ADDIS ABABA UNIVERSITY

SCHOOL OF EARTH SCIENCES

GROUNDWATER RESOURCE EVALUATION OF THE UPPER JEMMA CATCHMENT, BLUE NILE BASIN, ETHIOIPIA

A Thesis Submitted to the School of Earth Sciences in Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydrogeology

By: Yibeltal Mammo Gedle

Advisor: Tilahun Azagegn (Ph.D.)

Addis Ababa, Ethiopia.

May, 2022

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This is to certify that the thesis prepared by Yibeltal Mammo Gedle, entitled: Groun Resource Evaluation of the Upper Jemma Catchment, Blue Nile basin, Ethiopia, submitted in the partial fulfillment of the requirements for the degree of Master of Science in Hydrogeology complies with the regulations of the university and meets the accepted standard with respect to originality and quality.

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Declaration

I undersigned, declare and confirm that this thesis is my own work and have nc presented for a degree of in any other university. I have followed all the ethical and te principles of research in the data collection, data preparation, data analysis, compilation presentation of this thesis. All the sources of material used for this thesis have been acknowledged.

Yibeltal Mammo Gedle

Signature ______________

Date ______________

This thesis has been submitted for examination with my approval as university advisor

Tilahun Azagegn (Ph.D.)

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Table of Contents

Contents **Page**

List of Tables

Tables **Page**

List of Figures

Figure **Page**

Abstract

The study was conducted on the upper Jemma catchment, in Blue Nile basin, central highland Ethiopia, Amhara National Regional State, which is located 254 km from Addis Ababa on the way to Mehal-Meda. The study area covered 3250 sq.km and having an average elevation range from 1556m to 3708m above mean sea level. The main objective of the study was to evaluate the groundwater resource potential of the area. This study has also tried to estimate the groundwater recharge of the catchment using the water balance method. Field based physico-chemical parameters have also been used to characterize the groundwater. The annual precipitation of the basin calculated from long term mean monthly rain fall data is 1114.3mm/year. The actual evapotranspiration (AET) and surface runoff (SRO) are 745.77mm/year and 234.23mm/year, respectively. The mean annual groundwater recharge of the upper Jemma catchment is calculated to be 134.4mm/year, which corresponds to 12% of the total annual precipitation. The study area is mainly covered by tertiary volcanic rocks with some Mesozoic sandstone and quaternary deposits. In the catchment highly fractured and weathered basalt, elluvial and alluvial deposits with mixed aquifers have high permeability and productivity for groundwater reservoir. The main recharge area of the catchment is Tarmaber Megezez Mountain, Mezezo, Kobastil, Yegem and other mountain chain in the eastern part of the catchment, which are located at higher elevation. These highland areas get high rain fall compared to the surrounding lowland. Mostly the groundwater movement is parallel and sub-parallel with the surface water flow of the topography and structures of the area. The electrical conductivity and TDS of the catchment ranges from 85.8μS/cm to 334.2μS/cm and from 55.8mg/l to 217.2 mg/l, respectively. This shows that the groundwater quality falls within the freshwater group of the WHO standard.

Key words; Upper Jemma, Groundwater Potential, Water Balance, Recharge

Acronyms

ET----------------------- Actual evapotranspiration

DEM-------------------- Digital Elevation Model

EC ---------------------- Electrical conductivity

EMA-------------------- Ethiopian Mapping Agency

ET ---------------------- Evapotranspiration

GIS--------------------- Geographical Information System

GSE-------------------- Geological Survey of Ethiopia

IR----------------------- Igneous Rock

LST--------------------- Limestone

MAE------------------- Metrological Agency of Ethiopia

MER------------------ Main Ethiopian Rift

MR---------------------- metamorphic rock

NE---------------------- North East

NGO-------------------- nongovernmental organization

NNE-------------------- North North East

NWP------------------- north western plateau

PET--------------------- Potential Evapotranspiration

SE----------------------- South East

SEP--------------------- South eastern plateau

SR----------------------- Sedimentary Rock

SRO-------------------- Surface run off

SST--------------------- Sand Stone

SSW -------------------- South South West

TDS-------------------- Total Dissolved Solid

VR---------------------- volcanic Rick

CHAPTER ONE

INTRODUCTION

1.1. General Background

Groundwater is one of the most important resources for living things. It is the source of drinking water for many people around the world, especially in arid regions, rural area and increasingly in urban and suburban environments (Fetter, 2018). Groundwater is the highest source of freshwater, approximately half of the earth's population used for industrial, irrigation and domestic need. This groundwater occurs in geological formation (Fetter, 2014).

