AFRICA CENTER OF EXCELLENCE FOR WATER MANAGEMENT
ADDIS ABABA UNIVERSITY

A THESIS ON

EVALUATION OF ROOF TOPS RAINWATER POTENTIAL FOR ALTERNATIVE WATER SUPPLY SOURCE: A CASE OF WACHEMO UNIVERSITY, MAIN CAMPUS

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DECLARATION

I, Tamirat Abreham Solomon, declared this thesis as it's my original work. This not has been presented in any university before and will not be presented to any other university to award similar or any other degree.

Tamirat Abreham		04/11/2021
Author Name	Signature	Date

THESIS APPROVAL PAGE

APPROVED BY BOARD OF EXAMINERS

This is to certify that we the undersigned, have examined this MSc thesis entitled **"Evaluation of Rooftops Rainwater Potential for Alternative Water Supply Source: A Case of Wachemo University, Main Campus''** and that in our opinion; it is fully adequate in scope and quality, as MSc thesis for the degree of Master of Science in Water Management (Water Supply and Sanitation).

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ABSTRACT

Roofs top rainwater harvesting has been carried out worldwide to afford an alternative source of water for many people. The aim of the present study was to evaluate of the rooftop rainwater harvesting potential for alternative supply source in Wachemo University. A 20-years rainfall data was analyzed to determine the average monthly and annual rainfall potential in the study area. The possible volume potential that can be harvested from the selected rooftops of the Wachemo University was quantified using rational method. Ripple mass curve method was also applied to determine the storage capacity of the water tank for the harvestable rooftop rainwater in the study area. Google earth and ArcGIS 10.3 tools were used to digitize the buildings rooftops and to locate water sample points. The quality of the rooftop rainwater was examined as per the standard method for the examination of water and wastewater quality. Considering only the four wet season months (March through October), the monthly variation with coefficient of variation ranges between 33% and 69% and yearly variation between 13% and 24 % .The maximum potential of rainwater with annual average rainfall amount 1188 mm and rooftops area 107587 m^2 was found to be 102,268 m^3 /y which can be harvested from roofs provided that all rain falling on the roofs is collected. This is equivalent to 52.4 % of average water demand of the community in the university. The Ripple mass curve method showed that about 4269.2m^3 of storage tank capacity is essential to store the harvestable rooftop rainwater. The water quality examination revealed that of the qualities of the rooftop rainwater were found within the permissible limit of drinking water quality as per the WHO (2017) guideline except the values of the bacteriological parameters. Total cost for installing the rainwater harvesting system in 94 similar buildings inside the Wachemo University main campus evaluated as 6,937,200 Et.Birr (149,187 USD). The study concluded that rooftop rainwater harvesting is a promising alternative solution in Wachemo University to solve water scarcity problem and for ensuring a continual source of non-potable water.

Key words: Rooftops, ArcGIS, Water Quantity and Quality, Wachemo University

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LIST OF ABBREVIATIONS AND SYMBOLS

AAWD	Annual Average Water Demand
AAU	Addis Ababa University
ACEWM	Africa Center of Excellence for Water Management
AMRF	Average Monthly Rain Fall
Bra	Building roof area
C	Coefficient
CFU	Colonies Forming Unit
Du	Durame
EC	Electric conductivity
ES	Ethiopian Standard
FC	Fecal Coliforms
Fo	Fonko
GIS	Geographical Information System
GPS	Global Positioning System
IFAD	International Fund for Agricultural Development
KMZ	Keyhole Markup Zipped
MPL	Maximum Permissible Limit
NTU	Nephelometric Turbidity Units

PVC	Polyvinyl Chloride
RWH	Rain Water Harvesting
SNNP	Southern Nations Nationalities and People
Sh	Shone
TC	Total Coliforms
TDS	Total Dissolved Solids
TN	Total Number
TARF	Total Annual Rain Fall
UD	Unable to meet the daily water demand
USEPA	United States Environmental Protection Agency
USA	United States of America
UTM	Universal Transverse Mercator
WCU	Wachemo University
WGS	World Geodetic System
WHO	World Health Organization

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

Rainwater harvesting is an option which has been implemented in several parts of the world where conventional water supply systems have unsuccessful to meet the needs of the people (Awawdeh et al., 2012). Where provisions for water and sanitation are insufficient, the diseases that arise from unclean water, food and hands are among the world's leading causes of premature death and serious illness (Yewondossen, 2012). Water supply shortage is one of the problems which require greater attention and action in Hosana town, particularly in Wachemo University. The major community water supply problems are linked with having no alternative supply sources, inadequate water supply, limited budget/fund, limited forecasting strategies of the Hosaena Water Supply System Service (HWSSS) rapid population growth and common interruption make the provision services difficult generally in Hosaena town and particularly in Wachemo University (Ochocho, 2019).

These factors require that the water administrators consider immediately other possibilities that lessen the water stress that the population is facing. Adopting the concept of sustainability and conservation of water resources can help to deal with water shortage (Arthur and Enedir, 2016). Rainwater harvesting is promoted as an effective way to reduce consumption of potable water thereby reducing flooding risk, supplying water just in case of emergency or breakdown, empowering communities to manage their water resources, as well as, reducing water bills and operational costs (Rostad et al., 2016; Palla et al., 2012).

Rainwater harvesting practices are getting increased attention from urban water managers as a means of potentially reducing potable and non-potable water consumption (Al-houri et al., 2014; Sanches, 2015).

Only currently, in some residential areas, particularly those facing water scarcity, new trends are being observed and rainwater harvesting is being promoted through ambitious regulations and incentives. By utilizing rainwater harvested from urban catchments for a variety of non-potable water uses, the quantity of water extracted from source water can be reduced, with potential environmental, economic and even societal benefits (Hammes et al., 2020).

Great amount of the water used in buildings can be replaced by rainwater (Adugna et al., 2018). This water is a natural resource which could be easily collected and consumed in a variety of domestic, commercial and industrial applications, especially where the drinking water is not required.

Nowadays, rainwater is widely used as alternative supply source for potable and non-potable applications in countries, for instance Australia, South Africa, the USA, Germany and Japan, where funding is delivered for the construction of rainwater harvesting systems (Luís, 2015). Also in Ethiopia for supply sources (Andualem et al., 2019). It can also benefit, including a supply of non-drinking water for end uses such as toilet flushing, washing floors.

This can lessen a buildings' clean water demand and water bills (Campisano et al., 2017). Rainwater harvested from roof runoff is the most common type of RWH system as it requires minimum treatment and only consists of a collection area, a conveyance system and a storage tank (Imteaz et al., 2013).

Due to this, it is becoming increasingly more demanding to take advantage of rainwater in urban areas, mainly to meet consumption needs for which the use of drinking water is not imperative (Domènech and Saurí, 2011; Lupia et al., 2017).

However, the use of rainwater as a source depends on the local precipitation system, specifically on the precipitated volumes and their temporal variability. Therefore, rainwater harvesting practices have increasingly become prevalent in areas with high rainfall rates where pressure on water resources overpasses the recharge capacity (Campisano et al., 2017). Equally important are the storage capability and the accessibility of surfaces for effectively harvesting rainwater, such as roofs or terraces (Rostad and Montalto, 2012).

Subsidizations perform as an efficient means of adopting the installation of rainwater harvesting systems in already constructed buildings as long as inhabitants acknowledge the value of rainwater (Imteaz et al., 2011; Awawdeh et al., 2012; Sanches et al., 2015). Rainwater collection and utilization schemes are said to be optimum when implemented in combination with water demand management (Kim et al., 2021; Shadeed and Alawna, 2021).

To define the potential of rainwater harvesting, local hydrology, the purpose and productivity expected from the system should be considered. In areas where the water supply systems are functioning, majority of the existing buildings and other facilities as well as the development plans have been observed to place less emphasis on the incorporation of rooftop rainwater harvesting systems (Matos et al., 2013). This has been significantly recognized to budget limitations as well as to the limited knowledge on the potential of the harvested rainwater (Zacharia, 2013).

1.2. Statement of the Problem

The institution Wachemo University consists of employees including teaching faculties, administration staff and secretaries working and students learning on every floor. Scarcity and insufficiency of adequate water in Wachemo University are associated with the problems concerning having no alternative water supply source other than single borehole which was constructed by the Wachemo University for the common benefit together with the nearby community in the project area. The single borehole was constructed one year ago and is 8 km far from the university with the discharge capacity of 40L/s. All the communities of the university depend up on this single source and it discharges only 15 hours in day, because of pump operation may become heated and damaged if it operates longer time than this 14 hours. Also, University pays about 350,000 Et.Birr/ month for Hosaena town water supply service to lessen the scarcity of water in the community for potable and non-potable uses. In addition, the University is forced to limit the service hours per day due to lack of adequate supply of water.

The university encounters a severe water shortage to fulfill the needs of the students in the dormitory and cafeteria, for the staff in the administrative buildings and for both teachers & students in class rooms and lecture hall buildings. Moreover; staff members and students of the university use water only in the toilets located within the respective floors of the buildings. The three floor buildings have three toilets, one on each floor of the building. Water is regularly filled in a 120 liter plastic drum fixed inside the washrooms, and a plastic container of about 4 liters reusable paint plastic container is used to flush the toilet and to wash hands. Those water drums are refilled manually from the tap water networks inside the washrooms in all of the three floors of the building, because the water from tap is not always available. Currently, the cleaning staffs convey the water from the tap connection inside the toilet and fill the plastic drum every day. When there is no water from the taps inside the toilets, they carry water in buckets from the nearby taps next to the buildings to fill the plastic drum. The tap fixed to the bottom of the tank will be used to collect water and to fill it manually into the 120 liter plastic drum in all three floors of the buildings.

Consequently, the students and working community population generally face the problem of lack of enough water to drinkable and non- drinkable uses. Due to the foregoing, there is an urgent need to propose strategies helping to lessen the problem of water shortage that the communities of Wachemo University are currently facing.

Accordingly; to ensure the availability of sufficient amount of water to the increased population of the communities, it becomes indispensable to look forward using alternative water source, rain water harvesting which potentially slacken the shortage of water that the communities of the university are currently facing directly and the population of Hosanna town indirectly too**.**

1.3. Objectives

1.3.1. General Objective

The general objective of the study is to evaluate the potential of rooftops rainwater for alternative water supply source in Wachemo Univesrity.

1.3.2. Specific objectives

- To evaluate the probable quantity of rainwater that can be harvested from the selected rooftops of the buildings and annual average rainfall amount in the main campus of the Wachemo University.
- To compute the storage capacity of water tank for the amount of rainwater which can be harvested using Ripple mass curve method.
- To afford solution to the problem of water insufficiency based on rooftops rainwater quantity and quality.
- Evaluate the cost of rooftops rainwater harvesting and storing in Wachemo University

1.4. Research Questions

- How does the rainfall vary from season to season and how much rooftop rainwater can be harvested yearly?
- What volume of rainwater storage tank is needed for harvestable roof tops rainwater and which month determines the higher storage tank size?
- What is the quality of harvestable rainwater with respect to physicochemical and microbiological parameters and for what purpose can it be used for?

- What is the cost of rooftops rainwater harvesting for the selected buildings?

1.5. Scope and Limitation of the study.

This study is conducted on evaluation of rooftop rainfall potential in Wachemo University. The relevant process data were extracted from the rainfall data and roof area in the University. Incorporation of rain gauge stations information with MS. Excel Version 2016. GIS.10.3 tools were used to describe and specify location map of study area as well as sample location. To achieve the intended research objective, some of the scopes are carried out as following:

- Literature review and analysis on the current water issues and research gap in rainwater harvesting system in the aspect of development, quantification and potential in water savings.
- Collecting rainfall data of 20 years from SNNPR meteorological center.
- Quantification of rainfall amount based on total building’s roof area
- Determination of storage tank size/capacity using mass curve method and performing rainwater quality analysis based on WHO guidelines and Ethiopian standard for the quality and finally;
- Digitization of the building with the tools such as Google earth and ArcGIS 10.3.
- Providing some strategies to lessen the shortage of water based on the rainwater potential

1.6. Expected Outcomes.

- Indication of water potential or the amount of rain water in volume that can be harvested, in substituting potable and non-potable use and shortening the stress of water shortage.
- Appropriate size (storage capacity) of the water tank for the rainwater which can be harvested from buildings’ rooftops runoff for estimated non-potable end use.
- Possible solution with respect to quality and quantity on provision of rooftop rainwater as an alternative and significance water source.
- Cost of rainwater harvesting which is affordable using locally available materials with relatively low cost of current value.

1.7. Significance of the Study

This research will advance the basis that the community of the University to own a much greater possibility of having stress free and sufficient access by using rooftops rainwater as an alternative water supply source. Hence, it can also contribute in overcoming water shortage problems by fully utilizing a rainwater harvesting system when rainwater is available (Lee et al., 2016). Therefore, this study will bear clear idea of accessing alternative water supply source to minimize the scarcity of potable water demand and non-potable water directly. Beyond this, the research results will enhance water demand management mechanism and benefit researchers, experts, governments, and non-governmental agencies as a source of relevant information. In addition, this study will indicate to what extent that the water consumption bill is being reduced as the rainwater harvesting system is adopted.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

This chapter offers an overview of previous research on knowledge sharing and intranets. It introduces background about rain water potential, harvesting techniques, factors influencing adoption of rainwater harvesting techniques, and climate change impact on water resources and rooftop rainwater quality concern which comprises the focus of the research described in this thesis.

2.2. Water Resource Demand and Variation in Rate of Consumption

Demand on water resources witness an extensive increase due to development, population increase, and global weather change (Katambara, 2013). Adopting the idea of sustainability and management of water resources can help to deal with the worldwide water scarcity. Promoting of rainwater harvesting method for domestic, improving, and agriculture can assist to reduce the demand on water resources. Rainwater harvesting systems used in housing schemes can provide water for potable and non-potable uses (Anderson, 2013). Non-potable uses of potable water constitute a significant portion of water use in the residential, commercial, institutional, and industrial sector (Gleick et al., 2013).

The annual average daily consumption, while useful, does not tell the full story year. In practice it has been seen that this demand does not remain uniform throughout the year but it various from season to season, even hour to hour (Amirhossein, 2020). The variation may be categorized into two broad classes: 1. Seasonal variation **2**. Daily and hourly fluctuation.

Through the week, Sunday will typically have the highest consumption, and Monday the lowest. Some months can have an average daily consumption higher than the yearly average consumption. In most cites the peak month will be July or August (Capt et al., 2021).

Especially hot or dry weathers will produce a week of maximum consumption, and certain days will place still greater demand upon the water system.

Peak demands also occur for the duration of the day, the hours of occurrence depending upon the characteristics of the city and living standards of the communities. There will usually be a peak in the morning as the day’s activities start and a minimal approximately at four am. But there will be a fairly high consumption through the working day (Amirhossein, 2020).

2.3. Overview of Rainwater Harvesting System

2.3.1. Classifications of Water Harvesting

There are a dozen different terms of water harvesting and classification techniques used at the regional and international levels that have not yet been standardized. Generally used are listed below: Water harvesting is “The collection and controlling of floodwater or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance” (IFAD, 2013). It is the collection of runoff and its use for irrigation of crops, pastures and bushes, and for livestock consumption (IFAD, 2013). Rainwater harvesting is the collection and concentration of rainfall to make it available for domestic or agricultural uses in dry areas where moisture deficit is the primary limiting factor (Liniger et al., 2011; IFAD, 2013).

Rain water harvesting (RWH) is defined as the careful collection and storage of rainwater by natural or man-made structures for later use (Goonrey, 2009; Kim and Chen, 2018). Rooftop RWH systems can provide low-cost decentralized supplement water to urban households which can store and provide supplemental water during wet periods of the year (Sepehri, et al., 2019; Hermy, 2015). Due to capturing storm water across a city, RWH systems can be considered as decentralized detention system reducing flooding risk and inundation that are common problems most cities suffer from (Kim and Chen, 2018; Nguyen et al., 2019; Sahin et al., 2019).

Many techniques had been adopted to increase access to potable water supply in developing countries, including expansion in urban water supply infrastructure and the construction of wells and boreholes. Another strategy is the utilization of additional sources of water to supplement dominant or existing sources (Opare, 2012). In line with this alternative strategy, rainwater harvesting (RWH), an option which has historically been implemented in areas where conventional water supply systems have failed to meet the needs of the people and it is being promoted to solve the problem of water scarcity in some urban areas of the developing world (Owusu and Kofi Teye, 2014).

