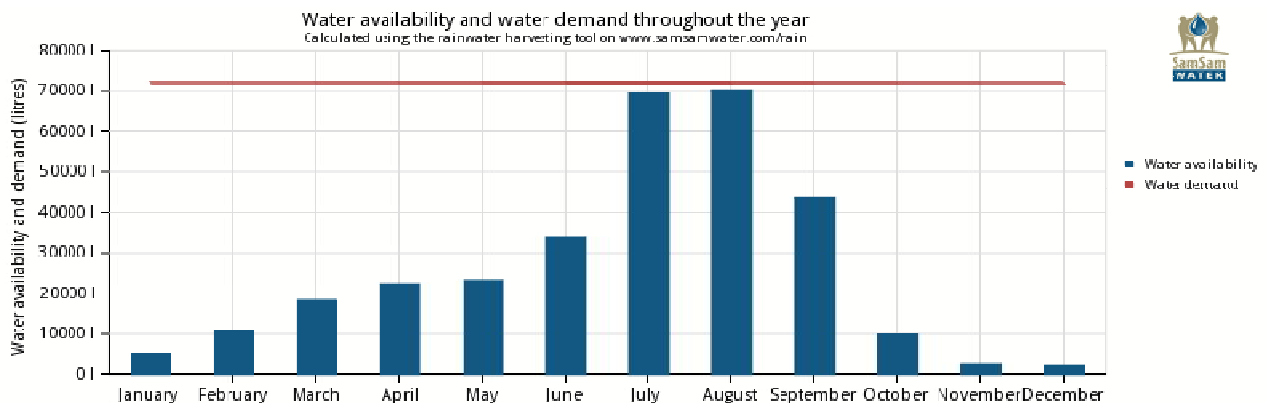


Figure 17 Water availability and water demand throughout the year, Jemo 2015 (Samsamwater)

## Required storage

Total amount of water that can be collected from this roof, 311200 litres, is not enough to fulfill the total yearly water demand of 876000 litres. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 113400 litres (113.4 m<sup>3</sup>) a rainwater harvesting system could provide 853 litres of water per day, which is 36% of the total demand. The storage reservoir will be full in and then slowly drain until it is (almost) empty at the end of May.

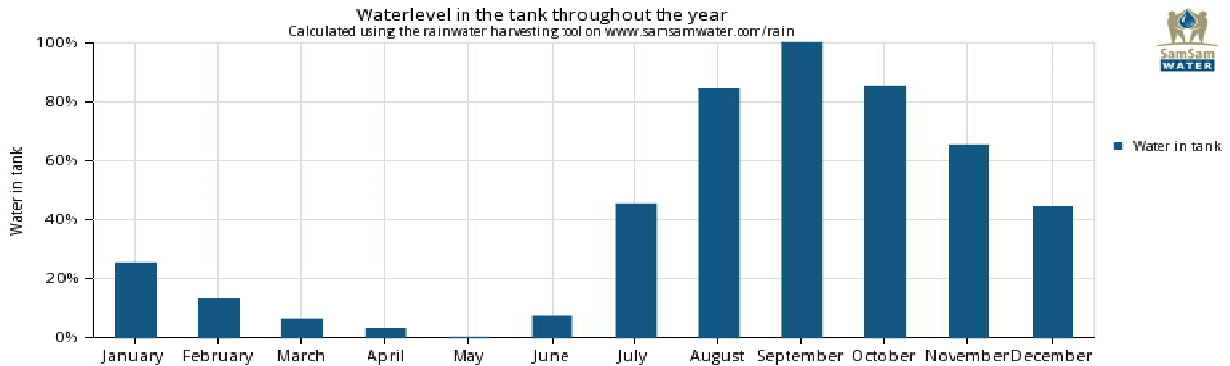


Figure 18 Water level in the tank throughout the year, Jemo I condominium site, Addis Ababa 2015 (Samsamwater)

## Dry and wet years

This calculation is based on the average monthly rainfall. The actual rainfall differs from month to month and year to year. The amount of available water and filling of the tank might therefore be different and change from year to year. When constructing a rainwater harvesting system it is important to take this into account. Below is a description of the situation in a dry year (20% chance) and a wet year (20% chance).

Situation in a dry year: during a dry year, there is less rain to fill the system. The system can provide a smaller amount of water compared to an average year. All rain is stored, so constructing a larger reservoir won't help.

Situation in a wet year: during a wet year there is more water available and constructing a larger tank will increase the water availability in this situation. With a storage reservoir of 130900 litres (130.9 m<sup>3</sup>) a rainwater harvesting system could provide 47% of the total demand.

#### 4.1.1.3 Rainwater harvesting potential for all 337 residential buildings considering all demand

Location: Jemo, Addis Ababa, Ethiopia

Latitude: 8.95914 degrees

Longitude: 38.71082 degrees

Roof size: 96382 square metres

Roof type: metal

Runoff coefficient: 0.9

Water demand: 2814140 litres per day

#### Rainfall

The average rainfall at this location varies between 8.7 mm in the driest month (December) and 272.8 mm in the wettest month (August). The total annual rainfall in an average year is 1209 mm.

#### Water availability

Metal roof has a runoff coefficient of 0.9, which means that 90% of the rain can be harvested. Based on this runoff coefficient and a roof area of 96382 square metres a volume of 754671 litres (8.7 mm x 96382 m<sup>2</sup> x 0.9) of water can be collected in the driest month (December) and 23663709 litres (272.8 mm x 30 m<sup>2</sup> x 0.9) in the wettest month (August). The total yearly amount of water that can be collected from the roof is 104864600 litres (104865m<sup>3</sup>) in an average year.

#### Water demand

The water demand is 2814140 litres per day, which equals to about 84424200 litres per month. The total water demand is 1027161100 litres (1027161.1 m<sup>3</sup>) per year. The amount of water that can be collected from the roof (104865m<sup>3</sup>) is less than the water demand (1027161.1 m<sup>3</sup>). Only a part of the water demand can be fulfilled using a rainwater harvesting system.

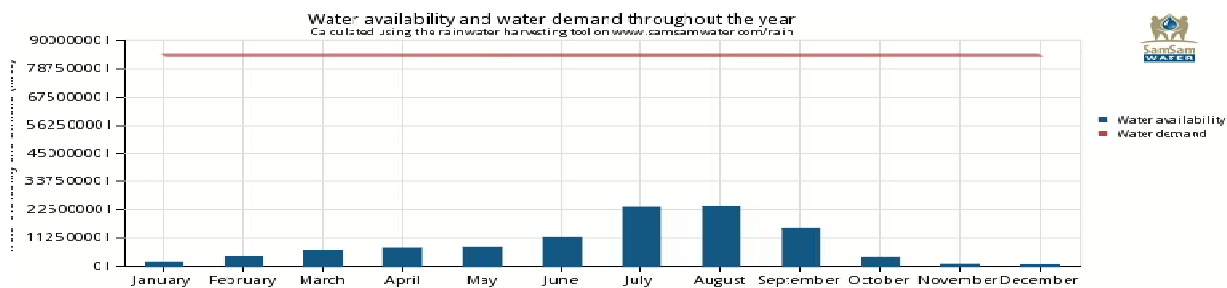


Figure 19 Water availability and water demand throughout the year, Addis Ababa 2015 (Samsamwater)

## Required storage

The total amount of water that can be collected from this roof, 104864600 litres, is not enough to fulfill the total yearly water demand of 1027161100 litres. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 38221900 litres (38221.9 m<sup>3</sup>) a rainwater harvesting system could provide 287300 litres of water per day, which is 10% of the total demand. The storage reservoir will be full in and then slowly drain until it is (almost) empty at the end of May.

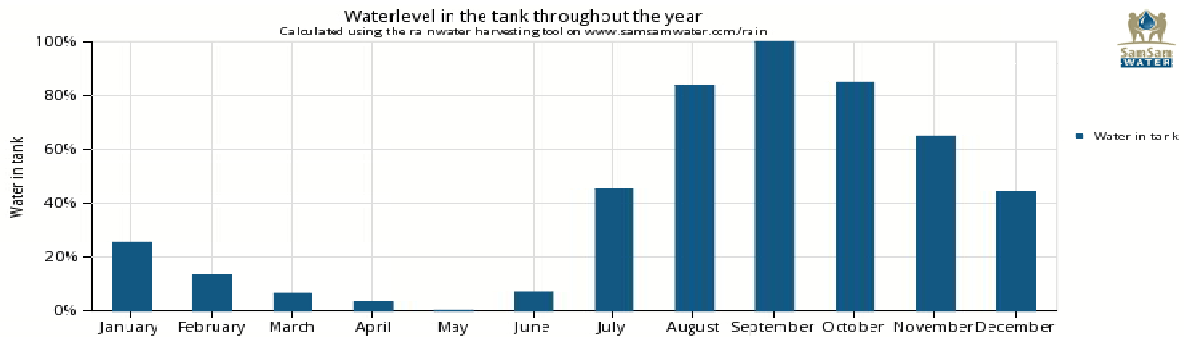


Figure 20 Water level in the tank throughout the year, Addis Ababa 2015 (Samsamwater)

## Dry and wet years

This calculation is based on the average monthly rainfall. The actual rainfall differs from month to month and year to year. The amount of available water and filling of the tank might therefore be different and change from year to year. When constructing a rainwater harvesting system it is important to take this into account. Below is a description of the situation in a dry year (20% chance) and a wet year (20% chance).

Situation in a dry year: during a dry year, there is less rain to fill the system. The system can provide a smaller amount of water compared to an average year. All rain is stored, so constructing a larger reservoir won't help.

Situation in a wet year: during a wet year there is more water available and constructing a larger tank will increase the water availability in this situation. With a storage reservoir of 44116000 litres (44116 m<sup>3</sup>) a rainwater harvesting system could provide 13% of the total demand.

#### 4.1.1.4 Rainwater harvesting potential for all 337 residential buildings considering non potable demand

Location: Jemo, Addis Ababa, Ethiopia

Latitude: 8.95914 degrees

Longitude: 38.71082 degrees

Roof size: 96382 square meters

Roof type: metal

Runoff coefficient: 0.9

Water demand: 804040 litres per day

#### Rainfall

The average rainfall at this location varies between 8.7 mm in the driest month (December) and 272.8 mm in the wettest month (August). The total annual rainfall in an average year is 1209 mm.

#### Water availability

A metal roof has a runoff coefficient of 0.9, which means that 90% of the rain can be harvested. Based on this runoff coefficient and a roof area of 96382 square metres a volume of 754671 litres (8.7 mm x 96382 m<sup>2</sup> x 0.9) of water can be collected in the driest month (December) and 23663709 litres (272.8 mm x 30 m<sup>2</sup> x 0.9) in the wettest month (August).

The total yearly amount of water that can be collected from the roof is 104864600 litres (104865m<sup>3</sup>) in an average year.

#### Water demand

The water demand is 804040 litres per day, which equals to about 24121200 litres per month. The total water demand is 293474600 litres (293474.6 m<sup>3</sup>) per year. The amount of water that can be collected from the roof (104865m<sup>3</sup>) is less than the water demand (293474.6 m<sup>3</sup>). Only a part of the water demand can be fulfilled using a rainwater harvesting system.

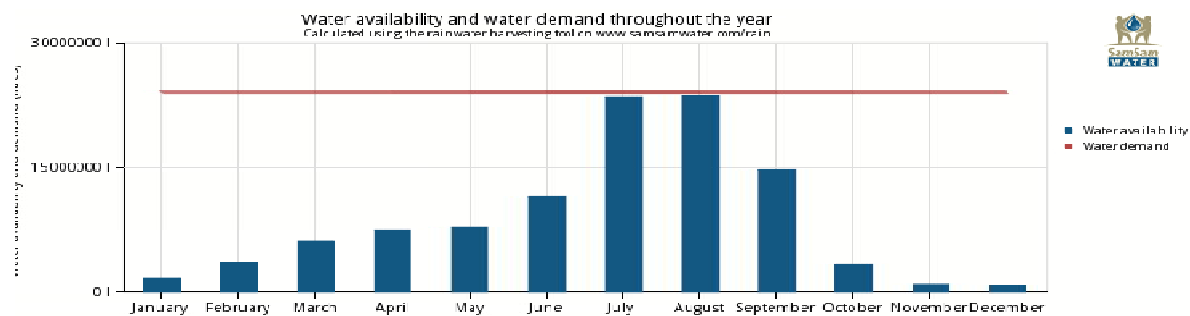


Figure 21 Water availability and water demand throughout the year, Jemo Addis Ababa 2015 (Samsamwater)

## Required storage

The total amount of water that can be collected from this roof, 104864600 litres, is not enough to fulfill the total yearly water demand of 293474600 litres. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 38221900 litres (38221.9 m<sup>3</sup>) a rainwater harvesting system could provide 287300 litres of water per day, which is 36% of the total demand. The storage reservoir will be full in and then slowly drain until it is (almost) empty at the end of May.