Most of the Ethiopian land mass is covered with volcanic rocks forming spectacular interconnected highlands and rift basins. According to (Tenalem Ayenew et al., 2008) he gives the explanation about the difficult reliefs of Ethiopia challenges but the physiographic of Ethiopia divided his simple classification into five topographic features these are the western highlands, western lowlands, eastern highlands, eastern lowlands, and the main Ethiopian rift valley.

This research investigates groundwater resources evaluation at the upper Jemma catchment in North Shewa, Amhara region, central Ethiopia. The upper Jemma catchment is located in the western highlands of Ethiopia. This catchment is an aquifer system to providing water supply to different towns like; Debre-Birhan, Dinbaro, Gudo-Beret, Tarmaber, Mezezo, Sela-Dingay, Sasit, Mehal-Meda, Molale, and other smaller towns and also for different rural communities found in the catchment.

Any development is related either directly or indirectly with groundwater utilization. Due to this dependency on water unavailability and scarcity will result in retarded economic development, which in turn leads to the deterioration of human life. Scarcity in water is the reflectance of rainfall shortage for both surface and groundwater accumulation.

Many countries like Ethiopia which are affected by recurrent drought, evaluation of water resources for appropriate utilization of both surface and groundwater should be basic and primary issue to bring significant socioeconomic development. Integrated development approach is essential to a given country. Among many other activities, irrigation is the one, which is the most effective practice in highly developed countries, both surface and groundwater important role in such activities. In an area where surface water is not available groundwater is the second alternative for irrigation purpose if the demand for irrigation and groundwater potential is promising without significant negative environmental effect.

1.2. Statement of the Problem

The groundwater resource of study area is not studied in detail quantitatively and qualitatively. But now a days, demand on the water resources for domestic, agriculture and industry is increasing with living standard. Upper Jemma catchment is one of the places with shortage of water. In the area, the number of population increases from time to time. Population growth and expansion of towns such as Mehal-Meda, Molale, and Debrebirhan may require huge amount of water resources in the future. As a result, the groundwater recharge, hydrogeology and management should be known. The present study (Groundwater resource evaluation of upper Jemma catchment) evaluates and characterizes the groundwater resource of the area. To address the water for the community near their homes.

1.3. Objectives of the Study

1.3.1. General objective

The general objective of this research is to evaluate the groundwater resource of the upper Jemma River Catchment in Blue Nile basin.

1.3.2. Specific objectives

The specific objectives of this research are to:

- ✓ Estimate the groundwater recharge of the catchment.
- ✓ Characterize the physicochemical nature of the groundwater using in situ water quality (EC, PH, T, and TDS) measurements.
- ✓ Characterize the aquifer potential based on their hydraulic properties.
- ✓ Identify the recharge and discharge areas.

1.4. Methodology and Materials

1.4.1. Methodology

Different methods and approaches have been followed at the different stages of the research (pre-field, field work and post fields) moreover, different materials were used. Previous works were reviewed about the study area and surrounding area about geological, hydro geological, geophysical and well completion report including geological and hydro geological field survey during field work and in-situ physicochemical measurement from springs, streams, hand dug wells, shallow and deep wells. As indicated above the research work was done in three phases: Pre-field/desk work (data collection), Field work and Post field work as presented below.

1.4.1.1. Pre-fieldwork/ Office work

During this phase different works were executed before going to the field like secondary data collection and organization from different governmental and private institutions. Some of the tasks are presented below:

- ✓ The watershed boundaries of the catchment were delineated.
- ✓ Hydro meteorological data within and near the study area were collected from metrological agency Ethiopian (MAE).
- ✓ Geological map, hydro geological map, and hydrochemical map were collected from geological survey of Ethiopia (GSE).

The major activities were done at home/office by collecting relevant data and reviewing previous works done within the area and outside of the catchment with similar methods to the current study (published and unpublished reports). Field equipments were prepared like, GPS, EC-meter PH-meter and other materials were helpful during field work. The data sources include thesis, research reports, journal articles and consultancy reports. Well completion reports, hydrogeological loges and pump test data were collected from different organization.