Rainwater harvesting in Ethiopia has a long history with strong attachment to the ancient Orthodox churches (Fitsume et al., 2014). According to the study (Fitsume et al., 2014) reported that the history of rainwater harvesting in Ethiopia date back to pre Axumite period (560 BC). During that period rainwater was harvested and stored in ponds and tanks for agriculture and water supply purposes. The remains of an ancient roof- rainwater harvesting practice is still visible in the oldest palaces in Axum.

2.4. Importance of Rainwater Harvesting

Rainwater usage will support significant potable water savings in many parts of the world if well harnessed (Rostad and Montalto, 2012). The problem of water shortages being presently experienced throughout the dry season may be solved using the abundant rainwater during the wet season (Maykot and Ghisi, 2020). With adequate storage, collected rainwater will sufficiently satisfy non-potable household water uses such as car washing, cleaning and other numerous uses (Katambara, 2013; Liaw and Chiang, 2014)**.**

Evidently rainwater (rainfall which is directly collected as roof run-off from buildings) has a major role to play in substituting and/or supplementing urban water supply from centralized water supply facilities (Awawdeh and Jaradat, 2012; Matos et al., 2013; Pesantez et al., 2020). The problem of water shortages being currently experienced in the country during the dry season will be solved using the abundant rainwater during the wet season (Ndeketeya and Dundu, 2019).

Rainwater harvesting may be profitable in a context where the capacity of water supply infrastructure is exceeded by demand, and where rainwater use may defer or prevent building new mains water infrastructures. Optimization of water utilization and the conservation of water as a natural resource can help to overcome water shortage (Pesantez, Berglund and Kaza, 2020). Rainwater can be used for potable and non-potable uses (Farreny et al., 2011). Efficient use of urban rainwater harvesting as a supplement or main water supply in areas with enough precipitation could have significant direct and indirect benefits along with reducing pressure on the existing water resources and resource preservation (Silva et al., 2019), reducing consumers' water bills (Sheikh, 2020), ecosystem protection and energy-saving (Tavakol et al., 2016).

The main advantages of rainwater harvesting systems are conserving water resources and environment, pollution reduction, help to control flooding, and reduction of impact of weather change (Megat et al., 2012). Improving living standards and population growth, coupled with radically increased urbanization, are placing increased pressures on available water resources, necessitating new approaches to urban water management.

Ethiopian Water Resources Management Policy (2011) is based on the following principles:

- The citizens of Ethiopia shall have access to adequate water of satisfactory quality to satisfy basic human needs. Policy ranks drinking water over other uses, but recognizes that water is both an economic and social good.
- Water resources development should be based on distributed management and participatory approaches. Management concern of water resources shall include all stakeholders, including the private sector, and ensure social equity, system reliability, and sustainability.
- Integrated water resources management is emphasized: the policy recognizes the hydrologic boundary or basin as the fundamental planning unit and water resources management domain. Ownership is developed to lower levels and management autonomy is at the lowest administrative level.
- Cost recovery is the aim for urban water supply systems and recovery of operational and maintenance costs for rural schemes (MoWR, 2011).

Rainwater catchments can be done at a local level for household uses, industrially for use in factories or at an agricultural level for irrigation purposes. For each of these types of uses, water can be stored differently; however, the way it is collected is always the same, sometimes rainwater is even used for groundwater recharge (Ferrera, 2010).

2.5. Factors Affecting the Quantity of Rainwater

According to Ferrera (2010), the six primary traits of a successful rainwater catchment systems are: (i) Only water from roofs may be gathered, calls for ok roofs with difficult, impermeable surface and storage tank, (ii) Provides water directly to homes, and does now not require huge areas to work. It is an opportunity that can be easily set up and maintained and (iii) Renders water of exact fine and if nicely maintained it represents no chance to human health. The quantity of water that can be harvested will depend upon 4 factors:

1. The amount of precipitation in the area.

2. The place of the rooftops.

3. Water losses due to evaporation and runoff.

4. Volume of the water storage tank.

2.6. Reliability of Rainwater Harvesting System

The reliability of a rainwater harvesting system has been well-defined as the measure of its capability to produce the water needed by its users. It is also well-defined as the percentage of days in a year when the rainwater storage tank is capable to supply the proposed partial demand for a specific purpose (Imteaz et al., 2013).

Public acceptance towards rainwater harvesting can be increased if the reliability of a system is improved and its potential understood locally (Palla et al., 2012). A simple and comprehensible methodology to define the performance of rainwater harvesting systems could promote its use and improve operational efficiency. RWH is becoming one of the reliable potable water supplies, especially in cities located in arid climatic conditions, stressed with water scarcity (Bruggen et al., 2018). The potential of harvestable rainwater is highly dependent on rainwater harvesting capacity that is mainly determined by the size of the roof area as well as storage tank and the amount of rainfall that is available for harvesting.

The available water volume can be significant when considering annual rainfall amounts in urban watersheds with a high density of buildings (Tamim Younos, 2011).

Many researchers provide a methodology to obtain regional design curves based on open access satellite rainfall data while considering the influence of the local hydrological characteristics (Toosi et al., 2020). Thereby, it reveals the regional potential of rainwater harvesting based on specific demand and design parameters. This supports suitability assessments of rainwater harvesting for different hydro climatic regions. Some year’s statics of rain fall provide the basis for assessing the rainwater harvesting potential (Toosi et al., 2020).

In determination of reliability; variation in rainfall between months is significant which helps to decide the season of climate reflecting even distribution and strong seasonality in rainfall (Yamile et al., 2015).

2. 7. Water Quality Concern

Water quality is denied by a collection of upper and lower limits on selected possible contaminants in water. This is evaluated by using water quality indicators, which can be physical, chemical and biological. In each class, a number of quality variables are considered. The magnitude of these indicators can affect the acceptability of water quality for its intended use and is often governed by regulations. Water is known as the “universal solvent” because it has the ability to dissolve solids and absorb gases and other liquids. Due to the its solvent power, all natural water comprises minerals and other substances in solution, which have been picked up from the air, the soil, and rocks through and over which it passes (Minwuye, 2015). Water derived from the resources may not necessarily pure since it contains dissolved inorganic and organic substances, living organisms such as viruses and bacteria. For this reason, according to (Amenu et al., 2014) guidelines water intended for domestic uses should be free from toxic substances and microorganisms that have health significance (Amenu et al., 2014).

Acceptable quality shows the safety of drinking water in terms of its physical, chemical and bacteriological parameters (WHO, 2017). User “intended purpose and perceptions of quality also carry great weight in their drinking water welfare” (França Doria, 2010).

At large; quality of roof runoff is acceptable to supply low quality domestic uses. Pollutant additions to roof runoff include organic matter, inert solids, fecal deposits from animals and birds, trace amounts of some metals, and even complex organic compounds. Factors for example: type of roof material, atmospheric deposition and surrounding environmental conditions (proximity of strong sources, such as motorways or industrial areas) have been shown to influence concentrations of heavy metals in roof runoff.

The physiochemical water quality parameters are the ones that are contributed by climatologically, hydrological and geological factors. They affect the bacteriological, chemical and physical components of water.

2.7.1. Temperature

Temperature also affects the concentration of dissolved oxygen and can influence the activity of bacteria in water bodies. In the analysis of the physiochemical quality of pipe water samples, temperature considered as a critical parameter affecting many reactions, including the level of disinfectant decay and by-product formation. As the water temperature increases, there is an increase in the disinfectant demand and byproduct formation, nitrification, and microbial activity. An aesthetic objective is set for the maximum water temperature to aid in the selection of the best water source or the best placement for water intake. It is necessary that the temperature of drinking water should not exceed 15ºC because the palatability of water enhanced by its coolness. Microbes have been found growing almost everywhere where there is water, irrespective of its temperature (Zamxaka et al., 2011). Temperatures above 15ºC can speed up the growing of nuisance organisms such as algae which can exaggerate taste, odor, and color problems in drinking water (Hailu, 2017).

2.7.2. pH

pH has no direct impact on consumers and it is one of the most imperative functioning water quality parameters". Whenever water treatment or storage is taking place (arsenic removal, clarification, disinfection, rainwater harvesting), careful consideration of the level of pH is necessary and the optimum pH required is generally within the range 6.5–8 (WHO, 2017).

Low pH levels cause severe corrosion of metals in the distribution systems while high pH values result in a progressive decrease in the efficiency of the chlorine disinfection process. Factors, such as pH, temperature, and turbidity have a major impact on bacterial population growth.

2.7.3. Turbidity

Turbidity is a measure of cloudiness of water. It has no health effects. However, turbidity can interfere with disinfection and provide a medium for microbial growth. High turbidity might be from the presence of disease-causing organisms. These organisms comprise bacteria, viruses, and parasites that can cause symptoms such as nausea, cramps, diarrhea, and associated headaches (Mebrahtu et al, 2011).

The WHO and EPA (Environment al Protection Authority) guideline value for turbidity is 5 NTU (Nephelometric Turbidity Unit) and the maximum permissible limit (MPL) of USA is defined as from 0.1 to 1 NTU on January 23, 2015. As per guidelines for drinking-water quality by the World Health Organization (WHO, 2017), turbidity in water caused by suspended particles or colloidal matter that obstructs light transmission through the water. It can be caused by inorganic or organic matter or the combination of the two. Microorganisms (bacteria, viruses, and protozoa) are naturally attached to particulates, and removal of turbidity by clarification will considerably reduce microbial contamination in treated water (Hailu, 2017).

2.7.4 Electrical Conductivity

Electrical conductivity (EC) (specific conductance) measures the total concentration, mobility, valence and the temperature of the solution of ions. EC depends on mobility, total concentration, valence and the temperature of the solution of the ions.

Electrical conductivity can be used as a fast method of indirect measure of total dissolved solids (TDS), but the factor used to convert EC into TDS will depend on the type of dissolved solids present in the water (Adeola Fashae et al., 2019).

2.7.5. Total Dissolved Solid

Total dissolved solids refer to the presence of materials suspended or dissolved in water and are associated to both electrical conductivity and turbidity (Wright et al., 2010).Total dissolved solids (TDS) are characterized primarily by major anions and cations such as carbonate, bicarbonate, sulfate, chloride, nitrate, sodium, calcium, magnesium, and potassium.

2.7.6. Nitrates and Sulphates

Nitrate is one of the extremely substantial disease-causing parameters of drinking water quality, particularly blue baby syndrome in babies and used as an indicator for the presence of organics. Nitrates can cause methemoglobinemia at greater than 100 mg/L where a baby cannot take breaths enough oxygen. The origins of nitrate are industrial waste, nitrogen cycle, nitrogenous fertilizers etc. Nitrate concentrations above 50 mg/L may result adverse health effects in babies (infants less than three months of age), and also nitrate concentrations beyond 100 mg/L can affect pregnant women (Lee, 2012).

Sulfate can cause scale accumulation in water channels like to other minerals and might be associated with a bitter taste in water that can have a laxative effect on humans and livestock. Elevated sulfate levels in combination with chlorine decolorize can make cleaning clothes difficult (Angrill et al., 2017).

2.8. Bacteriological Water Quality Parameters of Drinking Water

The presence of certain microorganisms in water is used as an indicator of possible contamination and an index of water quality (EPA, 2015). Some organisms known as indicator organisms are selected to determine the presence of human and animal wastes and hence the potential existence of pathogens in drinking water. Therefore, the presence of indicator organisms in water shows contamination of water by fecal matter, which could possibly contain pathogens such as Salmonella and Shigella (Farreny et al., 2011). Main groups of bacteria such as total coliforms (TC) and fecal coliforms (FC) are considered to serve as indicators to monitor water quality (Baldursson and Karanis, 2011).

2.8.1 Coliform Bacteria

Total coliforms are the ones that are commonly measured as indicator bacteria for drinking water quality (Lupia et al., 2017). They are defined as aerobic and facultative anaerobic non-spore-forming bacteria that ferment lactose at 35°C to 37°C with the production of acid and gas within 24-48 hours. Total coliform group has been selected as the primary indicator bacteria for the occurrence of disease-causing bacteria in potable and non-potable water. It is a primary indicator of the suitability of water for consumption.

2.8.2. Fecal Coliforms (Thermo Tolerant Bacteria)

These bacteria are existed in subgroup of coliform bacteria that grow at a temperature of 44°C. Fecal coliform lives in the intestine of warm-blooded animals. As a result, they show an excellent positive correlation with fecal contamination of water from warm blooded animals (Volk and Le Chevallier, 2002).

2.9. Rainwater Tanks

Rainwater tanks are part of assimilated urban water management approach that considers the whole water cycle to provide water services on a fit for purpose basis that minimizes the impact on the local environment and receiving waters (Shadmehri et al., 2020). Rainwater storage tanks are normally applied at the household level for non-potable water source uses such as clothe washing, floor washing, toilet flushing and garden irrigation. Rainwater harvesting can offer benefits, such as: economies of scale for capital costs, reduced land footprint, integrated disinfection and flexibility in corresponding supply and demand for different purpose (Awawdeh, 2011).

Mostly, the main calculation when designing a rainwater harvesting system can be to size the water tank appropriately to give passable storage capacity. The storage requirement will be determined by a number of interconnected factors. These are: hydrological (rainfall) data; roof area; runoff coefficient and user numbers and consumption rates. Supposing that rainwater harvesting has been determined to be viable, some techniques have been established to aid in determining the size of the rainwater storage tanks. These methods vary in complexity: Mass curve (Ripple diagram) method (Ripple, 1883; Abu-Zreig et al., 2013) and optimization analysis (Londra et al., 2015; Okoye et al., 2015).

The mass curve was first developed by Ripple in 1883 (Ripple, 1883). The mass curve is a plot of the cumulative rainwater amount harvested as a function of time. Indirectly the analysis undertakes that the time interval includes the critical period, which is the time period over which the flows have reached a minimum, causing the greatest drawdown of a reservoir (Fayez, 2019).

In Ripple method, typically used for variable supply and fixed demand, the cumulative inflow volume vs. time, the slope of the line denotes flow rate with flat portions of the curve being ‘dry’ and steep portions being ‘wet’. For a given demand value, the minimum storage is the largest positive deviation between supply and demand. Negative deviations denote water ‘spilled’ from the tank (Fayez Abdulla, 2019).

Cities in developing countries have gradually adopted rainwater tanks as an alternative water sources (Kim et al., 2021). The immediate acceptance of rainwater tanks has been encouraged by the need to reduce demand for nationwide water services that are under pressure to adapt to population growth and climate change effects. (Gleick et al., 2015).

2.9.1. Water Tank Dimensioning

The required storage capability depends on several factors, including: (i) Domestic water demand and its seasonal variation; availability of other (seasonal) water sources (and distance, quantity and quality); (ii) Characteristics of the dry season(s) (e.g. typical short periods without any rain); (iii) Rainfall characteristics (total rainfall and intensity); and (iv) Availability of catchment area, type of catchment and roofing surface material used. To get on the safe side, a 20% increase of tank volume is suggested. The operation concern comprises the demand and the intended period of supply.

Storage tanks are categorized as

(i) above-ground storage tanks and

(ii) Cisterns or underground storage vessels. These facilities can differ in sizes from one cubic meter to up to thousands of cubic meters.

The reservoir for rainwater storage is generally the most expensive part of a rainwater harvesting system. So, an optimized scaling of this storage tank is essential to avoid an excessive size which may hinder the economic feasibility of the system. The water tank sizing influences its own cost but also the system's efficiency, i.e., the capacity to satisfy the water demands (Canchala-Nastar et al., 2019; Nnaji, Tenebe and Emenike, 2019; Ridwan *et al.*, 2020; Shadeed and Alawna, 2021).

According to the (Ripple, 1883) technique, the reservoir volume corresponds to the maximum of positive accumulated differences between the consumption of non-potable water and the collectable rainwater volume, observed within an evaluation period.