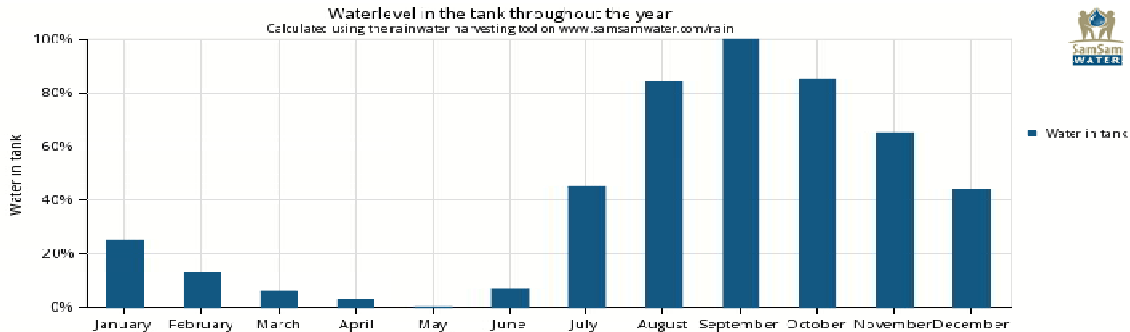


Figure 22 Water level in the tank throughout the year, Jemo Addis Ababa, 2015 (Samsamwater)

## Dry and wet years

This calculation is based on the average monthly rainfall. The actual rainfall differs from month to month and year to year. The amount of available water and filling of the tank might therefore be different and change from year to year.

When constructing a rainwater harvesting system it is important to take this into account. Below is a description of the situation in a dry year (20% chance) and a wet year (20% chance).

**Situation in a dry year:** during a dry year, there is less rain to fill the system. The system can provide a smaller amount of water compared to an average year. All rain is stored, so constructing a larger reservoir won't help.

**Situation in a wet year:** during a wet year there is more water available and constructing a larger tank will increase the water availability in this situation. With a storage reservoir of 44116000 litres (44116 m<sup>3</sup>) a rainwater harvesting system could provide 47% of the total demand.

**4.1.1.5 Rainwater harvesting potential for all 337 residential buildings considering all demand including demand for population equivalents (110l/c/d)**

Location: Jemo, Addis Ababa, Ethiopia

Latitude: 8.95914 degrees

Longitude: 38.71082 degrees

Roof size: 96382 square metres

Roof type: metal

Runoff coefficient: 0.9

Water demand: 4422220 litres per day

**Rainfall**

The average rainfall at this location varies between 8.7 mm in the driest month (December) and 272.8 mm in the wettest month (August). The total annual rainfall in an average year is 1209 mm.

**Water availability**

A metal roof has a runoff coefficient of 0.9, which means that 90% of the rain can be harvested. Based on this runoff coefficient and a roof area of 96382 square meters a volume of 754671 litres (8.7 mm x 96382 m<sup>2</sup> x 0.9) of water can be collected in the driest month (December) and 23663709 litres (272.8 mm x 30 m<sup>2</sup> x 0.9) in the wettest month (August).

The total yearly amount of water that can be collected from the roof is 104864600 litres (104865m<sup>3</sup>) in an average year.

**Water demand**

The water demand is 4422220 litres per day, which equals to about 132666600 litres per month. The total water demand is 1614110300 litres (1614110.3 m<sup>3</sup>) per year. The amount of water that can be collected from the roof (104865m<sup>3</sup>) is less than the water demand (1614110.3 m<sup>3</sup>). Only a part of the water demand can be fulfilled using a rainwater harvesting system.

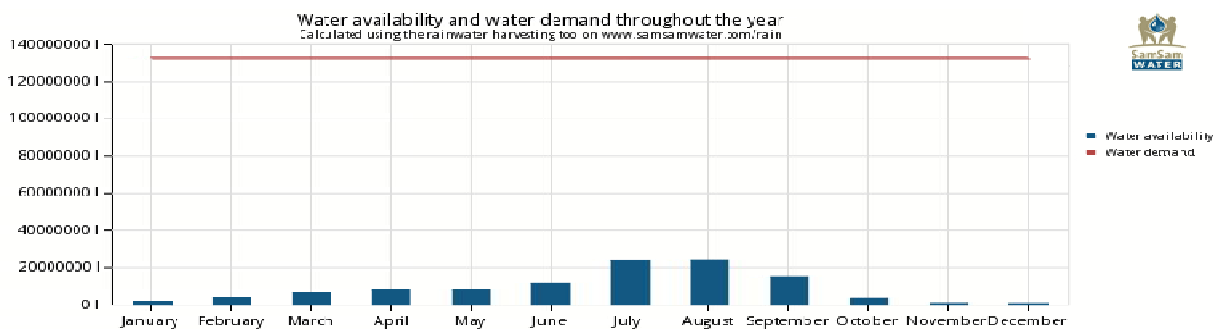


Figure 23 Water availability and water demand throughout the year, Jemo Addis Ababa, 2015 (Samsamwater)

## Required storage

The total amount of water that can be collected from this roof, 104864600 litres, is not enough to fulfill the total yearly water demand of 1614110300 litres. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 38221900 litres (38221.9 m<sup>3</sup>) a rainwater harvesting system could provide 287300 litres of water per day, which is 6% of the total demand. The storage reservoir will be full in and then slowly drain until it is (almost) empty at the end of May.

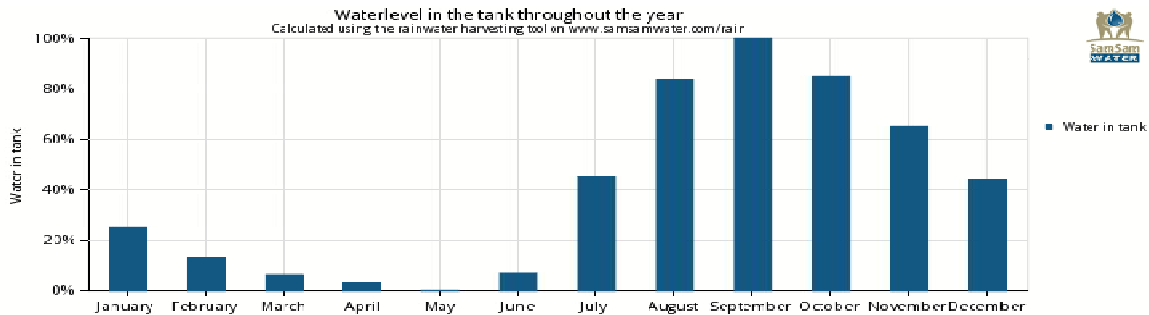


Figure 24 Water level in the tank throughout the year, Jemo Addis Ababa, 2015 (Samsamwater)

## Dry and wet years

This calculation is based on the average monthly rainfall. The actual rainfall differs from month to month and year to year. The amount of available water and filling of the tank might therefore be different and change from year to year.

When constructing a rainwater harvesting system it is important to take this into account. Below is a description of the situation in a dry year (20% chance) and a wet year (20% chance).

**Situation in a dry year:** during a dry year, there is less rain to fill the system. The system can provide a smaller amount of water compared to an average year. All rain is stored, so constructing a larger reservoir won't help.

**Situation in a wet year:** during a wet year there is more water available and constructing a larger tank will increase the water availability in this situation. With a storage reservoir of 44116000 litres (44116 m<sup>3</sup>) a rainwater harvesting system could provide 9% of the total demand.

**4.1.1.6 Rainwater Harvesting potential for all 337 residential and 50 communal buildings considering all water demand(70l/c/day)**

Location: Jemo, Addis Ababa, Ethiopia  
 Latitude: 8.95982 degrees  
 Longitude: 38.71176 degrees  
 Roof size: 107182 square metres  
 Roof type: metal  
 Runoff coefficient: 0.9  
 Water demand: 2814140 litres per day

**Rainfall**

The average rainfall at this location varies between 8.7 mm in the driest month (December) and 272.8 mm in the wettest month (August). The total annual rainfall in an average year is 1209 mm.

**Water availability**

A metal roof has a runoff coefficient of 0.9, which means that 90% of the rain can be harvested. Based on this runoff coefficient and a roof area of 107182 square metres a volume of 839235 litres (8.7 mm x 107182 m<sup>2</sup> x 0.9) of water can be collected in the driest month (December) and 26315325 litres (272.8 mm x 30 m<sup>2</sup> x 0.9) in the wettest month (August). The total yearly amount of water that can be collected from the roof is 116615100 litres (116615m<sup>3</sup>) in an average year.

**Water demand**

The water demand is 2814140 litres per day, which equals to about 84424200 litres per month. The total water demand is 1027161100 litres (1027161.1 m<sup>3</sup>) per year. The amount of water that can be collected from the roof (116615m<sup>3</sup>) is less than the water demand (1027161.1 m<sup>3</sup>). Only a part of the water demand can be fulfilled using a rainwater harvesting system.

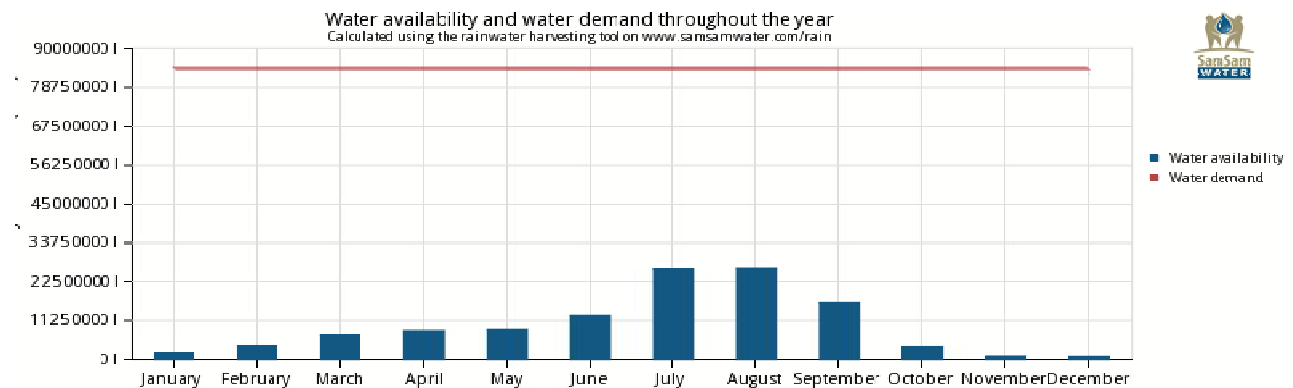


Figure 25 Water availability and water demand throughout the year, Jemo Addis Ababa, 2015 (Samsamwater)

## Required storage

The total amount of water that can be collected from this roof, 116615100 litres, is not enough to fulfill the total yearly water demand of 1027161100 litres. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 42504800 litres (42504.8 m<sup>3</sup>) a rainwater harvesting system could provide 319493 litres of water per day, which is 11% of the total demand. The storage reservoir will be full in and then slowly drain until it is (almost) empty at the end of May.

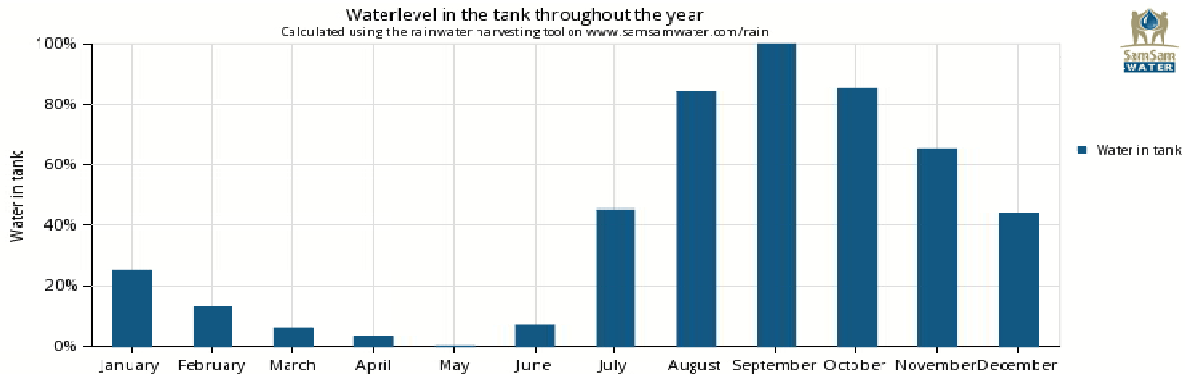


Figure 26 Water level in the tank throughout the year, Jemo Addis Ababa, 2015 (Samsamwater)

## Dry and wet years

This calculation is based on the average monthly rainfall. The actual rainfall differs from month to month and year to year. The amount of available water and filling of the tank might therefore be different and change from year to year. When constructing a rainwater harvesting system it is important to take this into account. Below is a description of the situation in a dry year (20% chance) and a wet year (20% chance).