1.4.1.2. Field work

During the field work original / primary data were collected and measured the pH, EC, TDS, and Temperature of the water in situ, measured GPS reading of boreholes, shallow wells, hand dug wells, surface waters and springs were recorded. Geomorphologic setting, geological units, hydro geological features, land use land covers, surface water divide and location of recharge and discharge of the area were properly observed and identified. Additionally, perennial and intermittent rivers and springs were investigated by different techniques. .

1.4.1.3. Post field work

Post field work was the main phase of the research work it includes data organization, processing, analyzing, preparation and interpretation of data collected from different sources. Post field work is mainly focused on the analysis, compilation and interpretation in the course of preparation of the final thesis. Several maps were produced using different soft-wares. Topographic and drainage maps were prepared using digital elevation model (DEM) and Arc GIS software. Moreover, maps like pH, EC, TDS, temperature were produced. After processing, analyzing and interpreting these different data of the catchment the groundwater potential of the area were evaluated and finally the thesis was compiled.

1.4.2. Materials

To complete this study different materials and instruments are used. These materials and instruments are required and used during the field work and post/after field work. These are Electrical conductivity meter were applied to test the conductivity and salinity of groundwater, pH-meter and non-corrosive plastic bottles to collect and keep water samples from spring, hand dug well, shallow well and deep well for laboratory analysis. Geographical positioning system (GPS) is used for recording absolute location of water points, Deep meter used to measure the water level in different deep wells, Topographic map or geological map, digital camera to take different photographs, Satellite image or aerial photo, bag or sample container collect samples, cell phone for communication, wearing equipments, computer to write the thesis and compile the research using different software like Arc GIS.

1.5. Significance of the Study

Even though Ethiopia is thought to have large amount of fresh groundwater resources Ethiopia is one of the lowest water supply and sanitation coverage levels in the world. Therefore characterizing and understanding the aquifers and locating the groundwater resource potential of the area is very essential. The aim this research is too aware the recharge and the discharge amount to the users to effectively manage the groundwater without affecting the ecosystem of the area. After evaluating the potential of the area it will help to protect the groundwater from pollutant like chemicals, different animals by constructing barrier for flooding and fence for animals. To increase the working hour for many rural community by reducing time of searching drinking water in the dry season enormous time cost of walking and queuing. Moreover, it can be used as a baseline input for the coming researchers in this area for related study.

1.6. Literature Review, Previous Studies and Research Gaps

Generally the upper Jemma catchment have limited and insufficient references. Mostly my study area has been poorly studied especially in the northern parts of the study area; however the southern parts of the study area studied by various authors and researchers around Debrebirhan on Beressa catchment. Some of the works conducted in and around the area are described below.

Imran Ahmad et al. (2020). The article explains on the title of “GIS and fuzzy logic techniques-based demarcation of groundwater potential zones: a case study from Jemma River basin, Ethiopia”. The author explains Ethiopia is the lowest water supply in the world. In some part of Ethiopia, people travels take two to three hours and water carried in 50 pound jerry-cans and makes three to five round trips to fetch unclean water from the river and springs per day.

Nigussie Kebede (2005). ``Water resources potential evaluation of Beressa river catchment, in north showa, amhara region``. To emphasis the ground water resource evaluation and aquifer characterization in the Ethiopian upland plateau adjoining of the western escarpment of the rift valley. This study area locates within Jemma river basin which is the main tributary of Blue Nile River.

Yonas Mulugeta (2009). ``Hydro geological investigation of Chacha catchment a volcanic aquifer system, central Ethiopia``. His studies focus on hydro geological investigation and groundwater resources consideration for sustainable improvement by forecast and conclusion building with governmental and nongovernmental organizations (NGO).

Melkamu Adimaw (2019). ``Groundwater Flow Dynamics in the Eastern Upper Jemma River Catchment, Blue Nile Basin, Ethiopia``. The aim of the researcher was to characterizing the groundwater flow dynamics and differentiates the main aquifer systems of the catchment.

Mekdes Nigatie (2012). "Characterization of Aquifers and Hydrochemistry in Volcanic Terrain of Central Ethiopia'' it focus on a systematical characterization of different aquifer system and their water chemistry in middle Ethiopia particularly in upper awash, Jemma, Mugher and Guder river catchments including Addis Ababa city.