Rainwater storage tank sizing generally, the main calculation incase designing a rainwater harvesting system will be to size the water tank correctly to give adequate storage capacity. The storage requirement can be determined by a number of interrelated essential factors. Those factors include; local rainfall amount roof area; coefficient of runoff and user numbers and consumption rates (Lizárraga-Mendiola *et al.*, 2015; Sountharajah et al., 2017; Silva et al., 2019). Assuming that rainwater harvesting has been determined to be feasible, many techniques have been developed to support in determining the size of the rainwater storage tanks. The sizing of tank can be performed based on estimated rainwater potential. The available water volume can be significant when considering annual rainfall amounts in urban watersheds with a high density of buildings (Tamim Younos, 2011).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the Study Area

Wachemo University (WCU) is one of the public higher educational institutions in Ethiopia, which was found in 2009 G.C. It is about 231 km far from the capital city of Addis Ababa and sited at Zonal town Hosanna, in the area of over 200 hectares. It is located between 7º 53' 00" N and 7º 55' 00" N latitudes and 37º 30' 00" E and 37º 40' 00" E longitudes and having the total population number (students, academic and administrative stuffs) about 21,000 in 2020 G.C. The altitude of the University ranges from 2140 m and 2380 m above mean sea level. The annual average temperature of the area is 14.4°C and the average annual rainfall is 1331.6 mm**.** This shows that the study area is mainly characterized by highland ('dega') climatic conditions.

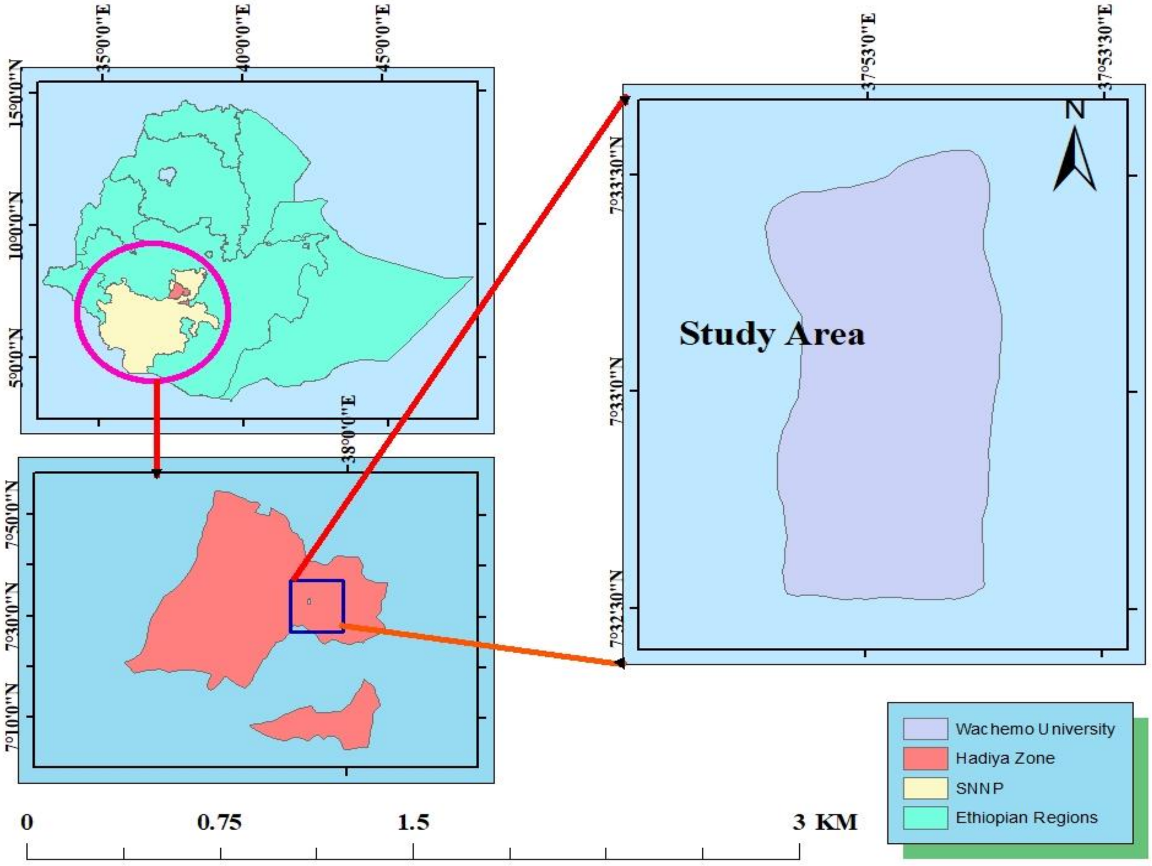

Figure 1.Map of Study Area

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3.2. Rain Gage Stations and Rainfall Data

To evaluate the potential of rooftop rainwater harvesting from roof areas: monthly and annual average rainfall data were extracted from SNNPR meteorological center (the nearest four meteorological stations such as; Hosanna, Shone, Fonko and Durame) spanning from the year 2000-2019 were accessed and the data were used for evaluation of the rainwater harvesting potential of the Wachemo University

There are four gage stations at relatively closer proximities namely;

Hosanna, which is located at about 3 km from the University, at a particular location of 374900E, 832800N. Durame station which is located at about 36.9 km South of Hosanna, at a specific location of 38 °40' 00" E, 79° 59' 00" N. Shone station which is located at 42 km South of Hosanna at a specific location of 37° 58' 00" E, 7° 08' 00" N. Fonko station which is located at 18 km North of Wachemo University at a specific location of 37^{0} 58' 08.9" E and 7^{0} 38' 54" N as illustrated in Figure 2.

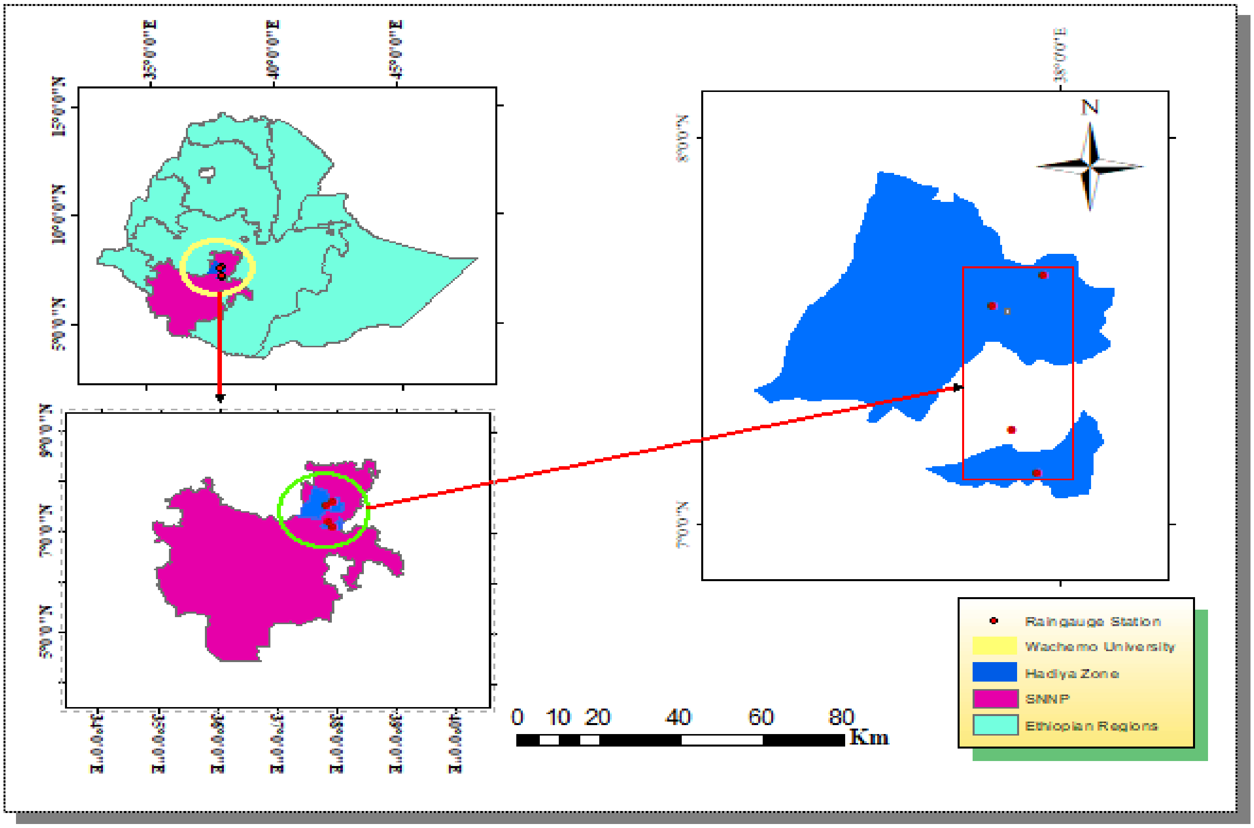

Figure 2. Location of rain gage stations

3.2.1. Estimation of Missing Data

The common method for estimation of rainfall on the ground is using a rain gauge. Rain gauges, as the merely direct measuring device of surface rainfall, are still considered as the best reliable source of precipitation data in hydrology. Rain gauges might be poor in capturing the instantaneous precipitation intensity, but the measurement error diminishes rapidly as the incorporation time increases (Mohamad, 2011).

Results of data analysis depend on the quality and completeness of data. This study considers arithmetic average method amongst many techniques for filling in missing rainfall data. To assess suitability of the different methods for filling in missing data, monthly precipitation data collected at four different stations were considered. Complete sets are used to forecast monthly precipitation.

3.2.2. Arithmetic Average Method

This method commonly used to fill in omitted meteorological data in meteorology and climatology. Missing data can be completed by evaluating the arithmetic average of the data corresponding to the nearest gage stations, as presented in the following equation.

$$V_0 = \sum_{i=1}^{n} {}^{V_i}\!/_{\mathbf{N}} \qquad (1)$$

Where V_o, is the estimated value of the missing data, Vi is the value of same parameter at i^{th} nearest weather station, and N is the number of the nearest stations. The arithmetic average method is satisfactory if the gauges are uniformly distributed over the area and the individual gauge measurements do not vary greatly about the mean (Canchala-Nastar et al., 2019; Ridwan et al., 2020).

From the incorporated rainfall data for the study period the average monthly rainfall in mm was taken to evaluate volume of rain. In addition, the main patterns of rain and drought during the studied period were identified. Intra-annual rainfall variation was obtained through the coefficient of variation of the monthly rainfall ($\boldsymbol{C_{vm}}$) using the following equation:

$$\mathbf{C_{vm}} = \frac{\mathbf{Sv}}{\mathbf{Va}} \qquad (2)$$

Where. $\boldsymbol{C_{vm}}$ is the coefficient of variation of the monthly rainfall; Sv is the standard deviation of the monthly rainfall in mm.Va is the average of the monthly rainfall in mm.

3.3. Water Demand and Consumption of the Community

Water demand for domestic use in urban area depends on many factors: such as living standards, availability and suitability of supply source, acceptance level of the quality, number of the population, end use of the water and etc. According to (UAP, 2011) average amount of 30 l/c/day domestic water supply was considered as basic level of service.

Concerning water demand of the community; the academic staffs, they usually do not avail themselves regularly in all the work days from Monday to Sunday, but they would be available in the office for research guidance and teaching classes in an average of 5 days in a week. Considering weekend students, holidays, regular availability of academic stuffs and admin staffs with per capita demand 30 L/c/day, the community water demand of the University is presented in Table 1.

Table 1. Estimated water demand in liters per week for potable and non-potable purposes in the community

S.N	Population Category	Number of Population	Days in a Week	Demand in Liter	Total Demand in a Week in Liter
1	Regular Students	15600	7	30	3276000
2	Extension	2800	2	>>	168000
3	Instructors	350	5	>>	52500
4	Admin Staffs	650	4	>>	78000
5	Others	1500	6	>>	270000
	Total	**20900**	**24**		**3844500**

3.3.1. Water Consumption Variation of the Community

Water consumption refers to domestic water use at daily, weekly, monthly or yearly basis. Water consumption of the community depends on the availability of water supply. Since the supply source is only from Hosaena water supply with limited and uncontinous discharge and from Guder borehole which is constructed 2019 E.C by Wachemo University for the mutual benefit with nearby community at about 8km distance from the University which discharges 40 L/s and for 15hrs in a day. From these sources, the limited amount (only about 91 m^3 /day) and about 84 m^3/day from Hosaena Water Supply services could be discharged to the elevated tank and then to the community through pipelines. This is about only 32% of average domestic demand of the community. A combination of these sources of water, for different purposes was used in the community, because in the study area the water supply from specific water source was not continuous and reliable.

Supplementary data from Wachemo University construction and facilities office (2020), shown the estimated average water consumption for each type of water appliance during the survey period. The shower was responsible for the highest consumption, followed by the toilet flush and cleaning house, washing purpose for clothes and dishes.

3.4. Conceptual Framework

Descriptive and experimental study designs were applied for the completion of the research. Regarding rainwater availability, affordability reliability and seasonal variation was performed using descriptive statics tools. While experimental study design was used for assessing physicochemical and bacteriological quality of rain water from roof tops from different distances from roof to the ground. The average community water demand and rainwater potential were used to assess the coverage of demand and amount of water for the community of the University.

- **In achieving the specified objectives methodological framework is presented as follows:**

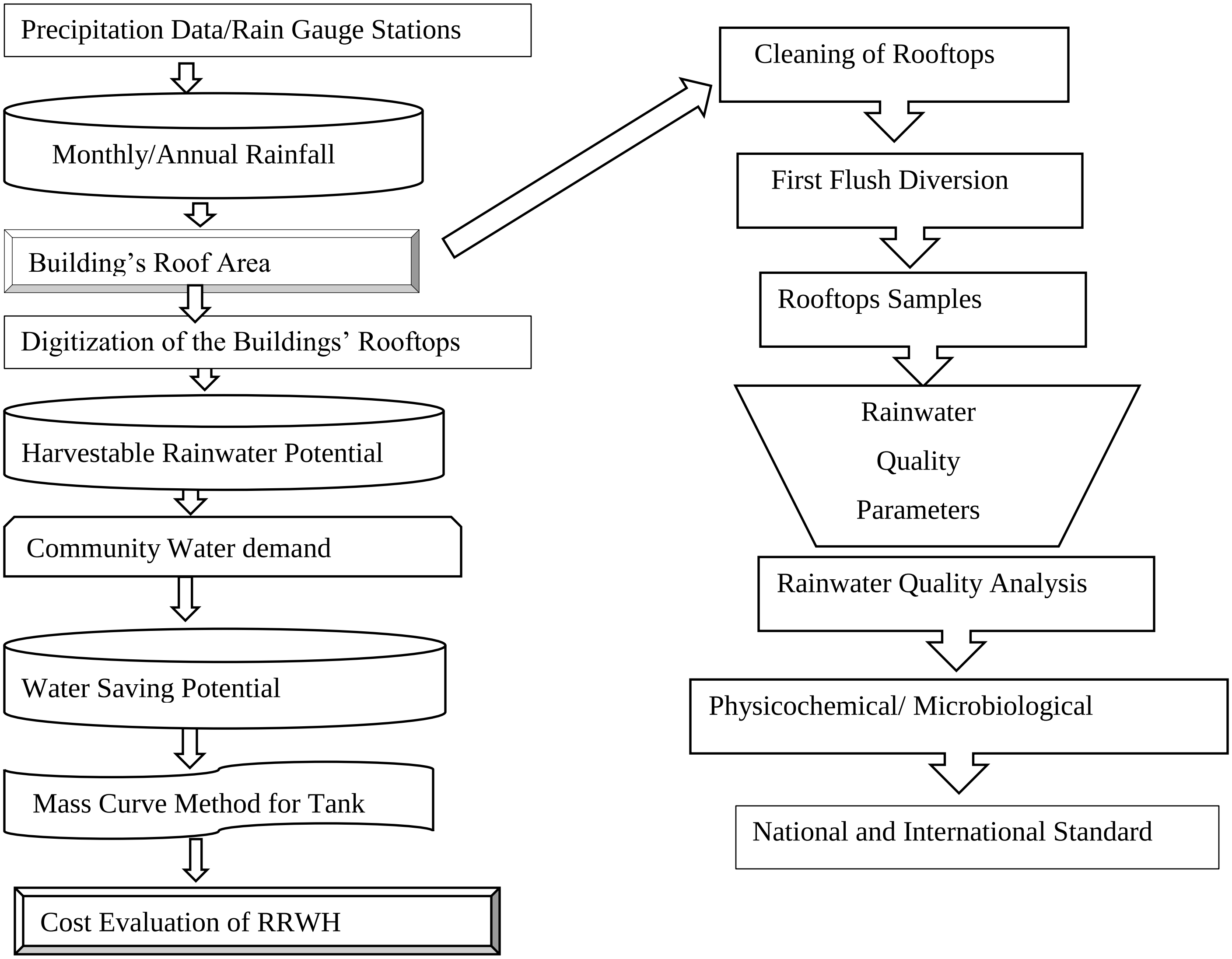

Figure 3.Methodological Framework

To evaluate the buildings roof area available for rainwater harvesting, identified that 172 buildings with different roof areas in Wachemo University. Total roof area was calculated summing each building roof area given by equation (3)

$$T_{ra}=\sum ra \qquad (3)$$

Where: T_{ra},total roof area; ra, roof area

3.4.1. Digitization of Buildings

In this study, recent satellite image that covers the areas of interest was obtained from Google Earth 2021.The acquired satellite images were used to digitize all the building's rooftops using the polygon tool available in Google Earth.