**Situation in a dry year:** during a dry year, there is less rain to fill the system. The system can provide a smaller amount of water compared to an average year. All rain is stored, so constructing a larger reservoir won't help.

**Situation in a wet year:** during a wet year there is more water available and constructing a larger tank will increase the water availability in this situation. With a storage reservoir of 49059400 litres (49059.4 m<sup>3</sup>) a rainwater harvesting system could provide 15% of the total demand.

**4.1.1.7 Rainwater Harvesting potential for all 337 residential and 50 communal buildings considering all water demand(20l/c/day)**

Location: Jemo, Addis Ababa, Ethiopia

Latitude: 8.95982 degrees

Longitude: 38.71176 degrees

Roof size: 107182 square metres

Roof type: metal

Runoff coefficient: 0.9

Water demand: 804040 litres per day

**Rainfall**

The average rainfall at this location varies between 8.7 mm in the driest month (December) and 272.8 mm in the wettest month (August). The total annual rainfall in an average year is 1209 mm.

**Water availability**

A metal roof has a runoff coefficient of 0.9, which means that 90% of the rain can be harvested. Based on this runoff coefficient and a roof area of 107182 square metres a volume of 839235 litres (8.7 mm x 107182 m<sup>2</sup> x 0.9) of water can be collected in the driest month (December) and 26315325 litres (272.8 mm x 30 m<sup>2</sup> x 0.9) in the wettest month (August). The total yearly amount of water that can be collected from the roof is 116615100 litres (116615m<sup>3</sup>) in an average year.

**Water demand**

The water demand is 804040 litres per day, which equals to about 24121200 litres per month. The total water demand is 293474600 litres (293474.6 m<sup>3</sup>) per year. The amount of water that can be collected from the roof (116615m<sup>3</sup>) is less than the water demand (293474.6 m<sup>3</sup>). Only a part of the water demand can be fulfilled using a rainwater harvesting system.

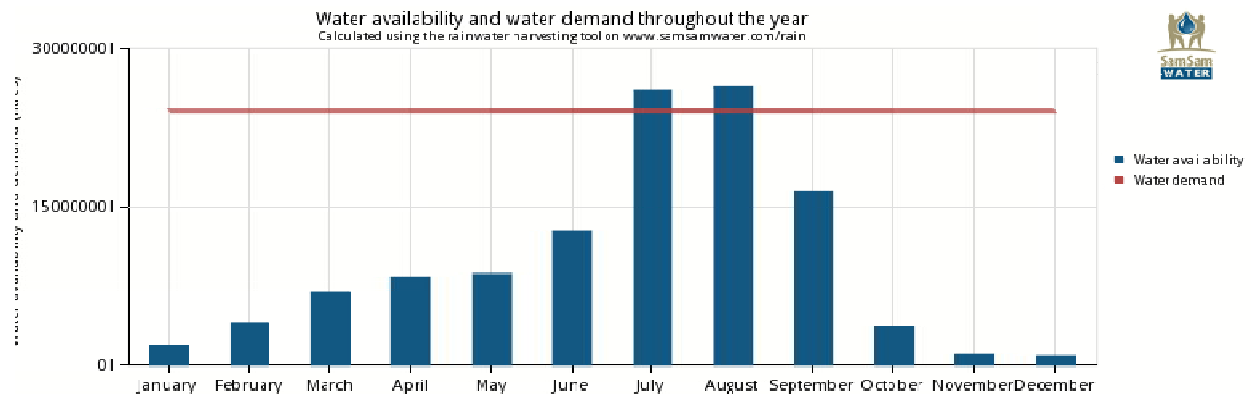


Figure 27 Water availability and water demand throughout the year, Jemo Addis Ababa, 2015 (Samsamwater)

## Required storage

The total amount of water that can be collected from this roof, 116615100 litres, is not enough to fulfill the total yearly water demand of 293474600 litres. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 42504800 litres (42504.8 m<sup>3</sup>) a rainwater harvesting system could provide 319493 litres of water per day, which is 40% of the total demand. The storage reservoir will be full in and then slowly drain until it is (almost) empty at the end of May.

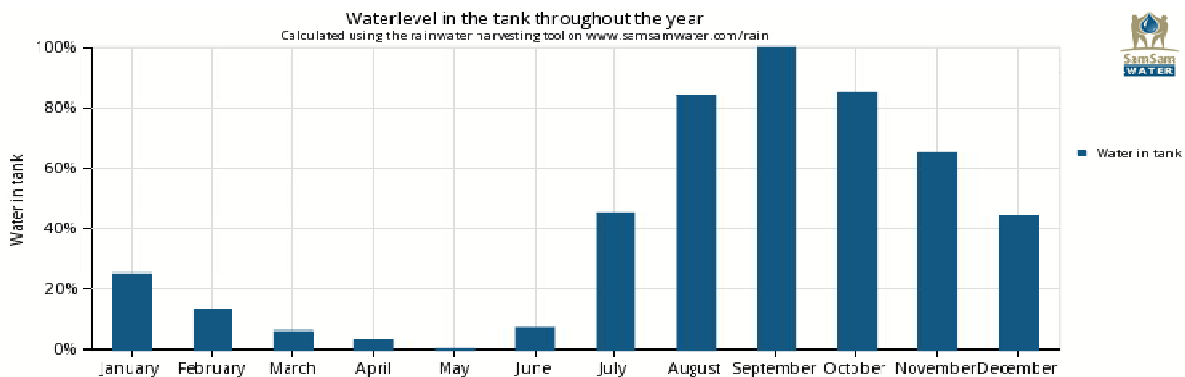


Figure 28 Water level in the tank throughout the year, Jemo Addis Ababa, 2015(Samsamwater)

## Dry and wet years

This calculation is based on the average monthly rainfall. The actual rainfall differs from month to month and year to year. The amount of available water and filling of the tank might therefore be different and change from year to year. When constructing a rainwater harvesting system it is important to take this into account. Below is a description of the situation in a dry year (20% chance) and a wet year (20% chance).

**Situation in a dry year:** during a dry year, there is less rain to fill the system. The system can provide a smaller amount of water compared to an average year. All rain is stored, so constructing a larger reservoir won't help.

**Situation in a wet year:** during a wet year there is more water available and constructing a larger tank will increase the water availability in this situation. With a storage reservoir of 49059400 litres (49059.4 m<sup>3</sup>) a rainwater harvesting system could provide 52% of the total demand.

**4.1.1.8 Rainwater Harvesting potential for all 337 residential and 50 communal buildings considering all water demand including for population equivalents(110l/c/day)**

Location: Jemo, Addis Ababa, Ethiopia  
 Latitude: 8.95982 degrees  
 Longitude: 38.71176 degrees  
 Roof size: 107182 square metres  
 Roof type: metal  
 Runoff coefficient: 0.9  
 Water demand: 4422220 litres per day

**Rainfall**

The average rainfall at this location varies between 8.7 mm in the driest month (December) and 272.8 mm in the wettest month (August). The total annual rainfall in an average year is 1209 mm.

**Water availability**

A metal roof has a runoff coefficient of 0.9, which means that 90% of the rain can be harvested. Based on this runoff coefficient and a roof area of 107182 square metres a volume of 839235 litres (8.7 mm x 107182 m<sup>2</sup> x 0.9) of water can be collected in the driest month (December) and 26315325 litres (272.8 mm x 30 m<sup>2</sup> x 0.9) in the wettest month (August). The total yearly amount of water that can be collected from the roof is 116615100 litres (116615m<sup>3</sup>) in an average year.

**Water demand**

The water demand is 4422220 litres per day, which equals to about 132666600 litres per month. The total water demand is 1614110300 litres (1614110.3 m<sup>3</sup>) per year. The amount of water that can be collected from the roof (116615m<sup>3</sup>) is less than the water demand (1614110.3 m<sup>3</sup>). Only a part of the water demand can be fulfilled using a rainwater harvesting system.

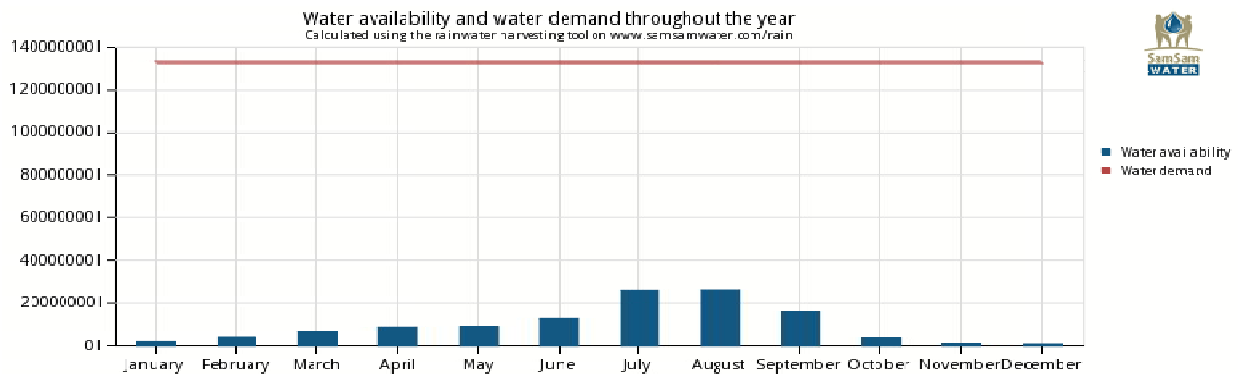


Figure 29 Water availability and water demand throughout the year, Jemo Addis Ababa, 2015 (Samsamwater)

**Required storage**

The total amount of water that can be collected from this roof, 116615100 litres, is not enough to fulfill the total yearly water demand of 1614110300 litres. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 42504800 litres (42504.8 m<sup>3</sup>) a rainwater harvesting system could provide 319493 litres of water per day, which is 7% of the total demand. The storage reservoir will be full in and then slowly drain until it is (almost) empty at the end of May.

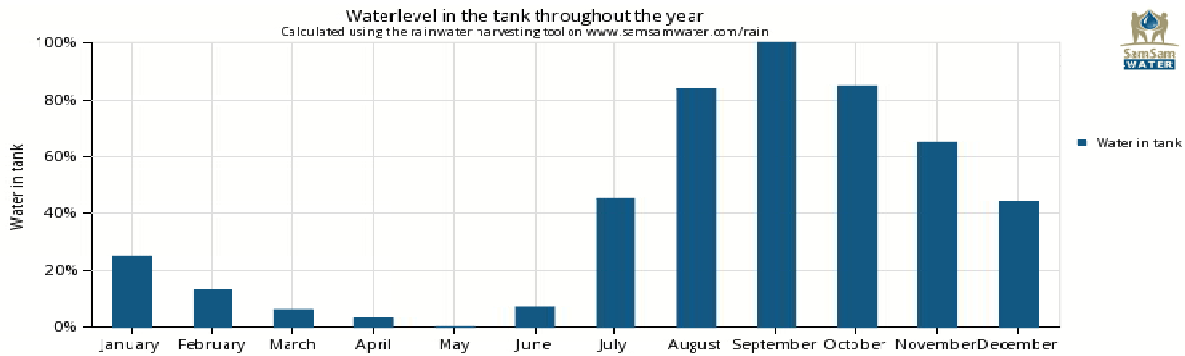


Figure 30 Water level in the tank throughout the year, Jemo Addis Ababa, 2015(Samsamwater)

### Dry and wet years

This calculation is based on the average monthly rainfall. The actual rainfall differs from month to month and year to year. The amount of available water and filling of the tank might therefore be different and change from year to year. When constructing a rainwater harvesting system it is important to take this into account. Below is a description of the situation in a dry year (20% chance) and a wet year (20% chance).

**Situation in a dry year:** during a dry year, there is less rain to fill the system. The system can provide a smaller amount of water compared to an average year. All rain is stored, so constructing a larger reservoir won't help.

**Situation in a wet year:** during a wet year there is more water available and constructing a larger tank will increase the water availability in this situation. With a storage reservoir of 49059400 litres (49059.4 m<sup>3</sup>) a rainwater harvesting system could provide 10% of the total demand

**4.1.1.9 Rainwater Harvesting potential for 7 residential and 1 communal buildings considering all water demand including for population equivalents(110l/c/day)**

Location: Jemo, Addis Ababa, Ethiopia

Latitude: 8.95982 degrees

Longitude: 38.71176 degrees

Roof size: 2218 square metres

Roof type: metal

Runoff coefficient: 0.9

Water demand: 92400 litres per day

**Rainfall**

The average rainfall at this location varies between 8.7 mm in the driest month (December) and 272.8 mm in the wettest month (August). The total annual rainfall in an average year is 1209 mm.