Tilahu Azagegn (2008). studies his MSc thesis on the title of "Hydrogeochemical characterization of aquifer systems in Upper Awash and adjacent Abay Plateau using geochemical modeling and isotope hydrology" to give emphasis to geochemical theoretical model resting on the hydrological performance estimation of shallow and deep aquifer systems and the natural history of inter-basin groundwater movement connecting upper awash river basin and adjacent Abay plateau.

Zekarias Ashine (2020). Research title "The comparative study between South-Jemma and Kesem catchment". On his MSc thesis in Addis Ababa University on the objective of recharge and hydrochemistry in the study area he understands the hydro chemical variability the region. Finally he conclude that sodium and calcium are the dominant cat-ions in the area and sodium increase in downward stream in both catchments but calcium concentration decrease downstream of Kesem but not decrease in south-Jemma catchment. Bicarbonates are the dominant anion it shows increment towards the downstream in both catchments.

According to Yasir Salih Ahmed Ali, (2014) on his PhD Dissertation on the title “the impact of soil erosion in the upper blue Nile on downstream reservoir sedimentation” he explain the comparison between the areas and rates of change of the land cover between from 1973 to 2000. In 1973, Jemma sub-basin was dominated by wooded grassland 45.8% but know highly decrease.

According to Jiri Sima et al., (2009) groundwater of the basin has good qualty used for drinking and irrigation during dry time for securink food. In the plateau area the groundwater potential resources can supplay more than ten million people with good quality drinking water. Depend on the study eleven potential eater well fields were located in the area. The well fields consisting of about tewnty wells can provide about 150l/s each can be uses in adequate quality and quantity.

CHAPTER TWO

OVERVIEW OF THE STUDY AREA

2.1. Location and Accessibility of the Area

2.1.1. Location of the study area

The study area is located in central highland of Ethiopia; at the north western margin of main Ethiopian rift particularly in Amhara National Regional State, North Shewa Administrative Zone and part of Jemma sub basin. The administrative zone town is Debre-Birhan town is located 130 km distance from Addis Ababa which is the capital city of Ethiopia and Molale town is located 124 km distance from Debre-Birhan town towards north direction. The study area part of Wer-Illu (NC-37-7) and Debre-Birhan (NC-37-11) map sheets and the total surface area coverage is 3250 sq.km. The study area is delineated based on water divide located in upper Jemma catchment. The minimum elevation in the study area is 1556m and the maximum elevation 3708 meter above mean sea level. The study area is approximately bounded between 530246 – 588718 meter easting and 1056692 – 1151573 meter northing.

2.1.2. Accessibility of the Area

The study area is accessed by the major asphalt road on the way from Addis Ababa through Debre-Birhan to Tarmaber 180 km asphalt on the way of Desse road and from Tarmaber to Molale 74 km all weathered gravel road and extend to Astoya to Kolo-Margefia and the other side Mehal-Meda. The total distance from Addis Ababa to Molale (mama midir district town) 254 km. There are also a number of dry weather roads and foot paths in the area. The location map of the study area is displayed beneath this and looks figure 1.