The digitizing process involves tracing of building roof tops directly on top of the satellite imagery in order to classify the rooftops from other objects **(**Figure 8). A satellite image from Google Earth was digitized in ArcGIS 10.3 to attain the areas of the buildings. This process resulted in digitized maps with thousands of boundaries that have been saved as several KMZ files each representing the building roof tops, streets, tank location and water sample points.

The KMZ files for each building are converted to shape files. The coordinate system for each shape file was defined as WGS 1984 UTM zone 37 N to be able to compute the areas of the digitized buildings automatically by the geometry calculation tool available in ArcGIS model (Figure 8) shows the final digitized maps for the university.

Run-off coefficient

The run-off coefficient is the fraction of the volume of rainwater that runs off a surface to the volume of rainwater that falls on that surface (Goel, 2011). This includes also losses from spillage in the gutter system**.**

Table 2. Values of runoff coefficient for traditional roofing materials.

Roof Type	**Runoff Coefficient**
Galvanized iron sheet	>0.9
Corrugated metal sheet	0.7–0.9
Tiles	0.8-0.9
Concrete	0.6–0.8
Brick pavement	0.5-0.6
Rocky natural catchment	0.2–0.5
Soil with slope	0.0–0.3
Green area	0.05–0.1

Table 2 Shows typical run off coefficient for different types of roofing materials (Biswas and Mandal, 2014).

However, a runoff coefficient of 0.8 was adopted in this study for the calculation of potential harvestable rooftop rainwater. Since runoff coefficient is associated with the efficiency of roof material to yield maximum runoff; which is corrugated metal sheet (0.7-0.9) and its average 0.8.

3.5. Potential of Rainwater Harvesting

The potential of monthly rainwater harvesting from the buildings rooftops was calculated using the Rational Method given by the equation:

$$\mathrm{VR}=\frac{\mathrm{R}*\mathrm{Bra}*\mathrm{Rc}}{1000} \tag{4}$$

Where: VR is the monthly volume of rainwater that can be harvested m^3); R is that the monthly rainfall depth (mm); Bra is that the building roof area (m^2); Rc is that the runoff coefficient (without units) = 0.80.

For the design of the systems for rainwater collecting and storage, United Nations Environment Programme (UNEP) recommends considering the “first flush” by deducting the first 0.50 mm of rainfall (Khastagir et al., 2015) to improve of the quality of harvested rainwater. So the potential water saving percentage was calculated by dividing the potential volume of harvested rainfall by the annual average water demand (potable and non-potable) by the equation:

$$\mathrm{WS} = 100\ \mathrm{V} / \mathrm{AAWD} \tag{5}$$

Where; WS is annual rainwater potential for water savings (%), V is annual volume of rainwater that could be harvested in (m^3/y), and AAWD is Average Annual Water Demand.

3.6. Data collection and Rainwater Quality Test Methods

First flush off

The importance of first flush diversion is considerably very high and it is necessary to judge the quality of rain water and further analysis. This is because, it is the water that could be the most contaminated by particulates, bird droppings and other materials laying on the roof.

Sample Size

Total number of buildings in the university was 172; from these buildings, due to the financial and time constraint, in this research only a total of 12 samples were taken for the analysis.

For rainwater quality analysis from a total buildings roof tops 5% was taken as a representative sample. As the basic assumption that Water quality may vary in very minimal value at a nearby distance for the same roofing material (WHO, 2013). Sample size =5%*172 buildings =8.25 which is rounded to 9 sample points.

Roof tops rainwater quality status in the university was performed considering three different collecting points. From each point three water samples (total of nine samples) were taken from different roofs depending on the suitability to take the samples through gutter and pipe ends using sample taking materials like buckets. All water samples from their source were collected using polyethylene sampling bottles; washed toughly with distilled water to avoid contamination and leveled it to understand where the sites of samples were collected.

During the collection of the rainwater sample the following instruments were utilized; such as gutters, PVC pipe, rain harvesting barrel, straps to fasten the gutters, adjustable pipe wrench, joint pliers, pipe cutter, pipe clamps, and ladder, buckets and pipe fittings.

In the course of rainwater quality analysis: Incubator, rack for petri dishes, filter funnel,100 mL capacity ,10 mL glass,100mL test tube, graduated measuring cylinders, filter support, suction vessel syringe ,forceps ,bottle containing alcohol, plastic petri dishes ,burner or ethanol for flaming , absorbent pad prepared media membrane filter, photometer and reagents (nitrates powder, Sulphate tablet) and distilled water were used.

In this section, the quality of harvestable water was checked considering several parameters such as pH, fecal coliform, total coliform, total dissolved solids, turbidity, nitrate, zinc and sulphate. The time period for analysis was from April 15/2021 to April 28/2021.

Rainwater quality analyses of different water quality parameters were done by evaluating the test value with respect to drinking water standard value of Ethiopia (ES, 2013) and International guideline (WHO, 2017) in evaluating its potential with respect to quality as far as considering alternative supply source based on its quality as well as quantity.

After the samples have been taken; water quality test was carried out in the Hosaena Town Water Supply Service (HTWSS) laboratory for the parameters which are coliform (Total and Fecal), electric conductivity, total dissolved solid, nitrate, turbidity, sulphate, zinc and pH.

3.6.1. Physicochemical Test Methods

pH, temperature, total dissolved solids and electrical conductivity measurements were conducted after properly washed and rinsed appropriate sampling bottles. The pH meter, wagWT-3020 Temperature and TDS having electrodes were used immediately on spot to measure pH, Temperature, Electrical Conductivity (EC).These electrodes were immersed in the samples and then the tested parameters were shown on the LCD screen of the devices.

Using YSI 9300 and 9500 Photometers tests were performed for nitrates, sulphates, turbidity and zinc. A powder reagent chemical was dissolved in 10 mL of water sample in a cylindrical sample cell and allowed to react. Color develops with intensity proportional to the amount of the target element was measured. Each element has a unique maximum absorption wavelength at which the spectrophotometer was adjusted. Light was allowed to pass through the sample cell so that light is absorbed at the required wavelength. The results were displayed on the LCD screen in mg/L in proportion to the amount of light absorbed at that particular wavelength.

3.6.2. Bacteriological Test Methods

The bacteriological quality of rainwater runoff testes were undertaken within 6 hours after collection to avoid the growth or death of microorganisms in the sample (WHO, 2017). Bacteriological analyses were performed for two types of bacteria: total coliform bacteria and the fecal coliform bacteria indicators. Water samples were collected in presterilized plastic bags and were filtered on the spot using membrane filters with a spore size of 45μm. The filters were incubated in an ELE Paqualab 25 field incubator, in sterilized aluminum Petri dishes with a bacterial medium of m-Coli Blue24 on absorbent pad, at 37^0C and 40^0C for total coli forms and E-coli/fecal coli forms, respectively. The filters were examined for 24 hours to assess bacterial growth and yellow or yellow-brown colonies were counted as TC. The results were compared with WHO guidelines maximum permissible limit value.

3.6.3. Method of Data Analysis

The result of the experimental data was used to analyzing by using application of software such as MS EXCEL Version 2016. Finally, the analysis results were compared with WHO guideline values and Ethiopia drinking water quality standard. The analytical determinations of the physico-chemical parameters of rainwater quality considered were carried out on the samples harvested within the holding time of each parameter, following applicable standard methods.

3.7. Water Tank Dimensioning based on Rainfall and Water Demand Pattern

- Better evaluation of storage capacity can be done using the Mass Curve technique based on rainfall and water demand pattern.
- Cumulative rainfall amount and cumulative water demand in year is calculated and plotted on the same curve.
- The quantity of the highest differences, on the either side, between the rainfall amount curve and water demand curve gives the size of the storage required.

3.8. Cost Calculation for System Installation per Suitable and Identical Buildings of the University.

- Cost calculation was performed based on current cost value of rainwater harvesting installation materials for each selected building to fix plastic rainwater tank to afford solution to water scarcity problem.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1. Quantity of Rooftop Rainwater

The quantity of rooftop rainwater obtained sequentially from the selected historical records is presented on monthly and annual basis.

4.2. Monthly Rainfall Potential

Monthly rainfall amount of each rain gage station and their coefficient of variation obtained after incorporation of 20 years historical data are shown in the next tables (Table 3 to Table 6).

Table.3. Monthly rainfall distribution of Hosaena Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0	0	15.4	205.8	105.2	145.5	86.2	124.5	177.9	64.9	21	45.5
2001	4.8	70.1	184	109.6	172.1	91.6	153.2	134.6	101.8	61.9	4.7	5.5
2002	83.2	47.2	150.7	111.7	135.5	90	103.6	244.7	154.7	2.8	0.4	126.4
2003	35.8	58.9	118.9	194.4	78.7	108.3	135.9	207.3	182.9	11.7	13.5	0
2004	96.8	19.4	90.6	176.2	82	123.4	133.6	152.3	182.1	74.8	17.3	14
2005	31.5	18.8	177.8	162.1	197.2	64.6	160.1	94.9	162.6	37.7	67.7	0
2006	28.9	53.9	131.5	160	75.8	169.8	183.9	222.2	88.2	50.3	6	27.2
2007	31.8	50.7	118.7	152.1	121.3	163.1	179.9	132.2	210.1	19	0	0
2008	0	1.2	43	71.3	238.9	144.6	192.9	136	138.6	126.1	117.5	0.5
2009	43.1	4.8	73.4	85.5	120.1	123.5	188.5	181.3	174.7	169.4	5.1	63.9
2010	11.8	110	139.9	111.3	182.8	94.4	116	145	138.5	18.9	19.3	33.7
2011	15.5	11.2	101.7	115.9	232.8	108.3	163.8	193.5	119.3	0	49.2	0
2012	0	0	67.4	138.3	68.3	150.3	233.1	155.9	163.5	1.4	57.6	7.1
2013	1	17.4	128.6	67.9	131.6	182.2	200.8	211	173	46.4	0.4	4.3
2014	25	117.8	76.6	134.9	251.8	76.2	188.3	270.9	193	148.2	14.2	2.2
2015	0	3	45.1	19.2	136.9	213	142.6	219.8	142.2	0	31.3	11.5
2016	92.8	0	81.2	258.6	135.9	122.8	156.9	123.8	138	68.8	111.2	6.4
2017	0.6	69.5	77.9	44.6	183.9	189.3	143	90.8	225.5	12.4	1.2	0

2018	12	106	47.7	258.5	151.6	100.9	109.7	194.1	181.4	139.9	147.7	5.3
2019	0	10	92.5	313.8	165.6	153.2	177.7	301.3	183.7	38.6	82.6	24.4
SD	**31.5**	**39.6**	**45.4**	**75.1**	**54.7**	**40.2**	**36.9**	**57.4**	**34.4**	**53**	**44.8**	**30.8**
Va	**25.7**	**38.5**	**98.1**	**144.6**	**148.4**	**130.8**	**157.5**	**176.8**	**161.6**	**54.7**	**38.4**	**18.9**
CV	**1.23**	**1.03**	**0.46**	**0.52**	**0.37**	**0.31**	**0.23**	**0.32**	**0.21**	**0.97**	**1.17**	**1.63**

Table 4. Monthly rainfall distribution of Durame Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0.0	0.0	28.8	202.9	114.7	134.3	145.6	146.6	156.9	115.7	96.2	29.4
2001	11.3	53.9	144.8	104.4	143.1	103.7	257.3	205.4	107.5	163.4	12.9	10.3
2002	57.3	49.1	132.1	187.4	101.8	103.7	116.9	209.2	120.6	23.0	0.0	120.3
2003	23.7	12.1	77.7	205.8	77.2	131.3	200.5	120.6	123.7	20.7	44.2	15.6
2004	99.3	29.2	57.8	183.9	80.2	54.2	159.1	126.5	109.7	150.0	10.6	6.0
2005	50.1	25.9	127.8	322.3	269.2	35.8	67.1	100.9	285.0	117.1	59.7	0.0
2006	2.5	47.1	78.7	196.8	83.9	40.2	113.0	228.2	37.2	95.7	20.0	10.0
2007	34.5	59.0	84.5	127.0	158.6	97.3	157.5	94.4	170.1	32.2	0.0	0.0
2008	0.0	0.0	33.6	46.0	145.1	112.9	174.0	124.1	148.3	117.2	103.4	0.0
2009	43.4	7.4	30.9	101.3	65.2	56.8	133.8	123.9	74.2	97.2	29.7	88.0
2010	30.2	40.0	101.3	100.7	158.2	89.7	134.5	98.2	198.3	26.6	9.2	0.0
2011	1.8	4.4	46.0	96.4	267.4	156.0	219.0	225.5	108.0	0.0	76.7	0.0
2012	0.0	0.0	38.2	176.9	55.6	175.7	160.6	117.5	180.3	6.5	23.8	71.2
2013	20.1	8.2	108.2	130.4	245.1	166.6	137.2	233.5	121.8	130.0	79.5	5.3
2014	9.6	63.4	121.3	0.0	286.4	47.8	165.7	274.9	270.0	0.0	0.0	0.0
2015	0.0	1.8	28.7	90.1	195.8	120.6	95.2	0.0	28.0	71.9	104.0	1.3
2016	55.1	39.6	64.4	338.1	256.8	121.5	267.7	94.5	162.3	69.4	124.8	0.0
2017	31.3	48.1	63.6	18.7	165.4	66.1	294.5	77.4	299.6	127.0	10.4	0.0
2018	0.0	92.5	167.9	206.1	173.4	207.8	150.7	254.8	96.6	135.8	217.6	0.0
2019	21.8	10.6	68.6	258.9	121.5	314.7	270.1	323.5	244.2	149.9	132.6	9.3
SD	**26.4**	**26.6**	**42.2**	**90.6**	**73.9**	**66.6**	**62.1**	**80.6**	**76.6**	**55.9**	**58.3**	**34.0**

Va	**24.6**	**29.6**	**80.2**	**154.7**	**158.2**	**116.8**	**171.0**	**159.0**	**152.1**	**82.5**	**57.8**	**18.3**
CV	**1.07**	**0.9**	**0.53**	**0.59**	**0.47**	**0.57**	**0.36**	**0.51**	**0.5**	**0.68**	**1.01**	**1.86**

Table.5 Monthly rainfall distribution of Fonko Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0	0	6.9	209.6	168	149.7	140	207	155	70	21.6	56.8
2001	7	60.9	270.1	109.4	188.5	171.3	143.9	266.3	136.7	57.8	3.9	1.2
2002	94.7	53.6	130.8	85.2	193.3	124.8	119.2	251.8	190.6	1.8	0	160.3
2003	69.9	47	154.8	269	42.8	186.4	238.4	175.5	206.3	12.6	8.2	55.7
2004	89.2	25.8	114.5	173.4	25.7	68.4	214	174.3	179.7	91.8	6	33
2005	24.8	0	110.8	169.1	169.9	111.1	165.6	172.4	166.5	76.5	58.8	0
2006	9.2	19.9	143.5	174.5	108.8	141.1	210.1	195.3	111.5	60.4	10.8	15
2007	58.5	77.9	93.2	112.8	149.1	143.6	199	117.1	137.3	22.2	0	0
2008	0	7.8	10.8	104.3	198.2	179.1	237.3	127	197	108.6	99.1	0
2009	52.5	12.8	16.2	39.6	115.5	87.2	197.9	172.9	134.3	127.4	12.8	39.9
2010	13.9	104.5	216.5	126.9	220.6	84.7	201.3	77.8	122.5	10.1	57.6	16.9
2011	14.1	6.3	199.8	80	207.9	91.1	155.9	152.3	129.6	0	27.4	0
2012	0	0	64.4	108	61.1	221.6	166.5	185.2	244.5	0	19.2	12.3
2013	0	54.7	155.3	114.7	143.6	177.7	174.3	171.2	99.6	70.8	7.9	0
2014	14.6	63.2	56.2	111.9	265.7	28.2	119.1	221.8	120	116.3	38.8	2.7
2015	0	0	32.9	204.6	206	239.6	90	175.5	93	163.5	17.6	8.2
2016	37.1	17.4	190.7	309	162	164.9	86.8	111.5	174.2	104.1	67.6	13.8
2017	0	127.2	97.1	0	219.2	128.8	77.8	158.9	212.7	15.6	10.5	0
2018	0	110.7	32.3	242.1	132	146	136.4	139.8	95.4	109.2	47.9	0
2019	0	16.1	62.3	258.9	136.1	103.2	168.6	144.1	219.1	74.3	19.4	2.9
SD	**31.6**	**40.1**	**74.7**	**80**	**62.3**	**52.2**	**48.2**	**45.6**	**45**	**48.7**	**26.6**	**37.6**
Va	**24.3**	**40.3**	**108**	**150.2**	**155.7**	**137.4**	**162.1**	**169.9**	**156.3**	**64.7**	**26.8**	**20.9**
CV	**1.3**	**1**	**0.69**	**0.53**	**0.4**	**0.38**	**0.3**	**0.27**	**0.29**	**0.75**	**0.99**	**1.8**