**Water availability**

A metal roof has a runoff coefficient of 0.9, which means that 90% of the rain can be harvested. Based on this runoff coefficient and a roof area of 2218 square metres a volume of 17367 litres (8.7 mm x 2218 m<sup>2</sup> x 0.9) of water can be collected in the driest month (December) and 544563 litres (272.8 mm x 30 m<sup>2</sup> x 0.9) in the wettest month (August). The total yearly amount of water that can be collected from the roof is 2413200 litres (2413m<sup>3</sup>) in an average year.

**Water demand**

The water demand is 92400 litres per day, which equals to about 2772000 litres per month. The total water demand is 33726000 litres (33726 m<sup>3</sup>) per year. The amount of water that can be collected from the roof (2413m<sup>3</sup>) is less than the water demand (33726 m<sup>3</sup>). Only a part of the water demand can be fulfilled using a rainwater harvesting system.

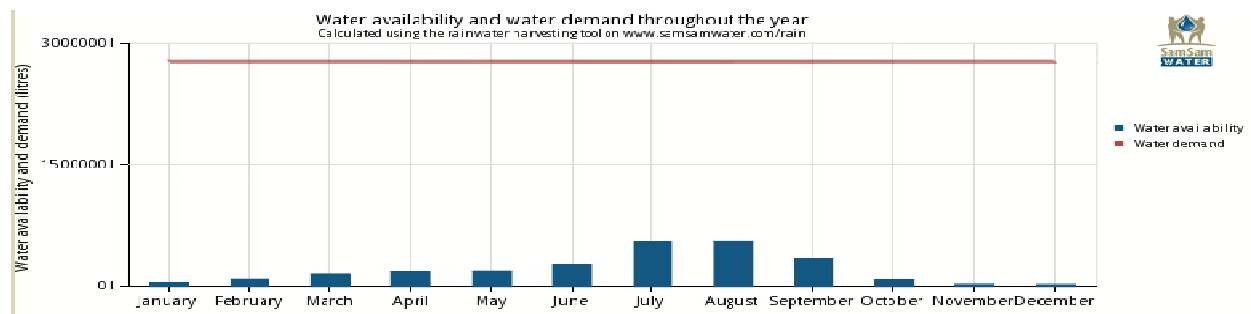


Figure 31 Water availability and water demand throughout the year, Jemo Addis Ababa, 2015 (Samsamwater)

### Required storage

The total amount of water that can be collected from this roof, 2413200 litres, is not enough to fulfill the total yearly water demand of 33726000 litres. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 879600 litres (879.6 m<sup>3</sup>) a rainwater harvesting system could provide 6612 litres of water per day, which is 7% of the total demand. The storage reservoir will be full in and then slowly drain until it is (almost) empty at the end of May.

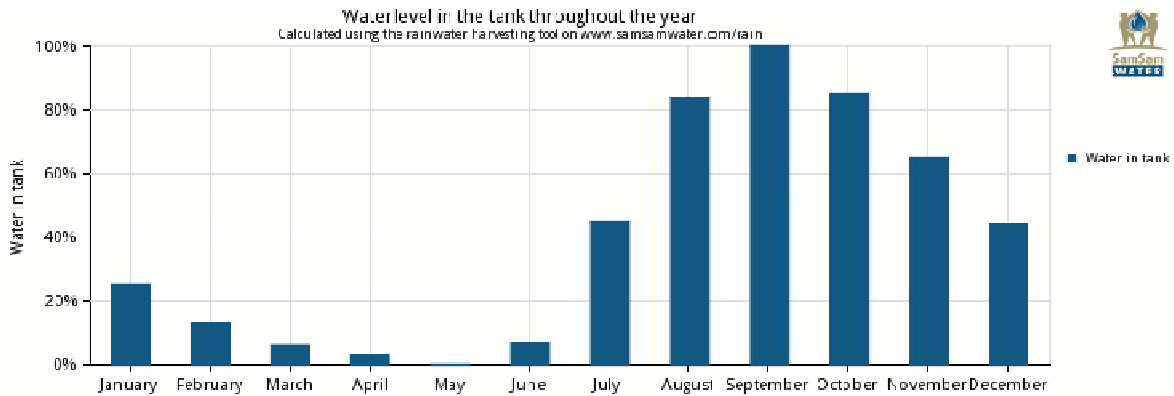


Figure 32 Water level in the tank throughout the year, Jemo Addis Ababa, 2015(Samsamwater)

### Dry and wet years

This calculation is based on the average monthly rainfall. The actual rainfall differs from month to month and year to year. The amount of available water and filling of the tank might therefore be different and change from year to year. When constructing a rainwater harvesting system it is important to take this into account. Below is a description of the situation in a dry year (20% chance) and a wet year (20% chance).

**Situation in a dry year:** during a dry year, there is less rain to fill the system. The system can provide a smaller amount of water compared to an average year. All rain is stored, so constructing a larger reservoir won't help.

**Situation in a wet year:** during a wet year there is more water available and constructing a larger tank will increase the water availability in this situation. With a storage reservoir of 1015200 litres (1015.2 m<sup>3</sup>) a rainwater harvesting system could provide 9% of the total demand.

**4.1.1.10 Rainwater Harvesting potential for all 7 residential and 1 communal buildings considering all water demand(70l/c/day)**

Location: Jemo, Addis Ababa, Ethiopia

Latitude: 8.95982 degrees

Longitude: 38.71176 degrees

Roof size: 2218 square metres

Roof type: metal

Runoff coefficient: 0.9

Water demand: 58800 litres per day

**Rainfall**

The average rainfall at this location varies between 8.7 mm in the driest month (December) and 272.8 mm in the wettest month (August). The total annual rainfall in an average year is 1209 mm.

**Water availability**

A metal roof has a runoff coefficient of 0.9, which means that 90% of the rain can be harvested. Based on this runoff coefficient and a roof area of 2218 square metres a volume of 17367 litres (8.7 mm x 2218 m<sup>2</sup> x 0.9) of water can be collected in the driest month (December) and 544563 litres (272.8 mm x 30 m<sup>2</sup> x 0.9) in the wettest month (August). The total yearly amount of water that can be collected from the roof is 2413200 litres (2413m<sup>3</sup>) in an average year.

**Water demand**

The water demand is 58800 litres per day, which equals to about 1764000 litres per month. The total water demand is 21462000 litres (21462 m<sup>3</sup>) per year. The amount of water that can be collected from the roof (2413m<sup>3</sup>) is less than the water demand (21462 m<sup>3</sup>). Only a part of the water demand can be fulfilled using a rainwater harvesting system.

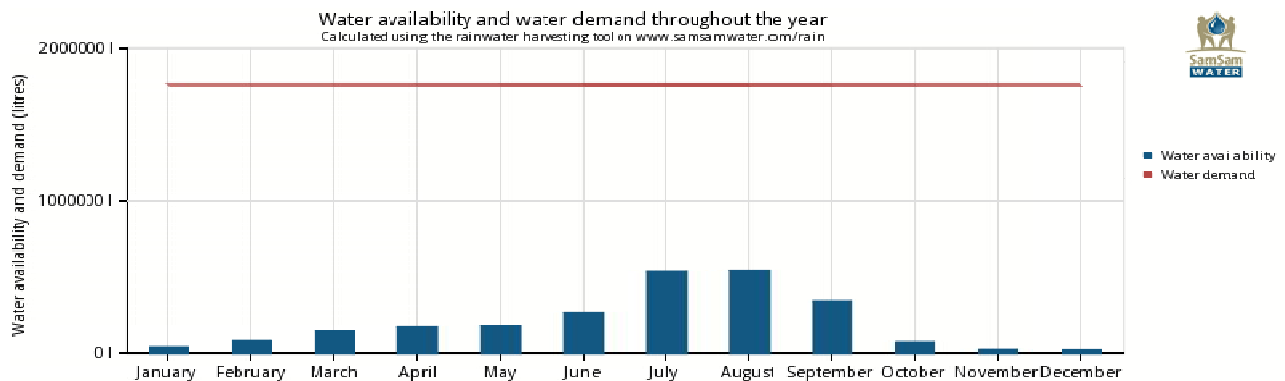


Figure 33 Water availability and water demand throughout the year, Jemo Addis Ababa, 2015 (Samsamwater)

## Required storage

The total amount of water that can be collected from this roof, 2413200 litres, is not enough to fulfill the total yearly water demand of 21462000 litres. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 879600 litres (879.6 m<sup>3</sup>) a rainwater harvesting system could provide 6612 litres of water per day, which is 11% of the total demand. The storage reservoir will be full in and then slowly drain until it is (almost) empty at the end of May.

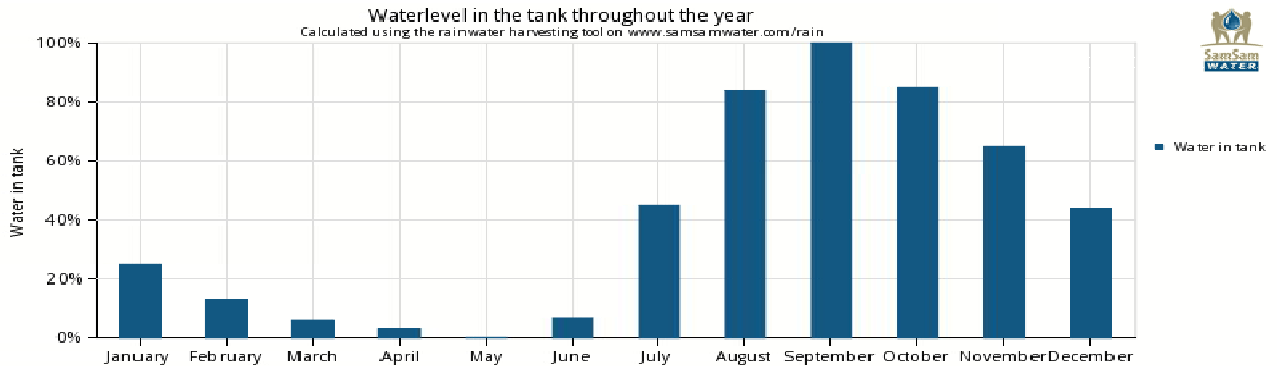


Figure 34 Water level in the tank throughout the year, Jemo Addis Ababa, 2015(Samsamwater)

## Dry and wet years

This calculation is based on the average monthly rainfall. The actual rainfall differs from month to month and year to year. The amount of available water and filling of the tank might therefore be different and change from year to year. When constructing a rainwater harvesting system it is important to take this into account. Below is a description of the situation in a dry year (20% chance) and a wet year (20% chance).

**Situation in a dry year:** during a dry year, there is less rain to fill the system. The system can provide a smaller amount of water compared to an average year. All rain is stored, so constructing a larger reservoir won't help.

**Situation in a wet year:** during a wet year there is more water available and constructing a larger tank will increase the water availability in this situation. With a storage reservoir of 1015200 litres (1015.2 m<sup>3</sup>) a rainwater harvesting system could provide 15% of the total demand.

**4.1.1.11 Rainwater Harvesting potential for all 7 residential and 1 communal buildings considering all water demand(20l/c/day)**

Location: Jemo, Addis Ababa, Ethiopia

Latitude: 8.95982 degrees

Longitude: 38.71176 degrees

Roof size: 2218 square metres

Roof type: metal

Runoff coefficient: 0.9

Water demand: 16800 litres per day

**Rainfall**

The average rainfall at this location varies between 8.7 mm in the driest month (December) and 272.8 mm in the wettest month (August). The total annual rainfall in an average year is 1209 mm.

**Water availability**

A metal roof has a runoff coefficient of 0.9, which means that 90% of the rain can be harvested. Based on this runoff coefficient and a roof area of 2218 square metres a volume of 17367 litres (8.7 mm x 2218 m<sup>2</sup> x 0.9) of water can be collected in the driest month (December) and 544563 litres (272.8 mm x 30 m<sup>2</sup> x 0.9) in the wettest month (August). The total yearly amount of water that can be collected from the roof is 2413200 litres (2413m<sup>3</sup>) in an average year.

**Water demand**

The water demand is 16800 litres per day, which equals to about 504000 litres per month. The total water demand is 6132000 litres (6132 m<sup>3</sup>) per year. The amount of water that can be collected from the roof (2413m<sup>3</sup>) is less than the water demand (6132 m<sup>3</sup>). Only a part of the water demand can be fulfilled using a rainwater harvesting system.