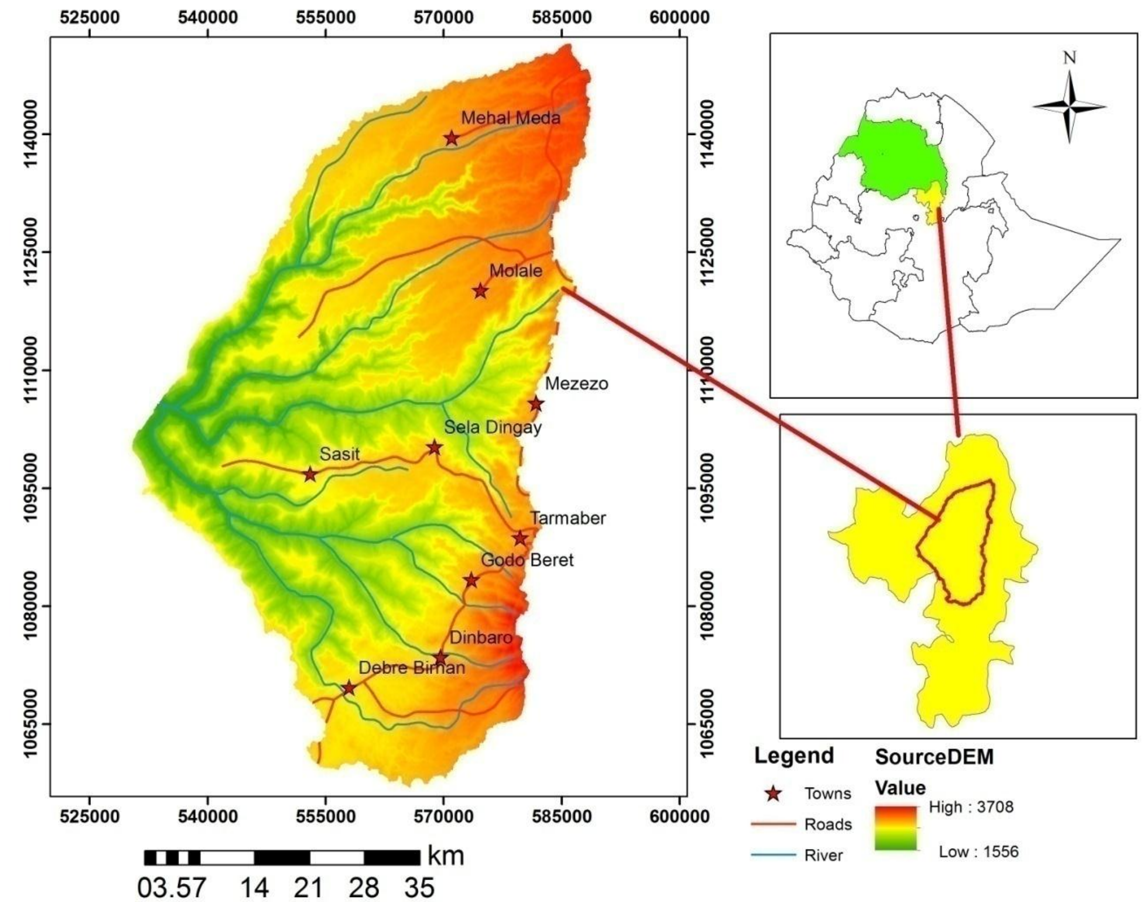

Figure 2. 1: location Map of upper Jemma catchment

2.2. Physiography and Drainage

2.2.1. Physiographic division

Physiography of the` study area include plateau, gorges and mountains. The plateau area forming flat lying topography covers Molale, Mehal-Meda, Wegere, Astoya, Seladingay and Debrebirhan area. This plateau area formed by different flood lava flows of the tertiary volcanic and its surface is mostly covered by quaternary elluvial sediments (regolith) located in central parts. The second part deep gorges, valleys and steep slops are formed by main rivers and streams erosion which located central and western parts the catchment. The third part highly elevated hills, ridges, steep slope, rugged topographic which are located eastern parts of the catchment. The topographic elevation of the study area ranges from the lowest

1556 m.a.s.l near the outlet to the highest elevation above 3708 m.a.s.l. The physiographic natures of the study area look the figure 2.2 below. The eastern part of the area formed by NE-SW oriented elevated land. These elevated highlands are surface water divide of Abay and awash basin which is a number of streams emerge from these area.