Table.6 Monthly rainfall distribution of Shone Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0	0.3	41.2	242.3	210.8	105.6	153.7	174.2	104.7	122.3	106.7	19.2
2001	1.4	32.9	116.2	46.7	163.8	159.4	291.4	273.1	123.6	156	10.3	1
2002	69.8	54.8	226.3	115	100.4	41.4	143.4	201.4	174.1	35.2	0	121.3
2003	27.7	26.4	98.2	105.7	54.6	128.9	123.1	163.6	95.1	45.3	37.8	24.8
2004	121.3	56.6	71.8	194.1	42.1	84.8	198.1	221.1	138	84.1	27.9	42.6
2005	51.9	34.3	114.7	167	300.2	73.9	74	110.4	220.3	68.2	65.2	5.3
2006	10.1	54.3	148.2	201.7	104.5	67.3	150.3	228.4	112.6	81.8	6.5	26.1
2007	34	35.8	109.5	169.7	119.9	210.8	148.3	161.7	142.5	14.7	1.3	0
2008	20.4	0	11.9	139.5	76.7	156.9	273	162.4	137	87	95.1	2.1
2009	72.6	14.3	40.1	81.6	95.4	85.6	65.5	103.5	155.8	90.5	17.1	136.6
2010	36.7	157.1	94.6	234.2	174.3	103.3	179.4	135.7	194.2	24.1	61.8	24.3
2011	19.9	20	68.7	217.7	272.6	203.1	155.9	235.3	246.6	38.6	45.3	0
2012	0	0	37.5	139.2	61.2	187.6	235.4	164.5	245.9	19	6.8	15.3
2013	21.5	6.3	88.1	103.6	140.8	110.4	173.3	190.9	139.2	47.1	48.3	0
2014	0	36.5	126.8	251	204.2	54.8	215.3	131.5	252.8	23.8	68.9	4.7
2015	0	1.7	24.2	100.2	171.2	131.5	87.7	138.8	155.7	14.4	105.9	20.3
2016	30.5	32.5	73.4	176.8	141.5	166.4	198.1	295.2	217.5	17.6	27.8	12.3
2017	0	21.4	67.6	223.8	134.7	47.5	129.8	192	136.1	24.6	9.3	0
2018	0	70.3	111.5	89.7	96.7	102.9	99.2	59.3	103.9	65.4	43.7	43.8
2019	0	48.4	50.8	52.4	79.7	38.5	102.7	66.1	103.6	82.8	18.1	0
SD	**32.2**	**35.6**	**49.4**	**64.2**	**69.9**	**53.6**	**62.2**	**62.1**	**52**	**39.2**	**34.3**	**38.2**
Va	**25.9**	**35.2**	**86.1**	**152.6**	**137.3**	**113**	**159.9**	**170.5**	**160**	**57.1**	**40.2**	**25**
CV	**1.24**	**1.01**	**0.57**	**0.42**	**0.51**	**0.47**	**0.39**	**0.36**	**0.33**	**0.69**	**0.85**	**1.53**

As shown in the tables above from table 3 to 6, monthly rainfall distribution of the four stations are almost in similar figures since they are in one zone . If considering only the four wet season months (March through October), the monthly variation with coefficient of variation ranges between 33% and 69%. And they show that the stations region has great rain water potential in average recorded in April for the stations

Hosaena, Durame and Fonko; while May and August for the station of Shone from 2000-2019 years record. From the rain gage stations (Hosaena, Durame, Fonko and Shone) the incorporated average monthly rainfall amount presented in Figure 4.

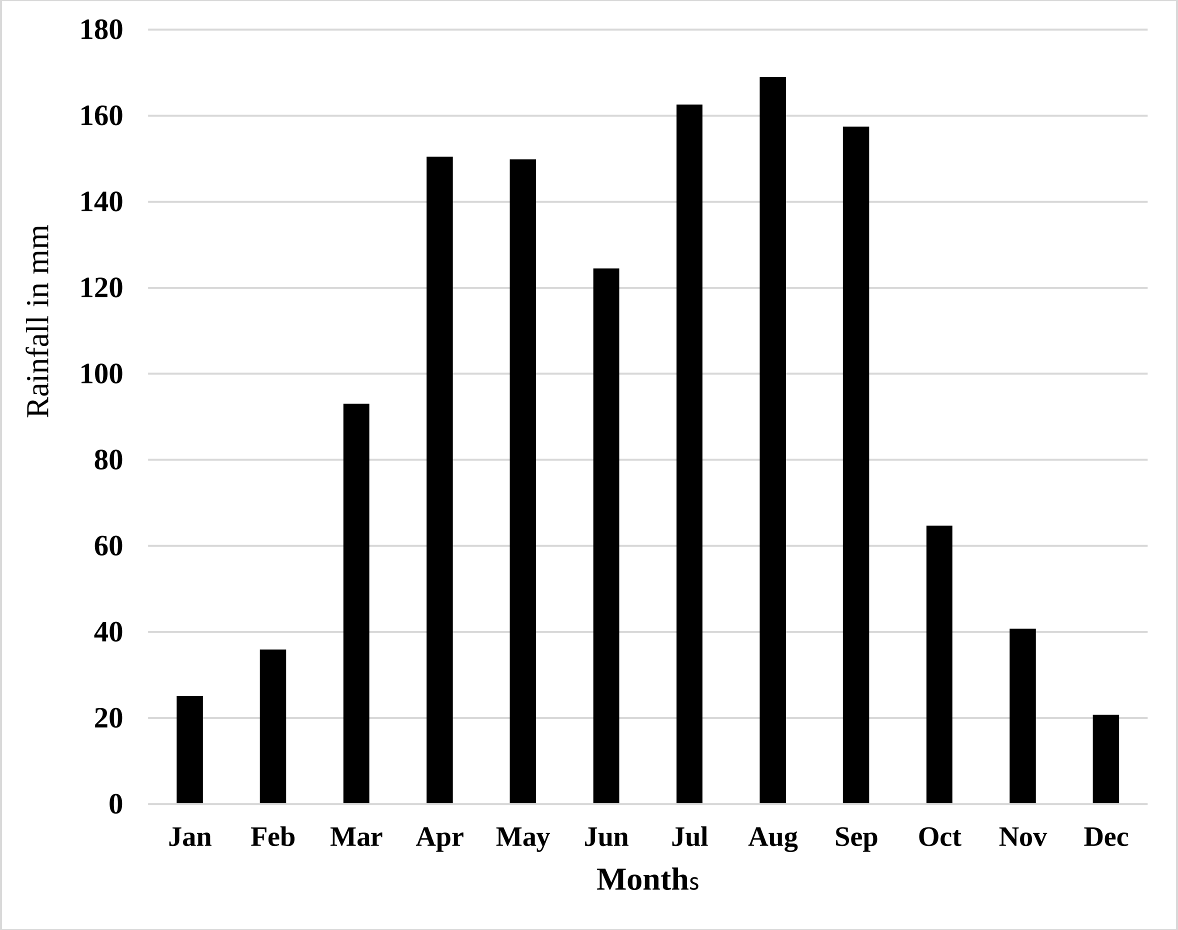

Figure 4. Incorporated average monthly rainfall distribution from the rain gage stations (2000-2019).

Figure 4 illustrates that for the two decades analyzed, Aug, Jul, Sep, Apr and May are the months with the most precipitation. January, Dec and February are the driest months of the year. Monthly, the University receives in average 99.5 mm of precipitation. This corresponds to the university's climate; rainy season and that states the area will receive from 1162.6-1204.9 mm of rain per year.

Monthly average rainfall amount for the purpose of rainwater tank sizing is presented in table 7.

Table 7. Monthly average rainfall amount of the four Stations.

Months		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Stations	Ho	25.2	38.0	97.6	144.1	147.9	130.2	157	176.3	161.1	54.2	37.9	18.4
	Du	24.1	29.1	79.7	154.2	157.7	116.3	170.5	158.4	151.6	81.9	57.2	17.8
	Fo	23.8	39.8	107.3	149.6	155.2	136.9	161.6	169.3	155.7	64.1	26.2	20.4
	Sh	25.4	34.7	85.5	152	136.7	112.5	159.3	169.9	159.4	56.6	39.6	24.5
Average		24.6	35.4	92.5	150	149.4	124.0	162.1	168.5	157.0	64.2	40.2	20.3

Average monthly rainfall amount occurred in between minimum of 20.3 mm and maximum of 168.5 mm in December and August.

4.3. Annual Rain fall Potential

Table 8. Average monthly and total annual rainfall amount of the four stations for the consecutive years of 2000-2019.

Year	Hosaena		Durame		Fonko		Shone	
	AMRF	TARF	AMRF	TARF	AMRF	TARF	AMRF	TARF
2000	82.66	991.9	97.6	1171.1	98.7	1184.6	106.75	1281.0
2001	91.16	1093.9	109.8	1318	118.0	1410	114.6	1375.8
2002	104.2	1250.9	101.8	1221.4	117.1	1311.4	106.9	1283.1
2003	95.5	1146.3	87.8	1053.1	122.2	1396.7	77.6	931.2
2004	96.8	1162.5	88.9	1066.5	99.6	1106.6	106.8	1282.5
2005	97.9	1175.0	121.7	1460.9	102.1	1200.7	107.1	1285.4
2006	99.8	1197.7	79.4	953.3	100.1	1190.9	99.3	1191.8
2007	98.2	1178.9	84.6	1015.1	92.5	1052.2	95.6	1148.2
2008	100.8	1210.6	83.7	1004.6	105.7	1269.2	96.8	1162.0
2009	102.7	1233.3	71.0	851.8	84.0	956.5	79.8	958.6
2010	93.4	1121.6	82.2	986.9	104.4	1239.4	118.3	1419.7
2011	92.6	1111.2	100.1	1201.2	88.7	1050.3	126.9	1523.7
2012	86.9	1042.9	83.9	1006.3	90.2	1082.8	92.7	1112.4
2013	97.0	1164.6	115.5	1385.9	97.4	1169.8	89.1	1069.5
2014	124.9	1499.1	103.3	1239.1	96.5	1143.9	114.19	1370.3
2015	80.3	964.6	61.5	737.4	102.5	1230.9	79.3	951.6
2016	108.0	1296.4	132.9	1594.2	119.9	1402	115.8	1389.6
2017	86.5	1038.7	100.2	1202.1	87.3	1047.8	82.2	986.8

2018	121.2	1454.8	141.9	1703.2	99.3	1191.8	73.8	886.4
2019	128.6	1543.4	160.5	1925.7	100.4	1205	53.5	643.1
Va	**99.5**	**1193.9**	**100.4**	**1204.9**	**101.3**	**1192.1**	**96.9**	**1162.6**
SD	**13.1**	**156.6**	**24.5**	**294.2**	**10.9**	**124.8**	**18.4**	**220.5**
CV	**0.13**	**0.13**	**0.24**	**0.24**	**0.11**	**0.11**	**0.19**	**0.19**

From Table 8 after incorporation, it is possible to have greater rainfall amount in 2018 and 2019 in Durame station. Regarding the variation in total rainfall between years with a coefficient of variation in the interval of 13% and 24 % reflecting a stable rainfall pattern. This high rainfall amounts makes rainwater as a potential source in Wachemo University, which increases the need for supply management initiatives and in similar range of value recorded in some studies (Biswas and Mandal, 2014) because of their climatic condition with their rainfall intensity).

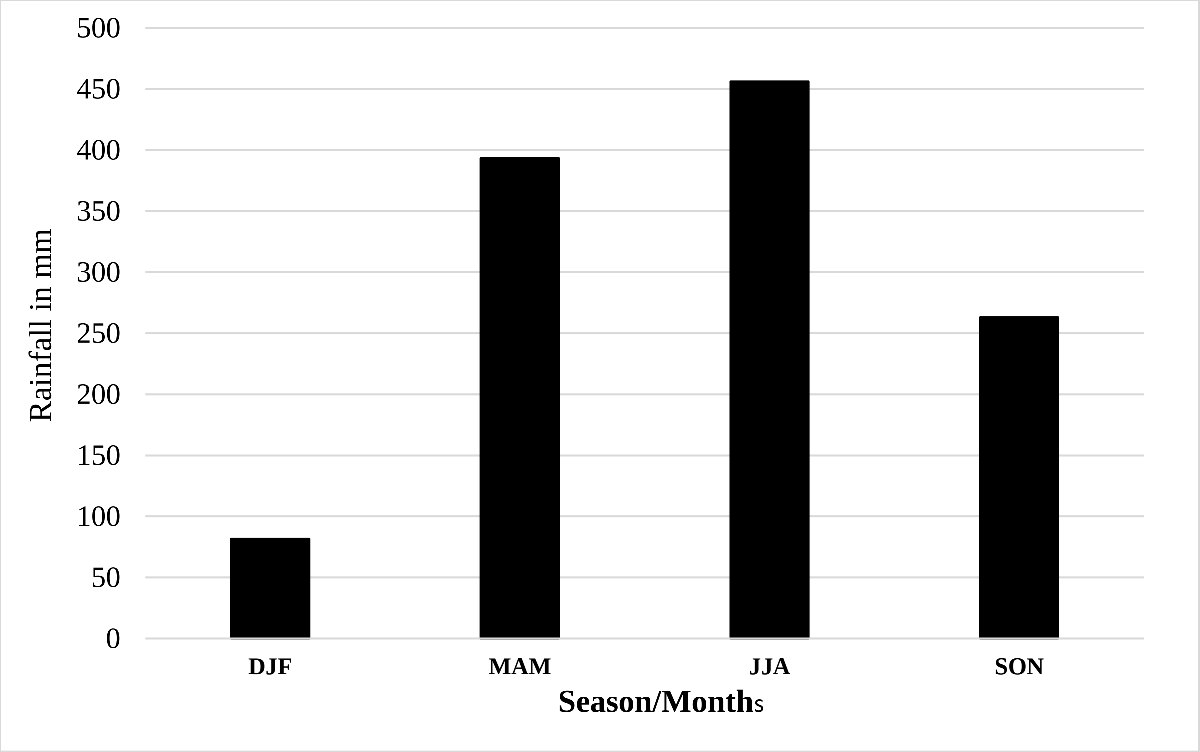

Figure 5.Seasonal rainfall distribution of the study area, 2000-2019.

As shown from the graph in Figure 5, the greater part of the rainfall occurs during summer, which is rainy season. From the figure it can be inferred that there is high variation from season to season and this seasonal variation of rainfall pattern affects the amount of total rainfall which can be harvested in relation to roof area of the buildings. For instance (Owusu and Kofi Teye, 2015) with similar rainfall pattern but with very high potential variation observed with respect to seasonal variation and climatic condition determines the rainfall pattern to be varied from season to season.

In addition all the stations have high rainfall amount with almost the same range of average monthly and annual rainfall amount since they are in the same zone around the study areas shown in Figure 6 below.