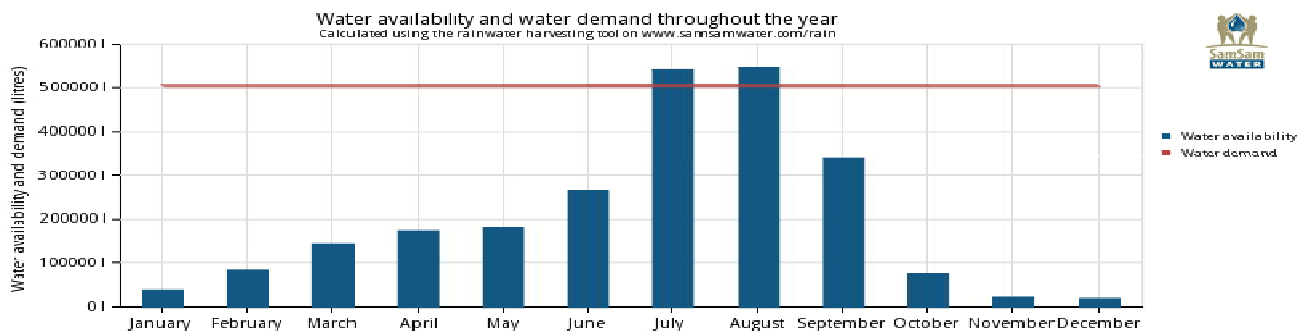


Figure 35 Water availability and water demand throughout the year, Jemo Addis Ababa, 2015(Samsamwater)

## Required storage

The total amount of water that can be collected from this roof, 2413200 litres, is not enough to fulfill the total yearly water demand of 6132000 litres. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 879600 litres (879.6 m<sup>3</sup>) a rainwater harvesting system could provide 6612 litres of water per day, which is 39% of the total demand. The storage reservoir will be full in and then slowly drain until it is (almost) empty at the end of May.

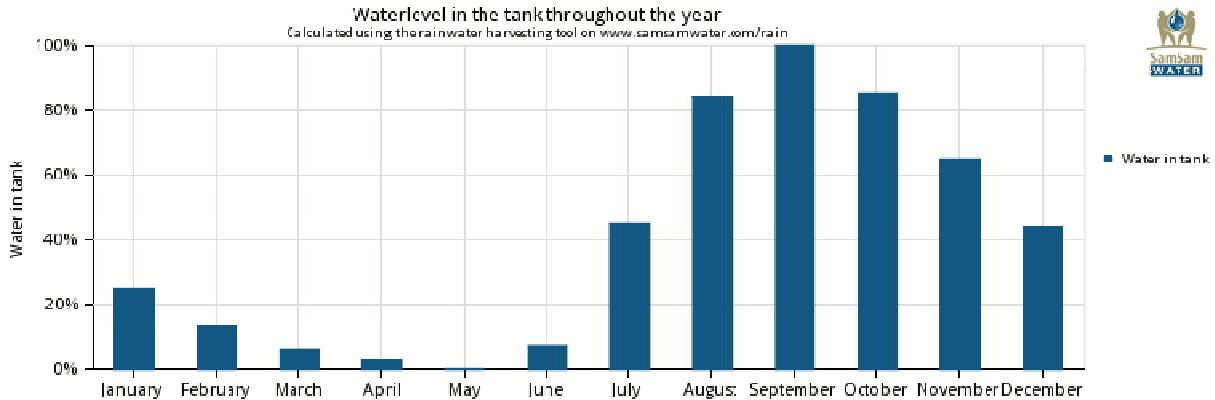


Figure 36 Water level in the tank throughout the year, Jemo Addis Ababa, 2015(Samsamwater)

## Dry and wet years

This calculation is based on the average monthly rainfall. The actual rainfall differs from month to month and year to year. The amount of available water and filling of the tank might therefore be different and change from year to year. When constructing a rainwater harvesting system it is important to take this into account. Below is a description of the situation in a dry year (20% chance) and a wet year (20% chance).

**Situation in a dry year:** during a dry year, there is less rain to fill the system. The system can provide a smaller amount of water compared to an average year. All rain is stored, so constructing a larger reservoir won't help.

**Situation in a wet year:** during a wet year there is more water available and constructing a larger tank will increase the water availability in this situation. With a storage reservoir of 1015200 litres (1015.2 m<sup>3</sup>) a rainwater harvesting system could provide 52% of the total demand.

## Summary

The average annual RWH potential at Jemo I condominium site is not enough to fulfill the total water demand at this site. However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 113400 litres (113.4 m<sup>3</sup>) for a single building a rainwater harvesting system could provide about 36% of non-potable demand and with a storage reservoir of 879.6m<sup>3</sup> for a single compound with an average of 1 communal and 7 residential buildings a rainwater harvesting system can provide about 40% of the non-potable water demand. Table 13 illustrates this value.

**Table 13 Summary of RWH potential and storage requirements at Jemo I condominium site, Jemo Addis Ababa, 2015**

Type of building	Roof area (m <sup>2</sup> )	Water Demand (l/c/day)	Annual RWH potential (m <sup>3</sup> )	Demand coverage (%)	Tank size (m <sup>3</sup> )
<b><i>Single building</i></b>					
Domestic demand	286	70	311.2	10	113.4
Non potable demand		20		36	
<b><i>All Residential buildings</i></b>					
All domestic demand	96382	70	104,865	10	38221.9
Non potable demand		20		36	
All demand including population equivalents		110		6	
<b><i>All Residential and communal buildings</i></b>					
All domestic demand	107182	70	116615	11	42504.8
Non potable demand		20		40	
All demand including population equivalents		110		7	
<b><i>One compound with 1 communal and 7 residential buildings</i></b>					
Domestic demand	2218	70	2413	11	879.6
Non Potable demand		20		39	
All demand including population equivalents		110		7	

For this study for a single condominium building a non potable demand of 20l/c/day is used for design purpose to address 36% of the demand with a storage capacity of 113.4m<sup>3</sup>.

With a storage reservoir of 90m<sup>3</sup> rainwater harvesting can cover about 80% of the non potable and 23% of all domestic demand of the site for summer season only.

#### 4.1.2 Water Demand Analysis

The collected data shows that there is a big gap between predetermined demand, surveyed demand and the water consumption rate obtained from bill readings and AAWSA Mekanisa branch office. AAWSA standardized that the per capita daily demand is 110l/c/day considering population equivalents to include non-domestic water demands. But the domestic water demand for the study area was 70l/c/day and data collected from survey shows that they demand 65l/c/day. Therefore for rainwater harvesting for a single building with 120 people 70l/c/day is used. The non-potable water demand is about 20l/c/day by only considering WC and gardening as non-potable uses. The following figure shows water demand used for rainwater harvesting potential analysis and the percentage of demand that RWH can support.

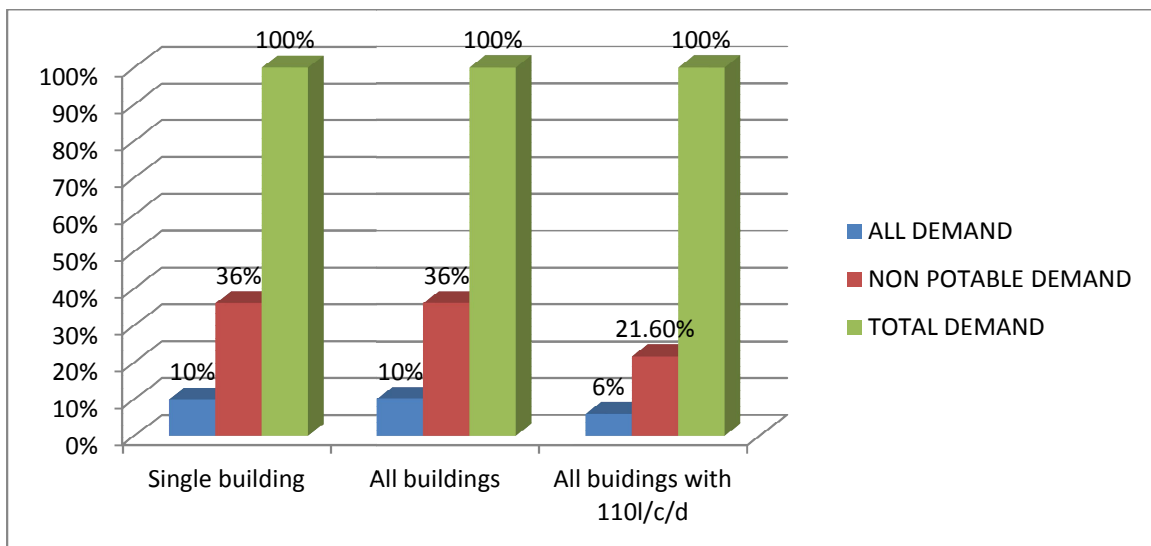


Figure 37 Percentage of demand that can be addressed by the RWH at Jemo I condominium site, Jemo Addis Ababa, 2015

Therefore the above figure shows that RWH can reduce water demand problems by 36% for only non-potable demands and 10% for all domestic demands based on the current AAWSA standard.

#### 4.1.3 Runoff reduction analysis

To analyze runoff estimation hydrological and land use characteristics were considered above. As the study area is a condominium site many of the land area is covered with impervious cover which is more than 80%. The annual average rainfall is about 1219mm. Taking different runoff coefficients for different land use characteristics considering the type of land, soil characteristics and slope a rational formula was used for analysis. Which is  $Q=AIR/360$ .

After the analysis using MS Excel spread sheets the total cumulative runoff generation from this site throughout the year is 723,450m<sup>3</sup> and the amount of water that RWH system only from roof

tops can harvest could be 90,290.2m<sup>3</sup>. With this estimation RWH from roof tops at Jemo condominium site can reduce runoff by 12.5%. This contributes for sustainable stormwater management and best management practices.

## 5 Chapter Five: Proposed RWH System

Based on the findings of the study the rainwater harvesting system in urban environment especially for this study consists of the following components in which most of them currently available in all condominium buildings in Jemo I site. These components are:-

- Roof Catchment
- Gutters and Downpipes
- First flush device
- Filter chamber
- Storage tank(underground /overhead)
- Water distribution mechanisms

### 1. Roof catchments

Roof catchments are the most commonly used for RWH especially in urban areas. Roofs intercept rainwater before it reaches to the ground. The existing roof at the condominium house with its gutters and downpipes will be used to collect rainwater. Since rainwater is pure as it falls from the sky it is necessary that the roof be kept clean for it to remain pure when it is collected. At the study area the roof is made of corrugated iron sheet. The roof surface area is about 286 m<sup>2</sup> for an average building and 216m<sup>2</sup> for buildings of communal facility. The following table shows the roof area available to collect the rainfall.

Table 14 Roof area for different buildings at Jemo I condominium site, Jemo Addis Ababa, 2014

Type of building	Building Roof section	Length(m)	Width(m)	Area(m <sup>2</sup> )	Total area(m <sup>2</sup> )
Type 1 <i>Residential</i>	A	26.5	9.8	259.7	272.2
	B	5	2.5	12.5	
Type 2 <i>Residential</i>	A	23	9	207	237.75
	B	12.3	2.5	30.75	
Type 3 <i>Residential</i>	A	13	9	117	347.9
	B	17	9	153	
	C	9.5	8.2	77.9	
Type 4 <i>Communal</i>	A	22	9	198	<b>216.125</b>
	B	12.5	1.45	18.125	
Average <i>Residential</i>		27	10.6	<b>286.2</b>	<b>285.95</b>
Average		30	7.2	<b>216</b>	

<i>Communal</i>					
					268.49375

The cost of installation for roof will be 0 since it is already constructed for other purpose.

## 2. Gutters and Downpipes(Conveyance system)

Network of guttering and pipes to transfer the rainwater from the catchment to the storage tank. This consists of connections to one or more down-pipes connected to the roof gutters.

For residential buildings the average gutter length at each sides of the building is presented in the following table.

Table 15 Length and diameter of gutter for each type of building at Jemo I condominium site, Jemo Addis Ababa, 2014

Type of building	Building Roof section	Direction		Total length(m)	Diameter(cm)
		X(m)	Y(m)		
Type 1 <i>Residential</i>	A	26.5	9.8	53	8
	B	5	2.5		
Type 2 <i>Residential</i>	A	23	9	46	8
	B	12.3	2.5		
Type 3 <i>Residential</i>	A	13	9	62	
	B	17	9		
	C	9.5	8.2		
Type 4 <i>Communal</i>	A	22	9	44	6.5
	B	12.5	1.45		
				<b>205</b>	

This is designed using table 14 which have different piping dimensions for different size of roof area.

The gutters on the building will be used to collect water from the roof surface so as to reduce costs. The current surfaces of the gutter will be covered with screens to prevent entrance of leaf and other large objects to the downpipe. The screens will have 210 meters length and 10cm width for residential and 8cm width and it will cost 1470ETB.