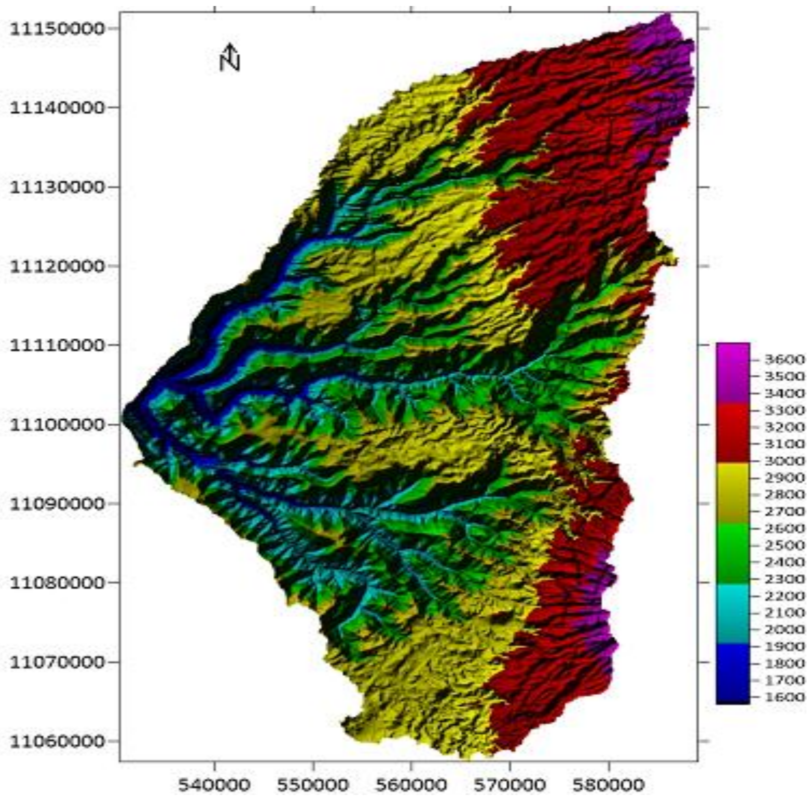

Figure 2.2: Physiography map the study area

2.2.2. Drainage pattern and density

The major rivers in the study area are Mofer-Wuha, Awel, Beressa, and Wizer & Shay River (around Mehal-Meda). The upper Jemma Rivers and most of the tributaries are perennial. These rivers and its tributaries are drained from the highland area to the lowland area that is from eastern, northeastern and southeastern parts of the catchment to the western direction of the outlet and link toward the Jemma River through steep gorges. The upper Jemma catchment is characterized by different drainage system. Rivers and streams are parallel to sub-parallel and dendritic to sub-dendritic drainage pattern which follow the fractures and weak zones (Serwit Amene and Tamrat Mojo 1995). All rivers and streams in the study area join Jemma River which is one of the Maine tributary of Abay basin. These rivers are flooded during the rainy seasons but reduced their thickness in the dry season (Serwit Amene and Tamrat Mojo 1995). The perennial streams emerge from the side of ridges and the top of the mountains and join to main rivers.