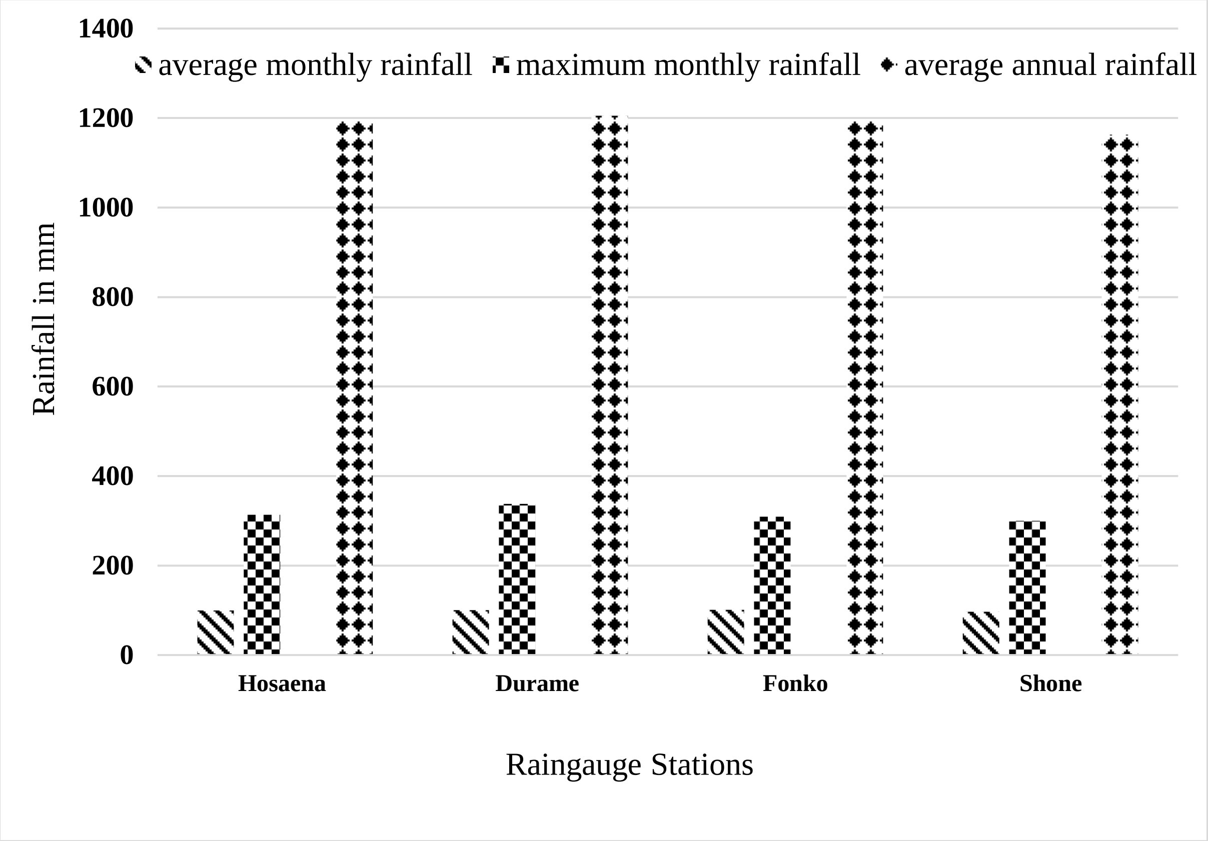

Figure 6. Graph of annual average rainfall of the four stations

Annual rainfall status in study area concerning maximum rainfall amount, minimum rainfall amount, average rainfall amount, standard deviation and coefficient of variation in the interval of 2000 -2019 is shown in Figure 7.

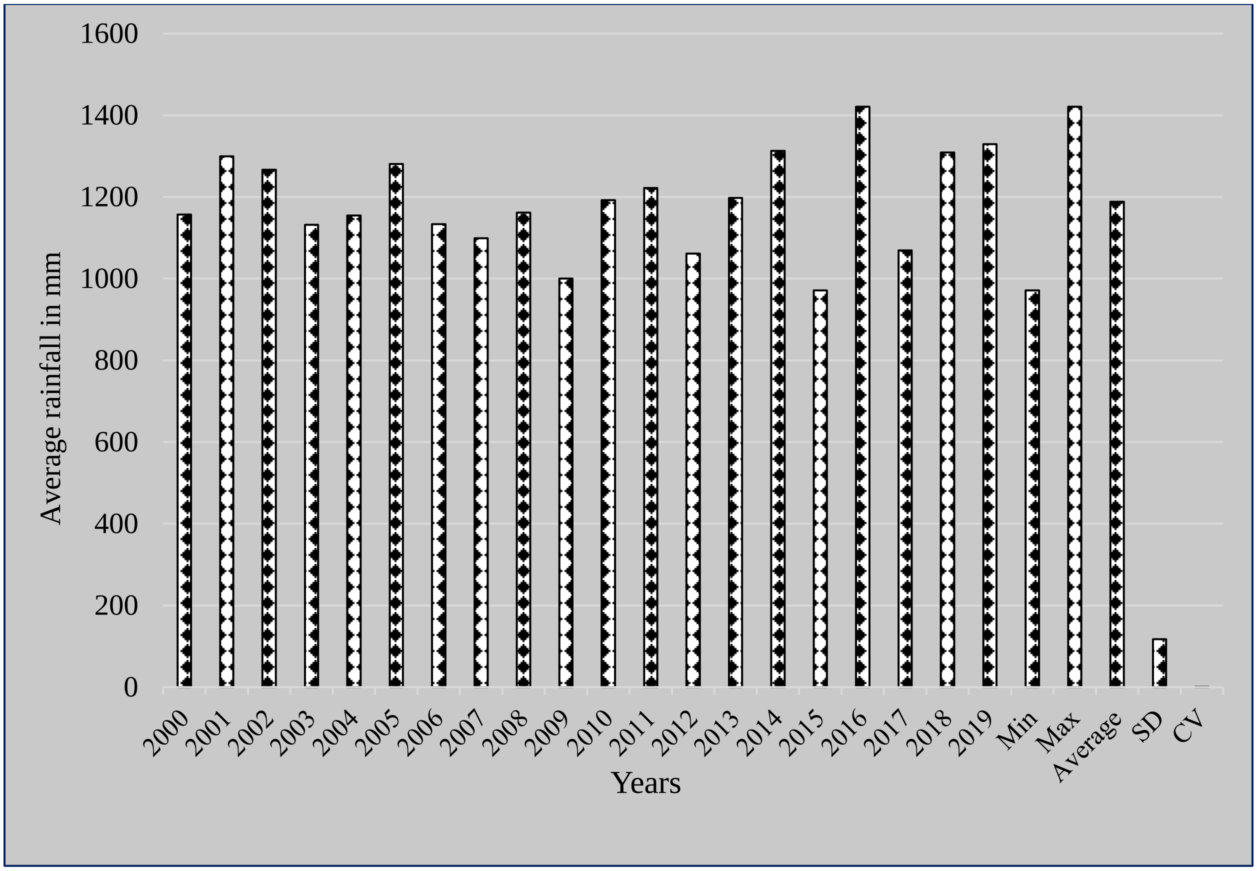

Figure 7. Annual maximum rainfall, minimum rainfall, average rainfall, standard deviation and coefficient of variation.

The overall monthly average rainfall became 99.01 mm while average annual total rainfall was 1188.2 mm from the incorporation of data of four rain gauge stations nearby study area that were from southern meteorological center data of twenty years. These indicate that great amount of rainfall distribution existed in the study area providing for high roof run off as that of (Lupia et al., 2017). The value of annual average annual rainfall recorded in this study is twice more than recorded in some studies (Al-houri, et al., 2014) because of climatic conditions of the respective study areas.

4.4. Selected Buildings and Their Respective Rooftop Area

Buildings rooftop area, roofing material and corresponding runoff coefficient are presented in Table 9 respectively.

Table 9. Roof catchment areas of the buildings with their respective runoff coefficient

Buildings	Roof Area In Square Meter	No Of - Buildings	Total Area in-Square Meter	Roofing Material	Runoff Coefficient
Lecture Type	346	13	4498	Metal sheet	0.8
Department Head Block	490	12	5880	Metal sheet	0.8
Dining hall	1500	3	4500	Metal sheet	0.8
Auditorium	490	3	1470	Metal sheet	0.8
Seminar1	657	20	13140	Metal sheet	0.8
Seminar2	465	17	7905	Metal sheet	0.8
Dormitory Block 1	490	26	12740	Metal sheet	0.8
Lounge	596	6	3576	Metal sheet	0.8
Dormitory Block 2	967	24	23208	Metal sheet	0.8
Admin Block	364	12	4368	Metal sheet	0.8
General Store	432	7	3024	Metal sheet	0.8
Baking House 1	432	3	1296	Metal sheet	0.8
Bread house 2	432	3	1296	Metal sheet	0.8
Laboratory 1	967	6	5802	Metal sheet	0.8
Laboratory 2	432	8	3456	Metal sheet	0.8
Workshop	432	5	2160	Metal sheet	0.8
Central Library	2317	4	9268	Metal sheet	0.8
Total	**11809**	**172**	**107587**		

Source: Wachemo Univerity construction office and own field measurements

Figure 8.Buildings, streets and sample points in Wachemo University, digitized from satellite imagery.

From the digitization of the buildings the summation of areas of all digitized polygons for the buildings found to be **141,561** square meter shown in Figure 8.The the correcction factor evaluated as **0.76** which was fom the ratio of actual to digitized area. Although it is possible to have areas of each builings using polygon tools in ArcGIS, its not as accurate as construction office document.Similar studies (Awawdeh and Jaradat, 2012) reported the correction factor above one which is very small area obtained using digitization while in this study it ha sbeen obtained above the actual one and it depends on identifing and tracincig accuracy on top of the buildings.

Potential harvestable rooftop rainwater evaluated based on the study area rainfall amount, total rooftops areas of the selected buildings (**107587 m^2**) and the runoff coefficient value which is 0.8. Therefore, total volume of rainwater using equation (4) became **1022678 m^3/year.**

By estimating the average annual rainfall, it was possible to determine that harvestable volumes are sufficient to meet large amount of water demand in general and non-potable consumption particularly, throughout the year, depending on the building roof area.

Potential of rooftop rainwater to meet the community demand resulted that it is about **52.4%** of total demand of the community when evaluated in yearly basis. This indicates that having all rainwater harvested, it is possible to have sufficient amount of water to compensate the current water supply for the community from limited source which was about **32%** of total demand. According to (Dakua et al., 2013), rainwater harvested from rooftops was able to meet around 90 % of the demand, with the remainder supplied from an onsite bore. This large amount from previous studies was achieved with large rooftops catchment area and high rainfall intensity and low respective demand when compared with this study.

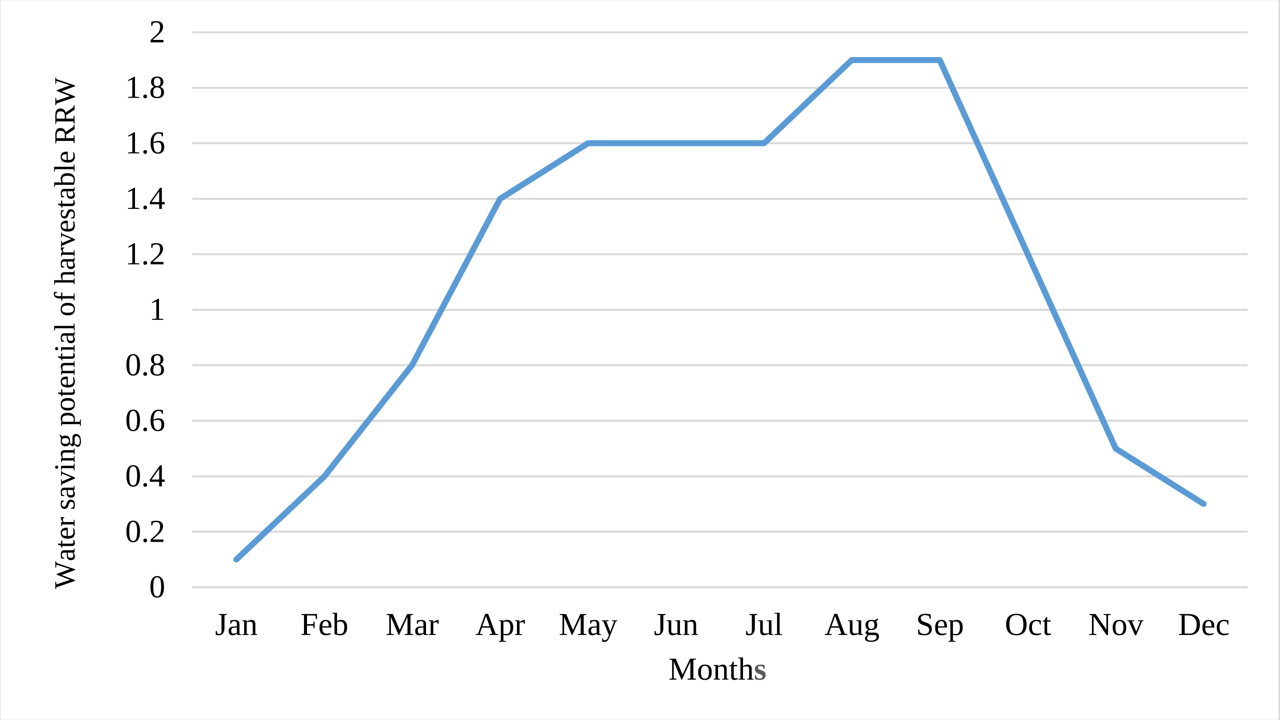

Figure 9.Potential Saving Results Based On Monthly Demand

As shown that greater water saving potential appeared in August and September in monthly basis while minimum value of saving in Jan. Similar studies for instance (Adugna et al.;2018) the maximum contribution of rainwater harvesting was found in July and minimum in January and December with the amount of less potential. This is due to weather condition of the study area having maximum rainfall amount and less water demand with respect to each months (Angrill et al., 2017).

N.B. Assumption: Constant population number and water demand through the year.

4.6. Rooftop Rainwater Quality Analysis

The rooftop water quality of the buildings was presented in Table 13 below. As the result indicated, the sample parameters like pH, turbidity, EC,TDS, nitrates, sulphates, zinc and fecal coliform were within the WHO guideline and Ethiopian standard limit whereas, total coliform was above the permissible limit. Parameters like total coliform and nitrates concentration showed increment from gutter to PVC as shown in Table 10. This could be a good indicator of possible source of water contamination increases through downpipes for the parameters specified.

Table 10.Rooftop rainwater quality results for intended parameters corresponding with WHO (2017) and Ethiopian standard.

SN	Parameters	Sample (From Gutter)			Sample (From PVC)			WHO(2017) Guideline	Ethiopian Standard
		Min	Max	Average	Min	Max	Average		
1	Temperature(°C	18.9	19.6	19.25	18.9	19.6	19.25	<15	-
2	pH	6.8	7	6.9	6.8	7	6.9	6.5 - 8	6.5 - 8.5
3	EC(µs/cm)	13.2	17.7	15.45	13.2	17.7	15.45	800	800
4	TDS(mg/L	8.58	8.9	8.74	8.58	8.9	8.74	<600	1000
5	Nitrates(mg/L)	0.528	0.54	0.534	0.12	0.14	0.13	50	50
6	Sulphates(mg/L)	2	4	3	4	6	5	250	250
7	Turbidity(NTU)	5	6	5.5	6	6	6	5	5
8	Zinc(mg/L)	1.89	1.91	1.9	0.14	0.16	0.15	3	3
9	Tc(CFU/mL)	42	46	44	43	49	46	0	0

10	Fc(CFU/100 mL)	1	4	2	1	3	3	0	0

4.6.1. Physicochemical rooftop rainwater quality.

From the results above in the Table 13, rooftops rainwater can provide a relatively high quality water source, which can be directly used for non-potable uses, or with filtration and disinfection for potable uses since some bacterial contamination found and some studies for instance (Rostad and Montalto, 2012) highly recommended that it is possible to use rooftops rainwater for non-potable use without any treatment.

4.6.1.1. Temperature

Temperature is another important factor to limit growth and reproduction of microorganisms. In the present study, all the recorded temperature values were not in accordance with the standard of drinking water (WHO, 2017).

In both cases, water temperature was above the standard value, which may be indeed accelerating the growth of microorganisms. This maximum value of water temperature may be due to warm climatic condition of study area.

4.6.1.2. pH

Increasing acidity results to greater values of (H), thus to lower values of pH. Low pH is linked with high acidity, high pH with caustic alkalinity. pH is very important in the control of a number of water treatment and waste water treatment processes and in control of corrosion. Generally, the pH status of the rainwater from gutter and PVC end was within the recommended standard limits of 6.5-8.5 (WHO, 2017) and Ethiopia guideline recommended values and similar with previous studies (Sadia et al.,2014).