PVC down pipes brings the water from the rainwater gutters or pipes vertically down to the storage tank. They should invariably be clamped firmly to the wall and should never be loosely fixed. Always check that the down pipe is firmly fixed and if necessary replace or tighten the clamp whenever necessary. For best efficiency, the gutter should have about a 1% slope (in other words, the bottom of the gutter should drop 1 inch for every 8 feet of gutter length).The down pipe have a diameter of 6cm for residential and 5cm for communal buildings.



Figure 38 Gutter and downpipes used for RWH system, 2015

### 3. First Flush Device

The first flush device for RWH is used for discharging/flushing most of the dust, dirt, chemical contaminants, or animal and bird droppings. In a first flush device a separate vertical pipe is fixed to the rainwater down pipe using a "T" junction or similar as shown in the figure below. The initial flush of rainfall (containing the majority of the contaminants) running off the roof washes into the 'first flush down pipe' or into lower chamber where it is retained. When this chamber becomes full, the floating ball seals the chamber and the continuing water flows down the collection pipe into the storage tank. The water containing contaminants in the first flush pipe or chamber can be used for other purposes besides drinking (e.g. outdoor cleaning, washing, gardening etc) depending on its quality. For this device, a minimum design criterion is that the device should divert the first 0.5 mm of the rainfall (Mosely, 2005). To calculate the volume of water needed to be diverted, multiply the length and width of the house or collection surface (in meters) by 0.5 (mm):

Required volume of diverted water (L) = Roof Area \* 0.5 (mm)

For the average building, (286m<sup>2</sup> roof area, diverting 0.5 mm rain), a first flush volume of 0.15 cubic meters(143liters) rainwater should be diverted. This shows that with a 6cm diameter downpipe the height of first flush section will be 3m in order to discharge the calculated amount of rain water at a time. The cost for this section will be 100ETB.

#### First-Flush Diversion

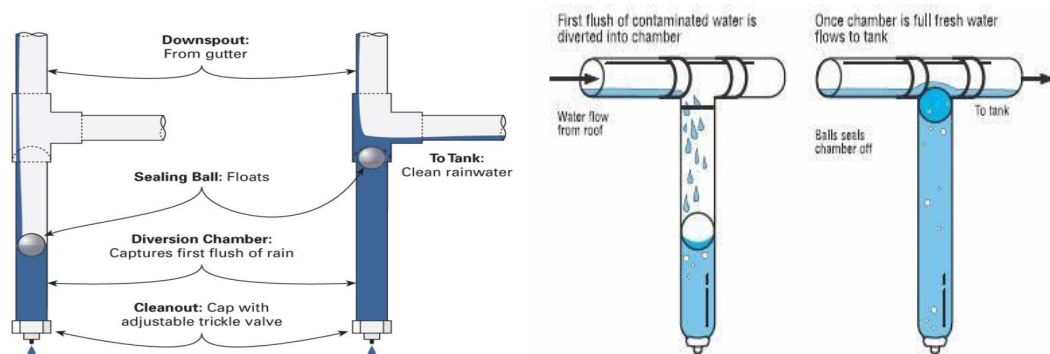


Figure 39 First flush devices to be used for RWH at Jemo I condominium site, Addis Ababa 2015

#### 4. Filter chamber

Filtering the water before it enters a tank has several advantages over filtering it as it leaves the tank. It prevents most of the nutrients that breeding insects and bacteria need from ever reaching the tank. Pre-filtration also means the tank will rarely or ever need cleaning. Combined with good tank ventilation, it stops the tank water from going anaerobic and smelling. Four layers are placed on top one another to form the filter. The filter chamber will have 30cm diameter and 70cm height (length). The materials that are used in different layers are:

Layer 1: large gravels in 10 cm layer, gravel size ranging from 12mm-14mm. Porous graves shouldn't be used

Layer 2: 10 cm thick layer of large charcoal size ranging from 6-8 cm. and

Layer 3: 25 cm thick layer of pre cleaned sand (grain size ranging from 1-3 mm).

Layer 4: 25 cm last layer of large gravels of 80 mm size.

After passing through this filter, the rainwater is ready to be used for gardening, outdoor cleaning, toilet flushing, house cleaning etc. But to make this water potable, it has to purify by chlorination.

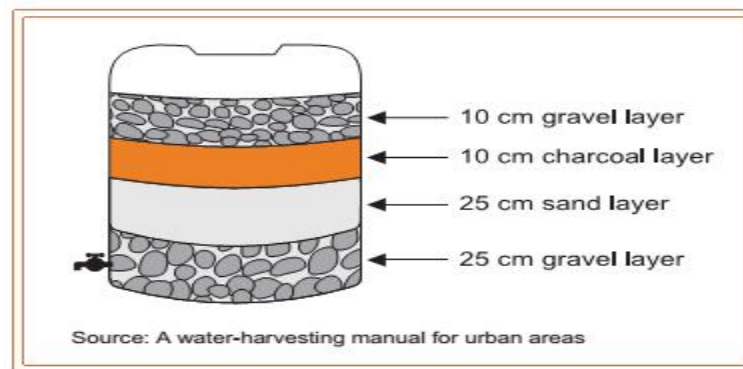


Figure 40 The filtration unit to be adopted at Jemo 1 condominium site, Jemo Addis Ababa, 2015

This is installed after the first flush device before the water enters the storage tank. The cost for this section will be 200ETB.

## 5. Storage tank

The storage tank is the most expensive component of the rainwater harvesting system. The size of storage tank or cistern is dictated by several variables: the rainwater supply (local precipitation), the demand, the projected length of dry spells without rain, the catchment surface area, aesthetics, personal preference, and budget. The higher the size of the tank, the higher the proportion of the cost.

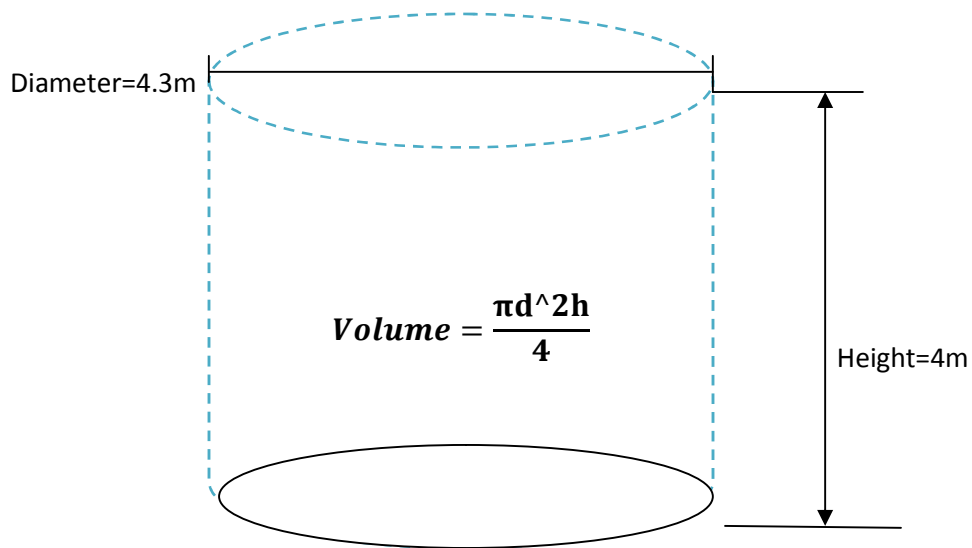
### *Option 1*

In order to support about 36% of the non-potable water demand for the given area, a volume of 113.4m<sup>3</sup> of storage tank will be required. This can be constructed at the two sides of the building. Ferro cement tanks constructed above ground each with the capacity of 60m<sup>3</sup> with concrete. A circular tank with a diameter of 4.3 meter and a depth of 4 meter is required.

The other necessary elements of the tank are:-

- Manhole for cleaning and maintenance
- Overflow pipe for the excess water connected to the drainage pipes.
- Should be connected to a power driven pump to supply water to the apartments.

An overflow is installed to reduce the possibility of system collapse during a rainstorm when the tank may fill rapidly.



In addition to the storage tank to be constructed at the ground additional elevated water tank will be required in order to supply water without continues pumping. This will increase the cost of installation but reduces the cost of operation. The elevated tank will have a capacity of 5,000 liters made of Plastic in order to continuously supply for 2 days without continuous pumping. It will be installed about 12m above ground at each side of the building. Both the

two storage tanks can also help store additional water from municipal pipelines during the dry season. The cost of construction will be:

- Cost of Ferro cement tank=186,300ETB
- Cost of 5,000l Fiber tank=15,000 ETB
- Cost for stand to elevate the tank=20,000ETB

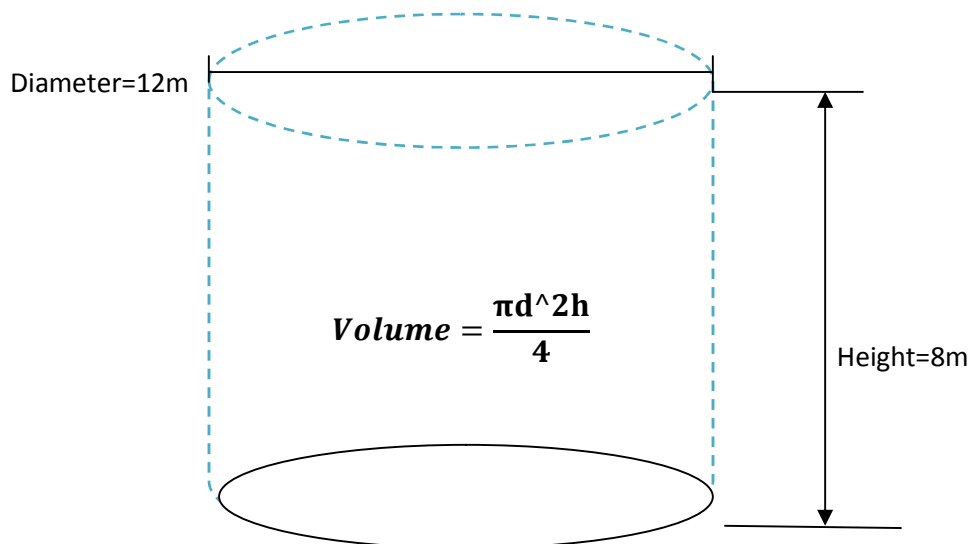
### **Option 2**

In order to support about 39% of the non-potable water demand for a single compound having 7 residential and 1 communal buildings, a volume of 879.6m<sup>3</sup> of storage tank will be required. This can be constructed at one side of the compound. Ferro cement tank will be constructed above ground with the capacity of 900m<sup>3</sup> with concrete. A circular tank with a diameter of 12 meter and a depth of 8 meter is required.

The other necessary elements of the tank are:-

- Manhole for cleaning and maintenance
- Overflow pipe for the excess water connected to the drainage pipes.
- Should be connected to a power driven pump to supply water to the apartments.

An overflow is installed to reduce the possibility of system collapse during a rainstorm when the tank may fill rapidly.



In addition to the storage tank to be constructed at the ground additional elevated water tank will be required in order to supply water without continues pumping. This will increase the cost of installation but reduces the cost of operation. The elevated tank will have a capacity of 5,000 liters made of Plastic in order to continuously supply for 2 days without continuous pumping. It will be installed about 12m above ground at each side of the building.

## 6. Water Distribution mechanism

The fact that the storage facility has to be placed below the level of the catchment surface (in the case of households, the roof) pumping will be required to lift the water from storage and maintain pressure in the water distribution network if the water is to be used for internal plumbing.

Here there are two ways to utilize the harvested water. One is to use the water by fetching at the ground directly from the reservoir or water tank. The other way is installation of a separate distribution system for the five floors. This will be costly but the most useful. The former one does not need pumping but the second option needs pumping if there is no elevated tank.

Pumps are usually readily available at hardware suppliers and the size selected can range depending on the number of taps or outlets to be serviced through the building or facility. In general for average homes with two bathrooms a ½ horse power (hp) pump with a 10 to 15 gallon pressurized storage tank and ½ inch pipes throughout the structure will suffice. A pressure switch that will maintain the pressure between about 20 pounds per square inch (psi) and 40 psi should be installed. Buildings with high water demands should increase the size of pumps, tanks and pipes as necessary. For buildings with multiple residential units, separate pressurized systems are recommended for each for ease of management and redundancy purposes.