4.6.1.3. Electrical Conductivity

In general, there was not significant variation for both samples and was within in the WHO and Ethiopia guideline recommended values.

4.6.1.4. Total Dissolved Solids

The sample mean was significantly less than WHO drinking water standard in both cases as shown in Table 13. This might be attributed to the fact that many of the pollutants in atmosphere are washed away after five to twenty minutes of rain depending on the intensity of rainfall (Biswas and Mandal, 2014). TDS mean value concentrations of all sampling areas was less than WHO guideline and Ethiopian standard recommended values. Consequently total dissolved solids did not pose any danger to water used for drinking purposes. The results were similar with previous studies; for instance (Haylamicheal et al., 2012).

4.6.1.5. Turbidity

Turbidity in rooftop rainwater can occurs as a result of the disturbance of deposits. It can seriously interfere with the efficiency of disinfection by providing protection for organisms, and much of water treatment is directed at removal of particulate matter before disinfection. This not only will increase the effectiveness of disinfection by chemical disinfectants such as chlorine. The result from the table for the turbidity test shows that it is above standard limit of National and International which is 6 NTU. This may be because turbidity is acting as an indicator of possible sources of microbial contamination as stated in similar study (Kormoke et al., 2017). So, turbidity measures should be investigated and the causes corrected. Whereas turbidity should be decreased as far as is possible within the constraints of the type of system and the resources available as one part of the management of distribution to attain water safety. It is also an essential consideration when investment decisions are made regarding causes and treatment for water provisions and should be well-known in the water safety plan as an exposure that needs to be controlled.

The physicochemical quality of rooftop runoff, as stated by many studies, is quite similar to potable water quality guidelines, with the exception of pH values (pH of rainwater is 4.5–6.5, increasing slightly once on the roof. However, wide variations in concentrations of ions, like, sulphates and nitrates were observed (Eran Friedler, 2017).

4.6.1.6. Nitrates

The existence of nitrogen compounds in surface waters typically indicate pollution excessive amount of ammonia and organic nitrogen might result from recent dirt discharges or runoff contamination by relatively fresh pollution. Consequently, water containing high organic N and ammonia N levels are considered to be potentially dangerous. While waters in which most of the nitrogen is in the nitrate form are considered to somewhat to be stabilized to constitute prior pollution. The nitrate level was quite below the standard limit (50 mg/L). The result from the table for the nitrate test showed that it within standard limit of National and International which is less than 50 mg/L. The concentration amount in gutters are higher than that of PVC which is similar with the previous studies (Farreny et al., 2011).

4.6.1.7. Sulfates

The result from the table for the sulphates test showed that it within standard limit of national and international guideline. Because this compound might come from, fuel combustion, soil, and dry deposition; the concentration decreases from gutters to PVC pipe end.

4.6.1.8. Zinc

Galvanized pipelines will discharge zinc (from the galvanizing cover) and can also leak cadmium and lead. Corrosion can be a particular problem where galvanized steel or iron piping is joined to dissimilar materials, such as brass, in taps and fittings. The concentration of Zn above standard limit causes loss of appetite and anemia. However the result for the concentration in the sample in average shows that it is within the standard limit.

In general many studies evaluated the physicochemical quality that meets WHO standards. A study for instance (Awawdeh and Jaradat, 2012) evaluated the quality of the harvested rainwater from the roofs of the houses showed that rainwater collected meets the WHO standards for physical and chemical parameters.

4.6.2. The Microbial Quality of Rooftop Rainwater

The bacteriological quality of rooftop rainwater usually exceeds bacteriological quality standards, possibly due to pollution arises from the excreta of animals (birds, rodents, etc.) that have access to roofs (Haifa and Friedler, 2017**)**.

4.6.2.1. Total Coliform

These bacteriological indicators of water quality or pollution are of particular concern since their relationships to human and animal health.

As it is indicated in the above table the result shows that there are high coliform bacteria existence beyond allowable limit both from WHO and national standard. The reason for this is might be the presence of contamination with dust during dry season and animals especially birds.

Studies (Ahmed et al., 2011) reported that the presence of coliforms was expected because, besides feces, they might originate from outdoors vegetation; as a result, this might not only be an indicator of total coliform contamination. Hence, efforts should emphasis on the installation of a water treatment method that removes pathogens from rainwater, which should be adapted to the end use of rainwater.

4.6.2.2. Fecal Coliform

Table 13 showed that the average fecal form bacteria that were measured at different selected roof sample. The measurement of fecal coliform in all different sample buildings rooftop was found to be 3 CFU/100mL which is above the standard limit. This might be from impurity of the rooftops from droppings of birds and other animals relatively. Moreover, a great number of individual studies stated the poor microbiological quality of urban rooftop runoff because of high levels of bacterial contamination (Angrill et al., 2017).Therefore this rooftop rainwater is not save to drinking purpose rather than non-potable use.

4.7. Storage Capacity of the Rainwater Tank with Corresponding Non-Potable Use.

The estimated non-potable water demand which is equivalent to $4300\ m^3$/month.Having this value as water demand and calculating harvestable rainwater potential on monthly basis, the storage tank capacity using mass curve method was determined in Table 11.

Table.11. Storage tank capacity determination on monthly basis using mass curve method considering non-potable water consumptions (in the community)

Months	Rainfall (mm)	Rainfall that Can be Harvested (m^3)	Water Demand (m^3)	Cum.Harvestable Rainfall CH (m^3)	Cum.Water Demand (m^3)	Difference CH - CD (m^3)
Jan	24.6	2117.3	4300	2117.3	4300	-2182.7
Feb	35.4	3046.9	4300	5164.2	8600	-3435.8
Mar	92.5	7961.4	4300	11008.3	12900	-1891.7
Apr	150	12910.4	4300	20871.8	17200	3671.8
May	149.4	12858.8	4300	25769.2	21500	**4269.2**
Jun	124	10672.6	4300	23531.4	30100	-6568.6
Jul	162.1	13951.9	4300	24624.5	34400	-9775.5
Aug	168.5	14502.7	4300	28454.6	38700	-10245.4
Sep	157	13512.9	4300	28015.6	43000	-14984.4
Oct	64.2	5525.7	4300	19038.6	47300	-28261.4
Nov	40.2	3460	4300	8985.7	51600	-42614.3
Dec	20.3	1747.2	4300	5207.2	55900	-50692.8

From Table 11, for constant water demand; May and April determine most because of their maximum rainfall amount record. As a result required storage capacity approximately became **4269.2 m^3** and the mass curve for rainwater storage tank shown in more detail in Figure 9.

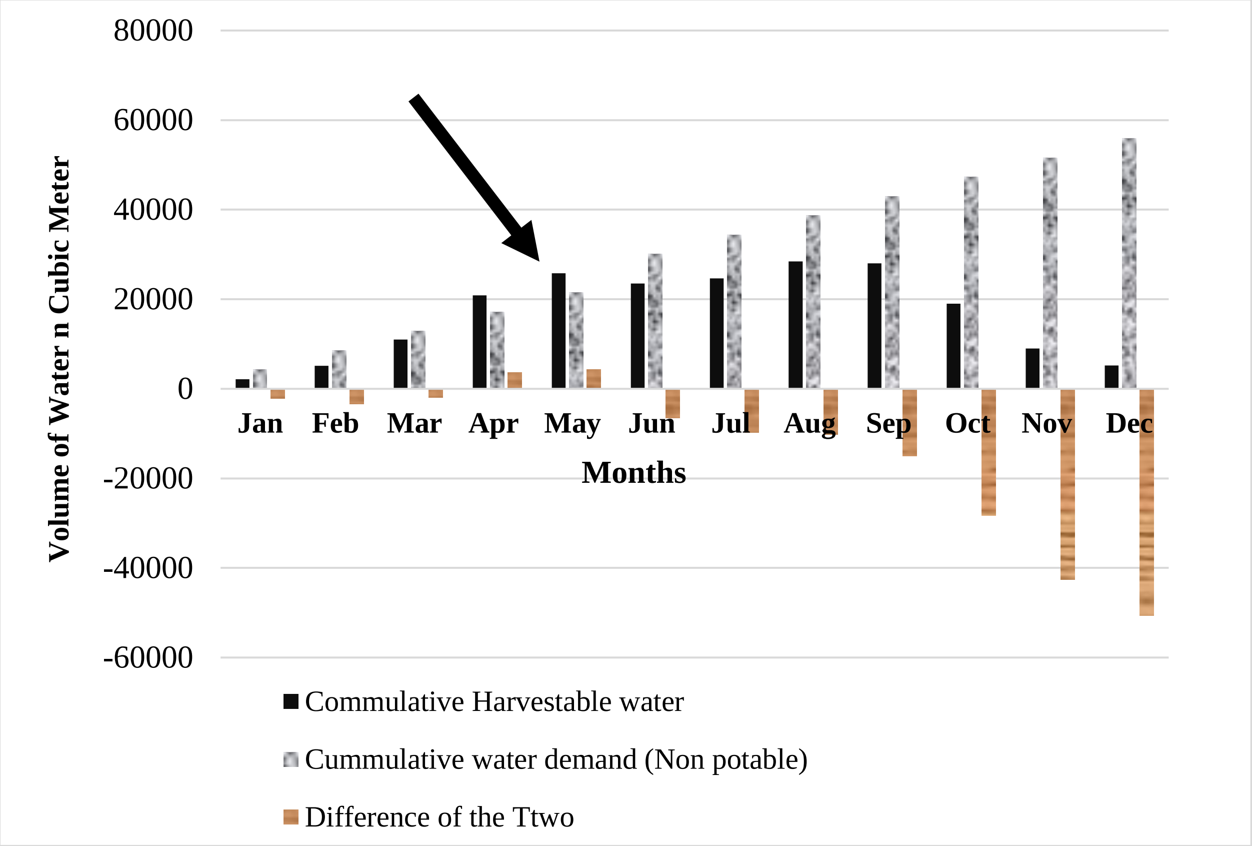

Figure 10. Mass Curve for Calculation of Required Storage

From the graph (Mass curve calculation), the potential of rooftops rainwater in months April and May can compensate all the demand of the respective months. The maximum interval of storage capacity where it exists in relation to water demand on monthly basis which is **4269.2 m^3** .The months April and May have the potential of compensating all water demand in that months to satisfy non-potable demand for toilet flushing ,cleanings and washing floors.

Construction of concrete rainwater tank storage is not feasible and cos effective for large amount of rainwater harvesting (Farreny et al., 2011). Therefore; using locally available installation materials and plastic rainwater tank may contribute much more in alleviating water scarcity in study area especially for the purpose of non-potable use since there has been shown microbial pathogens.

Most importantly, this cost-effective system might save a huge amount of money that can be invested in improving the water supply capacity on the main campus of Wachemo University

4.8. Cost Calculation for System Installation per Suitable and Identical Buildings of the University.

Table 12.The cost of fixing such a rain water harvesting system in one single building is calculated and presented below.

S.N	Installation Materisls	Amount	Unit	Unit cost	Total Cost (Et. Birr
1	Broom	1	Piece	90	90
2	Connecter and fixture	1	-	400	400
3	Sealer	1	-	190	190
4	Metal filter piece (Mesh net)	1		350	350
5	Metal lock	2	-	125	300
6	T-valve with flush facility	1	-	470	470
7	Metal tap to fit in the storage tank	1	-	130	130
8	Plastic bucket with jug	1	L	200	200
9	PVC pipes of 5 inches 10 meters	1	inch	1500	1500
10	Polyethylene plastic storage tank(20,000 L)	1	L	68500	68500
11	Bricks 15 cm size each	50	cm	11	550

12	Cement	15	kg	10	150
13	Sand 110 birr for 25 kg bag – for 3 bags 3x110=330 birr	3 bag	kg	110	330
14	**Labor Cost** a/ Fee of labor to clean the roof before first flush –300Birr b/ Wages to masonry preparation and a helper =250+200=400 c/ Cost of labor for installation of the system – 270 Birr				
15	**Total Sum**				**73,800**

Therefore, the cost to be invested on one single building is calculated as **73800** Ethiopian Birr, which includes the cost of labor, polyethylene tank, pipes, fittings and cement base. Gutter pipes to drain the rainwater from roof into the ditches beside of the buildings are already available in the buildings. If all the buildings in the main campus of Wachemo University are to be installed with the system, then the cost of installation would be: **73800**X 94 = 6,937,200 (149,187 USD) birr, which is the total cost for the university to install the rainwater harvesting system in all of the 94 similar buildings inside the Wachemo University main campus. The cost of installation materials are high in their cost when compared with some studies (Andavar et al., 2020) because of the current value is very high than previous costs. But it doesn’t mean it’s not cost effective. Contrary to this, for instance (Awawdeh and Jaradat, 2012) evaluated the cost of installation much more than the cost of this current study because of large amount of catchment area of the rooftops.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

The potential rooftop rainwater harvesting has been evaluated with respect to quantity and quality aiming for alternative supply source for the Wachemo University using the current existing buildings roof area and 20 years recorded monthly rainfall from SNNPR meteorological center. With minimum variation of rainfall amount in annual basis and maximum variation on monthly and seasonal basis were identified. Considering only the four wet season months (March through October), the monthly variation with coefficient of variation ranges between 33% and 69% and yearly variation between 13% and 24 % having great rain water potential in average recorded in April Month. Roof area is a critical factor especially in the months through March to August for promoting Rain Water Harvesting (RWH) parameters. As bigger roof areas provide a larger harvesting potential, and the season from June to August (JJA) has the highest sensitivity to the increase of the tank size in furthering rainwater harvesting parameters. Besides, the season (September, October and November) is the poorest values of rainwater harvesting parameters are expected for almost all combinations of roof area.

From the digitization of the buildings the summation of areas of all digitized polygons for the buildings found to be **141,561** square meter and the correcction factor became as **0.76** which was fom the ratio of actual to digitized area. Although it is possible to have areas of each builings using polygon tools in ArcGIS, its not as accurate as actual .

The maximum potential of rainwater with annual average rainfall amount 1188 mm and rooftops area 107587 m^2 square meter was found to be 102,268 m^3 /y which can be harvested from roofs provided that all rain falling on the roofs is collected. This is equivalent to 52.4 % of average water demand of the community in the university and greater water saving potential appeared in August and September in monthly basis while minimum value of saving in Jan. Therefore, collecting rainwater is important as an alternative source of water, since large amounts of water can be collected.

Rooftops rainwater can provide a relatively high quality water source, which can be directly used for non-potable uses, or with filtration and disinfection for potable uses since some bacterial contamination found. Most of the physiochemical and biological parameters reflected in this study were in accordance with the recommended values by WHO and Ethiopian standards except for the bacteriological parameters and temperature. Poor microbiological quality of urban rooftop runoff because of high levels of bacterial contamination.

Storage capacity in relation to water demand and cumulative harvestable rooftops rainwater on monthly basis which is **4269.2** m^3 .The months April and May have the potential of compensating all water demand in that months to satisfy non-potable demand for toilet flush, cleanings and washing floors**.**

Construction of rainwater storage tank with concrete may not be feasible and cos effective for large amount of rainwater harvesting. Therefore; using locally available installation materials and plastic rainwater tank may contribute much more in alleviating water scarcity in study area especially for the purpose of non-potable use since there has been shown microbial pathogens.

The harvestable rain water can be used for this non-potable water consumption without any cost of treatment. Theoretically, the harvested rainwater can cover all non-potable water needs at a community level. Therefore; by harvesting rooftops rainwater, the university can make water available for sanitation and washing; and can also solve conflicts in sharing of limited supply sources.

In provision of solution for scarce water supply of the community considering locally available material with respect to their durability the cost of installation calculated become **6,937,200** Et.Birr (**149187 USD**), which is the total cost for the University to install the rainwater harvesting system in all of the 94 similar buildings inside main campus.

5. 2. RECOMMENDATIONS

Rainwater harvesting might be profitable in a context where the capacity of water supply infrastructure is exceeded by demand. Moreover, it could become a good alternative source of water supply in Wachemo University to cope up with the ever-increasing demand and should be recognized and utilized by the respective authorities.

Determination of rainwater storage tank should be performed considering the purpose (end use) of rainwater and time to optimize and not to have oversized storage tank.

When installing and developing a rainwater harvesting system, it is required to notify end-users that such water is for non-potable uses, which can be done by using taps with different pipes of different colors and warnings signs reading like ‘non-potable water.