Power to drive pumping systems include photo-voltaic (PV) systems using solar panels or by small wind turbines. These renewable energy options require battery storage to meet the power requirements during periods when there are no direct energy sources available such as during overcast conditions, at night, or when there is no wind. It must be noted that battery storage adds to the cost of operation and maintenance of renewable energy solutions. To avoid the need for expensive batteries, water is commonly pumped to a tank at a high elevation at times when the renewable energy resource is available. Through gravity the water can then be supplied to the place of consumption. PV arrays need no special maintenance apart from a regular cleaning of the panel's glass surface. Wind turbines require yearly maintenance on all moving parts. If batteries are used, the acid level in the batteries needs to be checked regularly. An advantage of PV over wind is that it is easier to install, however site specifics such as solar insolation (sunshine) and average wind speed are more important factors.

## 6 Chapter Six: Conclusion and Recommendations

### 6.1 Conclusion

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. With a storage reservoir of 113400 litres (113.4 m<sup>3</sup>) for a single building a rainwater harvesting system could provide about 36% of non-potable demand and RWH can reduce water demand problems by 36% for only non-potable demands and 10% for all domestic demands based on the current AAWSA standard. The total cumulative runoff generation from this site throughout the year is 723,450m<sup>3</sup> and the amount of water that RWH system only from roof tops can harvest could be 90,290.2m<sup>3</sup>. With this estimation RWH from roof tops at Jemo condominium site can reduce runoff by 12%. This contributes for sustainable stormwater 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 goal. The community also interested to use rainwater for non potable purpose once it is treated for some physical impurities.

### 6.2 Recommendations

Based on the study results and conclusions the responsible bodies to supply water to residents and those who concern about stormwater needs to work with integration so as to adopt sustainable solutions for solving the problems. One of the sustainable solution is rainwater harvesting which will have high initial cost but least operation, maintenance cost but greatest benefits. This study focused on the quantitative aspects, therefore others also needs to study the qualitative aspects of rainwater in Addis Ababa city so as to utilize the rainwater for potable purposes after a certain additional treatment. Government and the Ethiopian Rainwater Harvesting Association also needs to work integrate to diversify the idea of rainwater harvesting.

Addis Ababa city municipality with its housing development agency needs to consider rainwater harvesting mechanisms during the designing of new condominium houses at different part of the city.

Additional studies also needs to be conducted for houses other than condominium and for industrial and commercial areas and buildings.

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## Annex

### Annex 1 Checklist for demand assessment

#### Addis Ababa University

#### Addis Ababa Institute of technology

#### School of civil and Environmental Engineering

This Checklist is prepared to assess real water demand and supply gaps among residents of Jemo condominium site and provide a sustainable solution for the available problems.

Are you willing to respond for questions below? Yes  No

Block \_\_\_\_\_ Site \_\_\_\_\_ site number \_\_\_\_\_ Floor \_\_\_\_\_ House number \_\_\_\_\_

#### I. HOUSEHOLD DEMOGRAPHIC CHARACTERISTICS

1. Nationality \_\_\_\_\_ Nation \_\_\_\_\_ Religion \_\_\_\_\_
2. Sex of the Household Head 1. Male 2. Female
3. Age of the HH head at completed year \_\_\_\_\_
4. Marital Status of the Household Head 1. Single 2. Married 3. Widow 4. Divorced
5. Sex and age of family members

Sex	Age group						Total
	0-5 years	6-15 years	15-30 years	31-45 years	46-60 years	>60 years	
Male							
Female							
Total							

#### 6. Educational status of family members

	Education level						
	Illiterate	Read and write	1-4	5-8	9-10	11-12	Diploma and above
Male							
Female							
Total							

#### 7. House ownership

Own house  rented  other

#### II. INCOME AND EXPENDITURE

1. What is the total income earned from various sources in the last month? \_\_\_\_\_ Birr
2. What is your cash expenditure for potable water last month? \_\_\_\_\_ Birr

3. What is your cash expenditure for buying water when there is no water at pipe lines?

\_\_\_\_\_

**III. WATER SUPPLY CONDITION**

1. What is the main source of water for your household?  
\_\_\_\_\_
2. Is the water source continuous and sufficient?  
\_\_\_\_\_
3. If you use public water point when there is shortage of water, what is the distance from your residence?
  1. Less than 50 meter
  2. From 51 – 100 meter
  3. From 101 – 150 meter
  4. Over 151 meter
4. If you use public water point when there is shortage of water, what is the estimated time for round trip?
  1. Less than 15 minutes
  2. From 15 minutes – 30 minutes
  3. From 30 minutes – 1 hour
  4. Over 1 hour
5. How many containers of water do you collect per day for the household (container is estimated to be 20 liters capacity) \_\_\_\_\_ How much do you pay for 1 container \_\_\_\_\_
6. Where do you wash your clothes? 1) public washing trough 2) at water source 3) Using washing basin
7. Do you regularly pay monthly water charges to AAWSA? 1. Yes 2. No
8. Is the current water tariff affordable? 1. Yes 2. No
9. How much do you pay per month on average for water consumption? ETB \_\_\_\_\_
10. How much do you cost for buying water when there is no water in private water pipes? \_\_\_\_\_
11. What is your general opinion to improve the water supply service?  
\_\_\_\_\_  
\_\_\_\_\_
12. Do you have experience of using rainwater? \_\_\_\_\_
13. Are you willing to use rainwater for non-potable purposes if it is harvested and treated very well? \_\_\_\_\_ What do you suggest? \_\_\_\_\_

**IV. Services in which water is used**

How much water do you need per day for the following purposes?

Type of services	Amount of water needed per day in liters	Type of sources	Frequency of use per day
Bathroom			
Dishwashing			
Cooking			
Washing clothes			
Cleaning house			
Washing machine			
WC			

Gardening			
Washing hands			
Other uses			
Total			

**THANK YOU FOR YOUR COOPERATION**

**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
*School of Civil and Environmental Engineering*

**Introduction**

My name is **Ashebir Kebede** and I am a postgraduate graduating class student at Addis Ababa University in water supply and Environmental Engineering. Currently I am conducting my research work on "**Rainwater harvesting for solving both problems of water demand and stormwater in Addis Ababa city, a case of Jemo condominium site**".

Hoping that your organization is willing to cooperate with my research work, I am seeking the following information from your organization.

Name of the organization    **ADDIS ABABA WATER AND SEWERAGE AUTHORITY**

Responsibility \_\_\_\_\_

Name of the respondent \_\_\_\_\_ Responsibility \_\_\_\_\_

**Data required from the specific organization**

1. Per capita water demand of Addis Ababa city \_\_\_\_\_
2. Total water demand for Addis Ababa city
  - 2.1. Domestic \_\_\_\_\_
  - 2.2. Industrial \_\_\_\_\_
  - 2.3. Institutional \_\_\_\_\_
  - 2.4. Fire fighting \_\_\_\_\_
  - 2.5. Others (Specify) \_\_\_\_\_
3. Currently available water supply \_\_\_\_\_
  - 3.1. Ground water \_\_\_\_\_
  - 3.2. Surface water \_\_\_\_\_
  - 3.3. Rainwater harvesting (if any) \_\_\_\_\_
4. Production capacity of AAWSA \_\_\_\_\_
5. Sources of water supply for Addis Ababa city  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6. Which sources supply water for Jemo condominium site

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7. Is there an information about the total water demand of Jemo condominium site? \_\_\_\_\_ If yes, Please specify it

---

8. Is there a water consumption data of Jemo condominium site? \_\_\_\_\_ If yes(take the detail data)

9. Number of customers at Jemo condominium site

9.1. Jemo 1 \_\_\_\_\_

9.2. Jemo 2 \_\_\_\_\_

9.3. Jemo 3 \_\_\_\_\_

10. Water distribution network data (Collect the data)

11. Which AAWSA branch is responsible for Jemo site?

12. Other data \_\_\_\_\_

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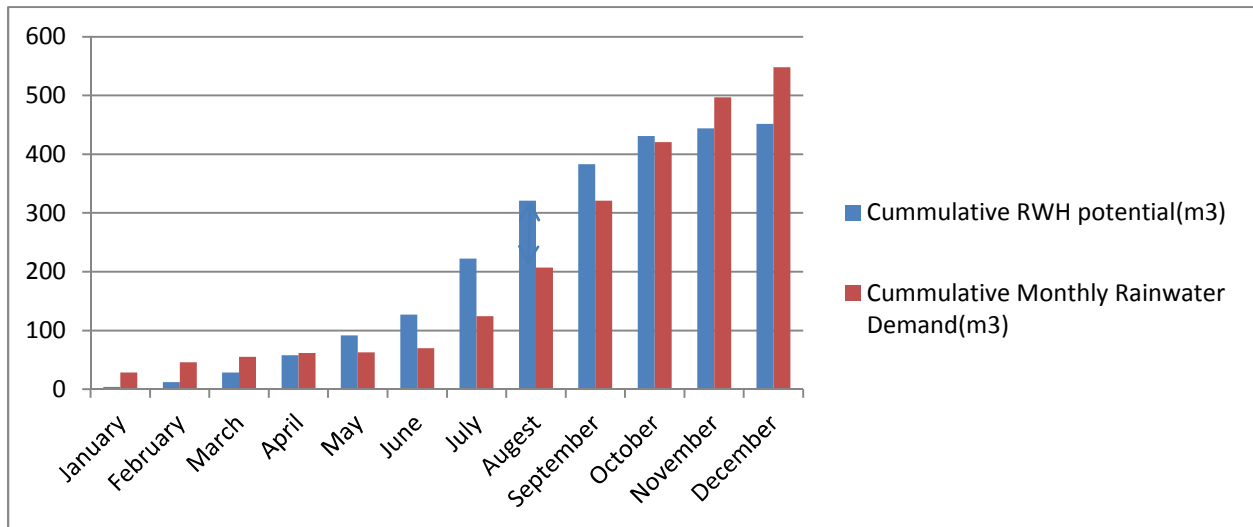
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***THANK YOU FOR YOUR COOPERATION***

**Annex 3 Storage tank sizing method for Rainwater Harvesting at Jemo site**

Month	Mean monthly Rainfall (mm)	Total RWH potential (m3)	Cumulative RWH potential(m3)	Monthly Rainwater Demand (m3)	Cumulative Monthly Rainwater Demand(m3)	Difference between the cumulative
January	12.4	3.8	3.8	28.2	28.2	-24.4
February	32	8.2	12	17.6	45.8	-33.8
March	60.7	16.3	28.3	9.1	54.9	-26.6
April	88.1	29.5	57.8	6.5	61.4	-3.6
May	80.6	33.6	91.4	1.2	62.6	28.8
June	144.6	35.4	126.8	7.3	69.9	56.9
July	274.4	95.6	222.4	54.2	124.1	98.3
August	294.8	98.6	321	83	207.1	113.9
September	178.1	62	383	114	321.1	61.9
October	34.6	48	431	99.2	420.3	10.7
November	9.4	12.2	443.2	76.4	496.7	-53.5
December	9.5	8.6	451.8	51.3	548	-96.2

The largest range from the graph for each month will determine the size of the tank for rainwater harvesting.



#### Annex 4 Land use data of Jemo I condominium site, Jemo Addis Ababa, 2015

Section	Commercial	Elementary School	Secondary School	KG	Admin	Sport field	Green	Health center	Residential	Police	open market	Factory	Road	Total
1	4480.02	17917.53	23520.4	7616.69	1903.29	12987.01	2752.52	8222.44	36145.5					
2	3435.1					9772.32	2795.46		10019.19					
3	5106.97						2969.24		20772.33					
4	5348.5						2971.68		65061.9					
5	6525.79						3048.86		14605.35					
6	4635.36						3048.86		21687.3					
7	3277.08						2225.4		24141.69					
8	5605.12						2205.17		7229.1					
9	2300						5095.62		8259.7					
10	8634.24						2310		3586.9					
11	5408.24						2310		4084.36					
12	26651.72						2310		5313					
13	230						2310		6169.73					
14	4682.71						2310		5908.53					
15	2297			2392.74			7255.18	8504	7229.1	3250.71	15579.73	114380		
16	5812.74			2570.68			1123.3		7229.1					
17	4996.5			2363.63			1123.3		7229.1					
18	16132.74			3407.59			1485		6137.61					
19	9906.2			2844.64			1485		3100					
20	14027.63			2377.26			5332.12		3034.81					
21	4886.6						2775.41		6760.57					
22	2038.22						903.04		7229.1					
23	6712.49						8046.31		7229.1					
24	7973.78						8910		8293.67					
25	6366.5						2028		9307.63					
26	5850.21						493.3		7229.1					
27	5144.98						1144.1		7229.1					
28	9935.3						349		7229.1					
29							776		11341.67					
30	188401.74	17917.53							28916.4					
31									7256.97					
32									24631.9					
33			23520.4	23573.23	1903.29	22759.33	81891.87	16726.44	6697.52					
<b>Sum</b>	<b>188401.74</b>	<b>17917.53</b>	<b>23520.4</b>	<b>23573.23</b>	<b>1903.29</b>	<b>22759.33</b>	<b>81891.87</b>	<b>16726.44</b>	<b>406296.13</b>	<b>3250.71</b>	<b>15579.73</b>	<b>114380</b>	<b>11299.6</b>	<b>927500</b>
	20.30%	1.93%	2.53%	2.54%	0.20%	2.50%	8.80%	1.80%	43.80%	0.40%	1.70%	12.33%	1.21%	100%