This study focused only on evaluation of rooftops rainwater potential with respect to quantity and quality for alternative water supply source from university buildings in terms of quality and quantity; because of time and budget constraints. Hence; the following action should be considered in further research;

- ☞ Rooftops rainwater harvesting system could be attained on large scale commercial, residential, or industrial sector.
- ☞ Comparisons could be made with rooftops rainwater harvesting systems to ground water system on the basis of quality, quantity, environmental effects, availability and water conservation.

To have good quality of harvested rainwater, it is suggested that:

- ➢ Roof tops and land catchment must be cleaned before the rainfall season.
- ➢ Locating culverts at a far distance from the collected rainwater storage tanks to avoid any leakage of containments.
- ➢ Harvested rainwater samples should be collected and analyzed on regular basis from the storage tanks before using the water for drinking purposes.

This study should increase the attention to the prominence of implementing rainwater harvesting technique in Wachemo University as a sustainable alternative for ensuring a continued source of non-potable water.

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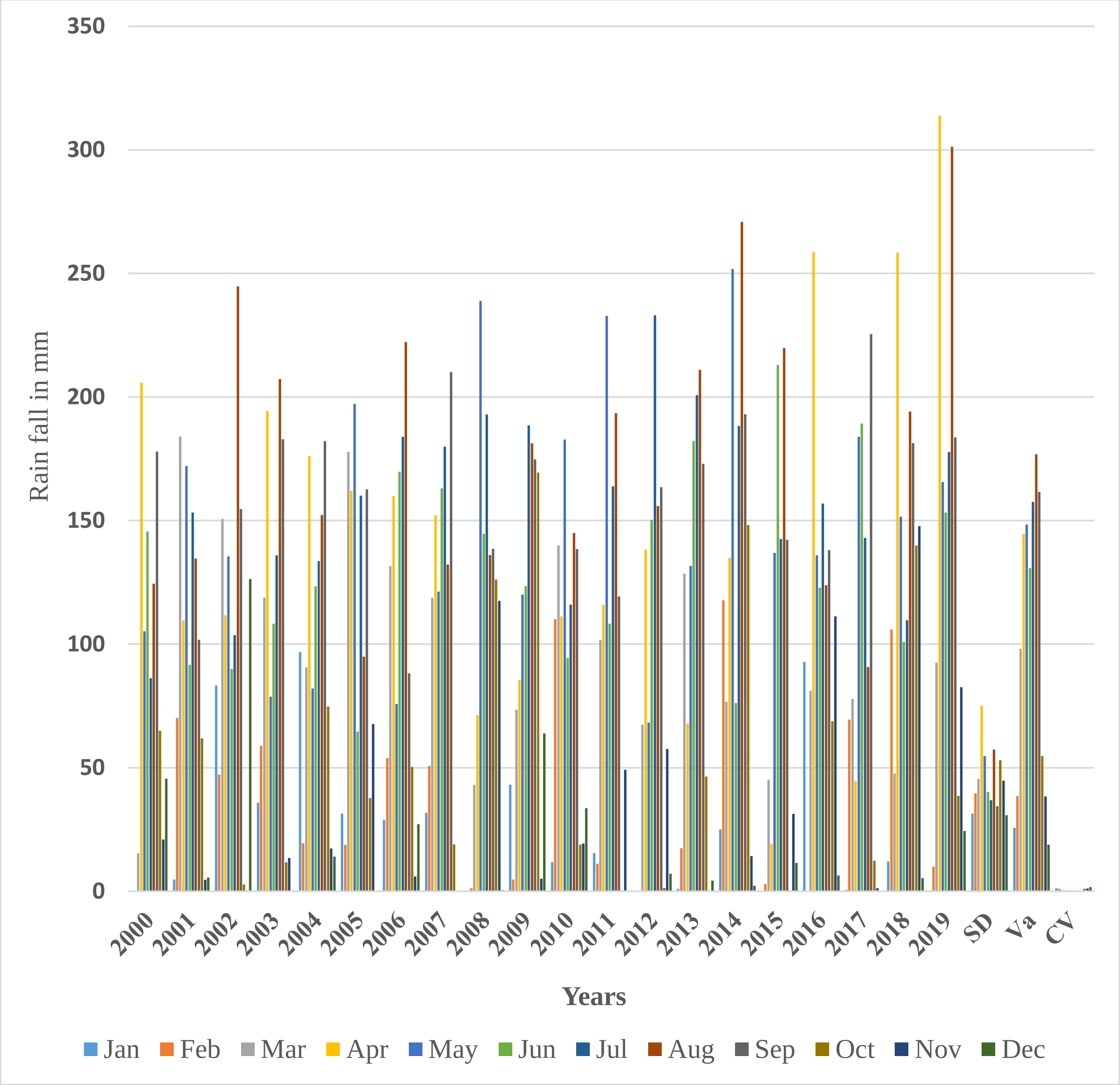
APPENDIXES

Partial View of Wachemo University

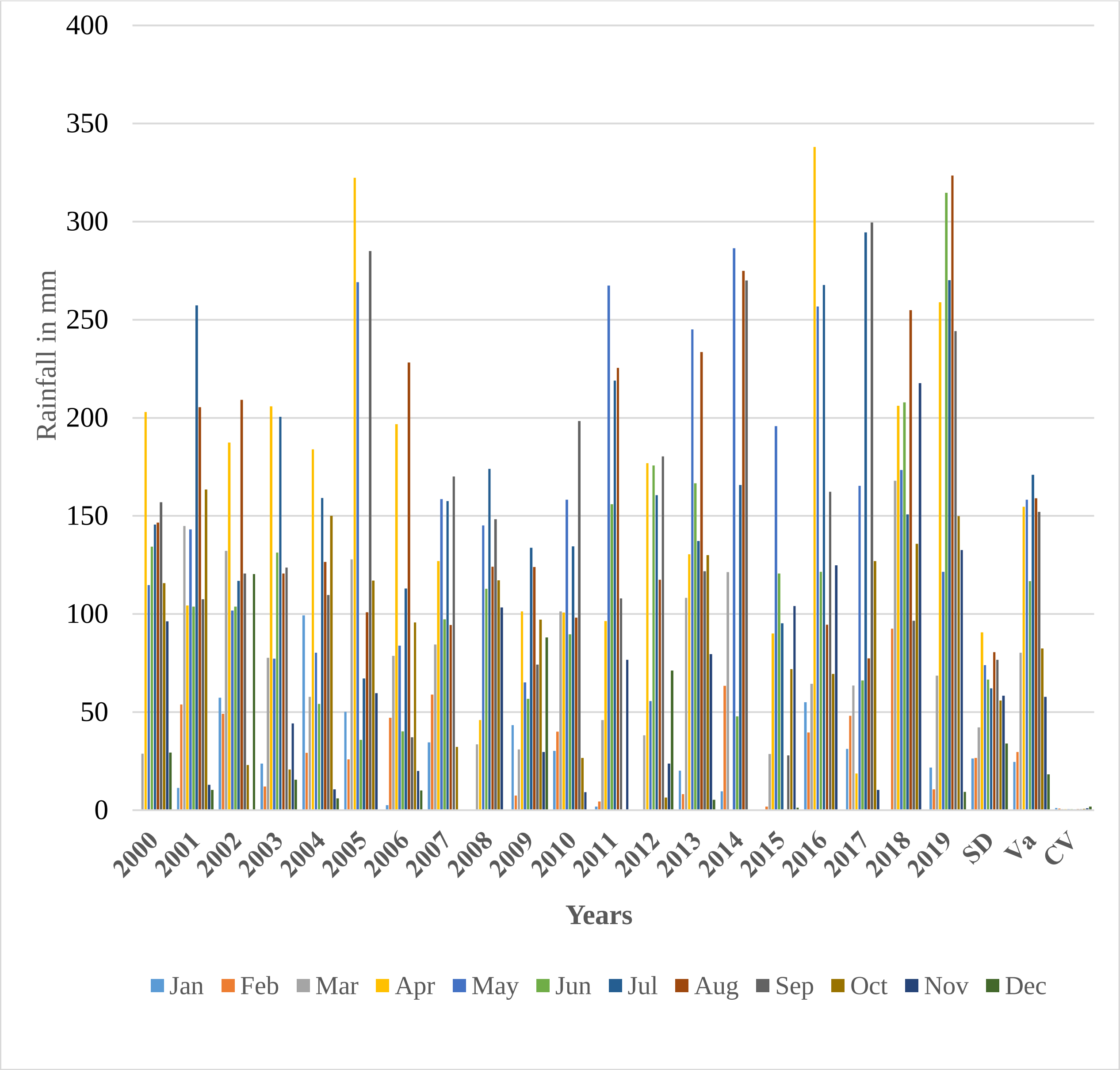
Admin Block of WCU

Seminar Block Buildings

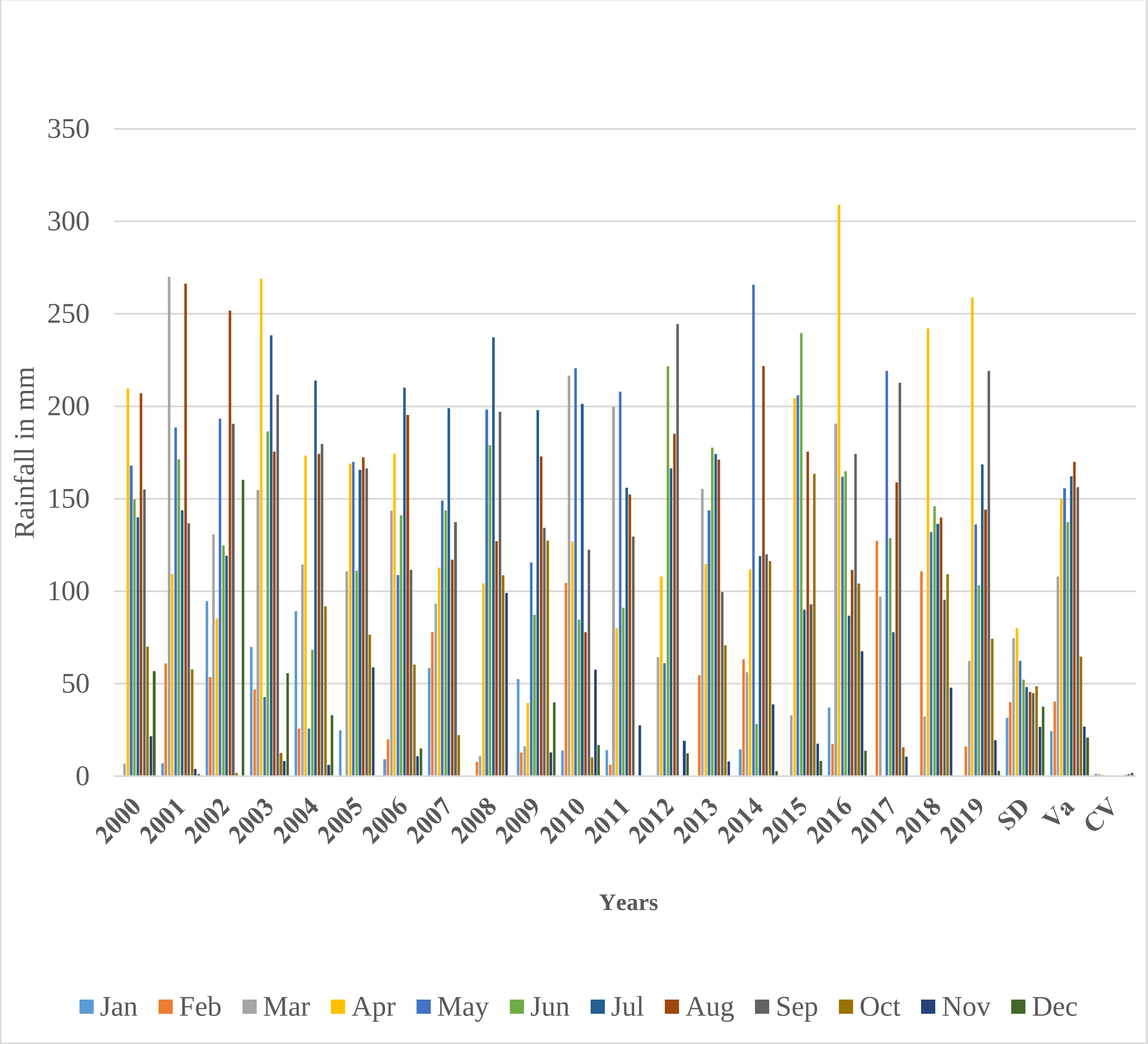
Partial View of Garden



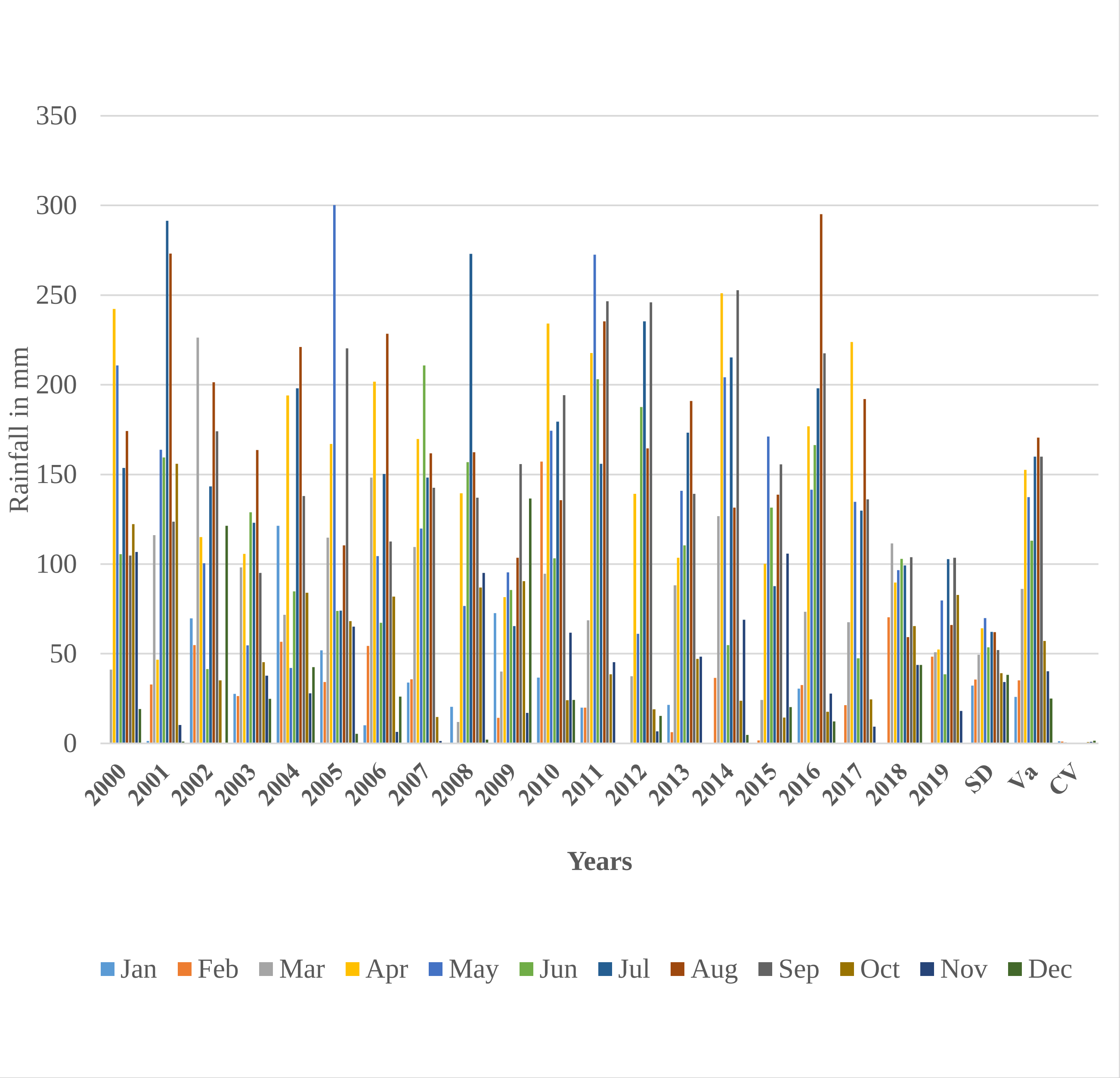
Hosaena Gage Station Rainfall Distribution



Durame Gage Station Rainfall Distribution



Fonko Gage Station Rainfall Distribution



Shone Gage Station Rainfall Distribution

Physico Chemical and Microbiological Testing Instruments