Annex 5 Rainwater Harvesting Potential of roofs at Jemo I

<b>Rainwater Harvesting potential calculated from 30 year rainfall data-Jemo 1</b>														
		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	Annual
Residential single	Rainfall Intensity	0.0124	0.032	0.0607	0.0881	0.0806	0.1446	0.2744	0.2948	0.1781	0.0346	0.0094	0.0095	1.219
286	Runoff coefficient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Area	286	286	286	286	286	286	286	286	286	286	286	286	286
	RWH potential(m3)	2.83712	7.3216	13.8882	20.157	18.4413	33.0845	62.78272	67.4502	40.74928	7.91648	2.15072	2.1736	<b>278.9072</b>
Residential all Jemo 1		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	Annual
96382	Rainfall Intensity	0.0124	0.032	0.0607	0.0881	0.0806	0.1446	0.2744	0.2948	0.1781	0.0346	0.0094	0.0095	1.219
	Runoff coefficient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Area	96382	96382	96382	96382	96382	96382	96382	96382	96382	96382	96382	96382	96382
	RWH potential(m3)	956.1094	2467.38	4680.31	6793	6214.71	11149.5	21157.78	22730.7	13732.51	2667.85	724.79264	732.503	<b>93991.726</b>
Communal single		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	Annual
216	Rainfall Intensity	0.0124	0.032	0.0607	0.0881	0.0806	0.1446	0.2744	0.2948	0.1781	0.0346	0.0094	0.0095	1.219
	Runoff coefficient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Area	216	216	216	216	216	216	216	216	216	216	216	216	216
	RWH potential(m3)	2.14272	5.5296	10.489	15.224	13.9277	24.9869	47.41632	50.9414	30.77568	5.97888	1.62432	1.6416	<b>210.6432</b>
Communal all Jemo 1		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	Annual
10800	Rainfall Intensity	0.0124	0.032	0.0607	0.0881	0.0806	0.1446	0.2744	0.2948	0.1781	0.0346	0.0094	0.0095	1.219
	Runoff coefficient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Area	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800
	RWH potential(m3)	107.136	276.48	524.448	761.18	696.384	1249.34	2370.816	2547.07	1538.784	298.944	81.216	82.08	<b>10532.16</b>

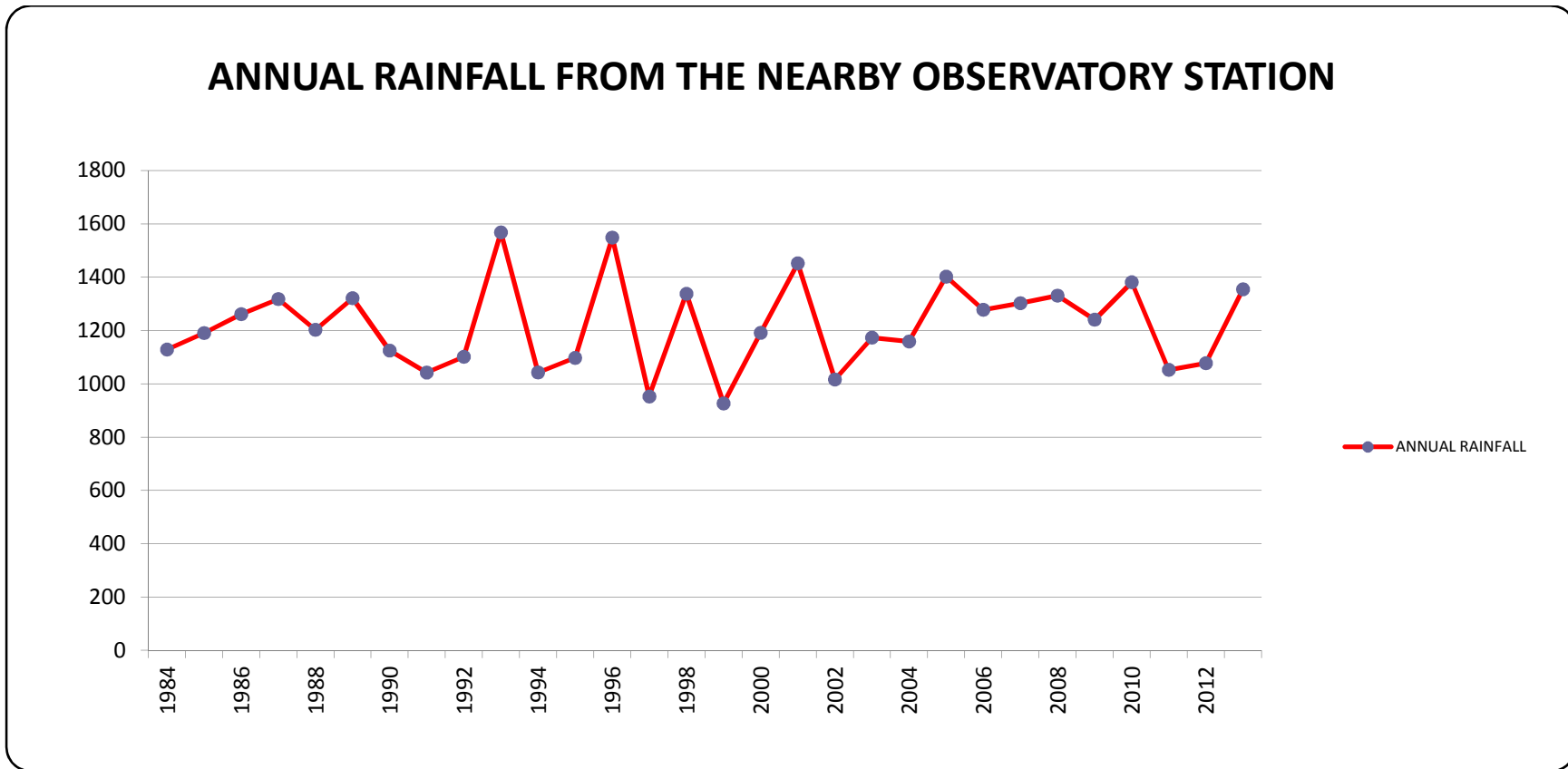
Annex 6 Rainwater Harvesting Potential of roofs at Jemo II

<b>Rainwater Harvesting potential calculated from 30 year rainfall data-Jemo 2</b>														
		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	Annual
Residential single	Rainfall Intensity	0.0124	0.032	0.0607	0.0881	0.0806	0.1446	0.2744	0.2948	0.1781	0.0346	0.0094	0.0095	1.219
286	Runoff coefficient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Area	286	286	286	286	286	286	286	286	286	286	286	286	286
	RWH potential(m3)	2.83712	7.3216	13.8882	20.157	18.4413	33.0845	62.78272	67.4502	40.74928	7.91648	2.15072	2.1736	<b>278.9072</b>
Residential all Jemo 2		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	Annual
46618	Rainfall Intensity	0.0124	0.032	0.0607	0.0881	0.0806	0.1446	0.2744	0.2948	0.1781	0.0346	0.0094	0.0095	1.219
	Runoff coefficient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Area	46618	46618	46618	46618	46618	46618	46618	46618	46618	46618	46618	46618	46618
	RWH potential(m3)	462.4506	1193.42	2263.77	3285.6	3005.93	5392.77	10233.58	10994.4	6642.133	1290.39	350.56736	354.297	<b>45461.874</b>
Communal single		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	Annual
216	Rainfall Intensity	0.0124	0.032	0.0607	0.0881	0.0806	0.1446	0.2744	0.2948	0.1781	0.0346	0.0094	0.0095	1.219
	Runoff coefficient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Area	216	216	216	216	216	216	216	216	216	216	216	216	216
	RWH potential(m3)	2.14272	5.5296	10.489	15.224	13.9277	24.9869	47.41632	50.9414	30.77568	5.97888	1.62432	1.6416	<b>210.6432</b>
Communal all Jemo 2		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	Annual
6696	Rainfall Intensity	0.0124	0.032	0.0607	0.0881	0.0806	0.1446	0.2744	0.2948	0.1781	0.0346	0.0094	0.0095	1.219
	Runoff coefficient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Area	6696	6696	6696	6696	6696	6696	6696	6696	6696	6696	6696	6696	6696
	RWH potential(m3)	66.42432	171.418	325.158	471.93	431.758	774.593	1469.906	1579.18	954.0461	185.345	50.35392	50.8896	<b>6529.9392</b>

Annex 7 Rainwater Harvesting Potential of roofs at Jemo II

<b>Rainwater Harvesting potential calculated from 30 year rainfall data-Jemo 3</b>														
		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	Annual
Residential single	Rainfall Intensity	0.0124	0.032	0.0607	0.0881	0.0806	0.1446	0.2744	0.2948	0.1781	0.0346	0.0094	0.0095	1.219
286	Runoff coefficient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Area	286	286	286	286	286	286	286	286	286	286	286	286	286
	RWH potential(m3)	2.83712	7.3216	13.8882	20.157	18.4413	33.0845	62.78272	67.4502	40.74928	7.91648	2.15072	2.1736	<b>278.9072</b>
<b>Residential all Jemo 3</b>														
		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	Annual
42042	Rainfall Intensity	0.0124	0.032	0.0607	0.0881	0.0806	0.1446	0.2744	0.2948	0.1781	0.0346	0.0094	0.0095	1.219
	Runoff coefficient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Area	42042	42042	42042	42042	42042	42042	42042	42042	42042	42042	42042	42042	42042
	RWH potential(m3)	417.0566	1076.28	2041.56	2963.1	2710.87	4863.42	9229.06	9915.19	5990.144	1163.72	316.15584	319.519	<b>40999.358</b>
<b>Communal single</b>														
		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	Annual
216	Rainfall Intensity	0.0124	0.032	0.0607	0.0881	0.0806	0.1446	0.2744	0.2948	0.1781	0.0346	0.0094	0.0095	1.219
	Runoff coefficient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Area	216	216	216	216	216	216	216	216	216	216	216	216	216
	RWH potential(m3)	2.14272	5.5296	10.489	15.224	13.9277	24.9869	47.41632	50.9414	30.77568	5.97888	1.62432	1.6416	<b>210.6432</b>
<b>Communal all Jemo 3</b>														
		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	Annual
4320	Rainfall Intensity	0.0124	0.032	0.0607	0.0881	0.0806	0.1446	0.2744	0.2948	0.1781	0.0346	0.0094	0.0095	1.219
	Runoff coefficient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	Area	4320	4320	4320	4320	4320	4320	4320	4320	4320	4320	4320	4320	4320
	RWH potential(m3)	42.8544	110.592	209.779	304.47	278.554	499.738	948.3264	1018.83	615.5136	119.578	32.4864	32.832	<b>4212.864</b>

Annex 8 A 30 year yearly rainfall taken from Addis Ababa observatory station



**Annex 9 Monthly Annual Rainfall of Addis Ababa city (Observatory station)**

<i>Year</i>	<i>JANUARY</i>	<i>FEBRUARY</i>	<i>MARCH</i>	<i>APRIL</i>	<i>MAY</i>	<i>JUNE</i>	<i>JULY</i>	<i>AUGEST</i>	<i>SEPTEMBER</i>	<i>OCTOBER</i>	<i>NOVEMBER</i>	<i>DECEMBER</i>	<i>ANNUAL</i>
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		1261.3
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	12.42333	32	60.69333	88.12333	80.64	144.5733	274.4167	294.8467	178.14	34.63333	9.37	9.531034	1219.073
MAX	55.2	155.9	248.9	197.6	241.3	271.1	428	426.5	294.2	126.9	79.4	65	1567.9
MIN	0	0	0	8.4	0.5	69.4	180.1	194.3	88.4	0	0	0	926.3

**Annex 10 Cost of water at Jemo I condominium site as data collected from residents**

Amount of water(m3)	Cost of water AAWSA	Cost of water at private market
0.02	1.75	8.33
0.1	1.75	41.65
0.5	1.75	208.25
1	1.75	416.5
2	3.5	833
3	5.25	1249.5
4	7	1666
5	8.75	2082.5
6	10.5	2499
7	12.25	2915.5

**Annex 10 A 6 months Water consumption data at Jemo I condominium site (AAWSA Mekanisa branch)**

Month	May	June	July	August	September	October
# of Customers	9403	9405	9415	9428	9429	9430
Consumption	45295	40599	39540	39569	39569	37471
Demand	124119.6	124146	124278	124449.6	124462.8	124476