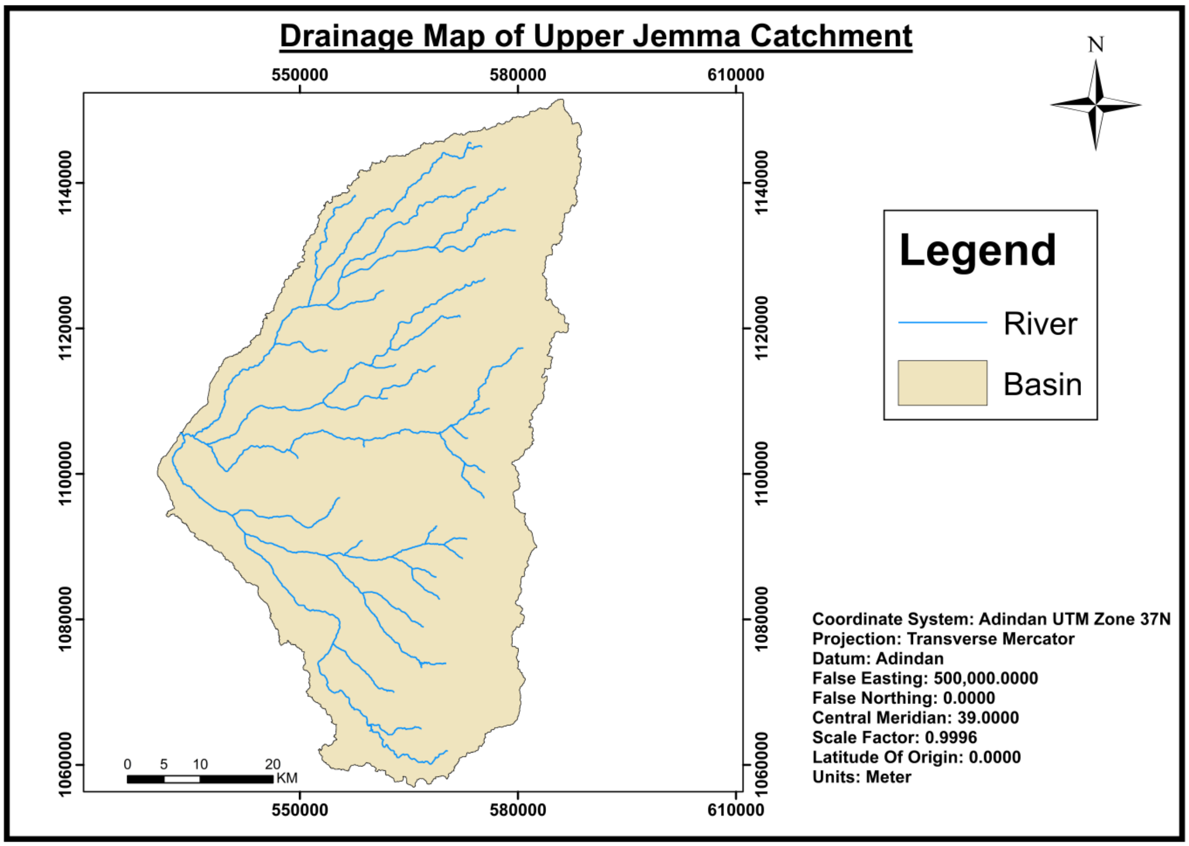

Figure 2.3 Drainage Map of Upper Jemma Catchment

2.3. Climate and vegetation

2.3.1. Climate

The climate condition of Ethiopia is highly influenced by altitude this indicated that rainfall is directly proportional with altitude but temperature inversely proportional with altitude. The climate of the area divided in to two dry and wet seasons. The climate of the study area varies from place to place as a result of the large topographic difference. Generally the climate regions of the study area include Alpine (Kur), Temperate (Dega), Subtropical (Weynadega) and Tropical (Kola). The elevated and highland areas wet and cold climate which has low temperature and the temperature reach below $0^{o}C$ but in the lowland and gorge area is hot climate. In the study area has two main rainy seasons; the first one is main rainy season it extends from June to September, locally called "Kiremt"/winter have high precipitation. The second one is small rainy season is called "Belg" the rains of spring to the study area have moderate precipitation it extend between February to the end of April. The annual rain fall of the area is 1114.3mm/year. The rest dry months locally called "Bega"/summer it extends from October to February is hot and dry climate (GSE, 2010). The calculated mean annual temperature is 13.72 ^{0}C from 33 years meteorological analysis.

2.3.2. Vegetation

Vegetation of the study area varies with elevation and climate. The dominant vegetation types in the study areas are eucalyptus tree (artificial forest) common in settlement areas and highland area around water dived zone of upper Jemma catchment and upper awash basin. The other common tree in the highland area is junipers locally called "Tid" and podocarpus trees like acacia trees. In addition to these small shrubs, grass land, thorn bushes and many undifferentiated ever green plants. Menz Guwassa Park is the unique grass land in the area on the way of Meleya to Mehal-Meda both side of the road.

2.4. Land Use and Land Cover

The land use land cover of upper Jemma catchment depends on the climate, landscape and agricultural activities. Most of the land use in the area is covered by moderately to highly cultivated land, artificial protected forest, sparsely vegetated tree, grass-land, bush lands, settlement and urban. The eastern parts of mountainous and highland areas are covered by eucalyptus trees, shrubs, bush and undifferentiated vegetation. The forest area coverage decreases from time to time due to population increase and consume the forest for burning wood, cultivation and for shelter purpose. The agricultural land covers in gentle slope area and flat land. The expansion of cultivated land at the expense of natural vegetation is significantly affecting the natural environment and cause of land degradation which increase soil erosion. The main crops cultivated in the Jemma Sub-Basin are wheat, barley, teff, maize, and sorghum (Gebrekidan Worku et.al, 2019). In the study area also Wheat, barley, beans, teff, peas, and sorgam are common crops. The study area is covered by nine land use land cover classes which area closed shrub land, cropland/ natural vegetation, cropland, grass-land; mixed forest, open shrub land, permanent wet land, savanna and woody savanna. Relatively Cropland covers most part of the watershed area. Land cover change, associated with the intensification of agriculture, cattle rising and urbanization have power to influence on the hydrological processes in small watersheds and at a regional level (Legesse, et al. 2010).

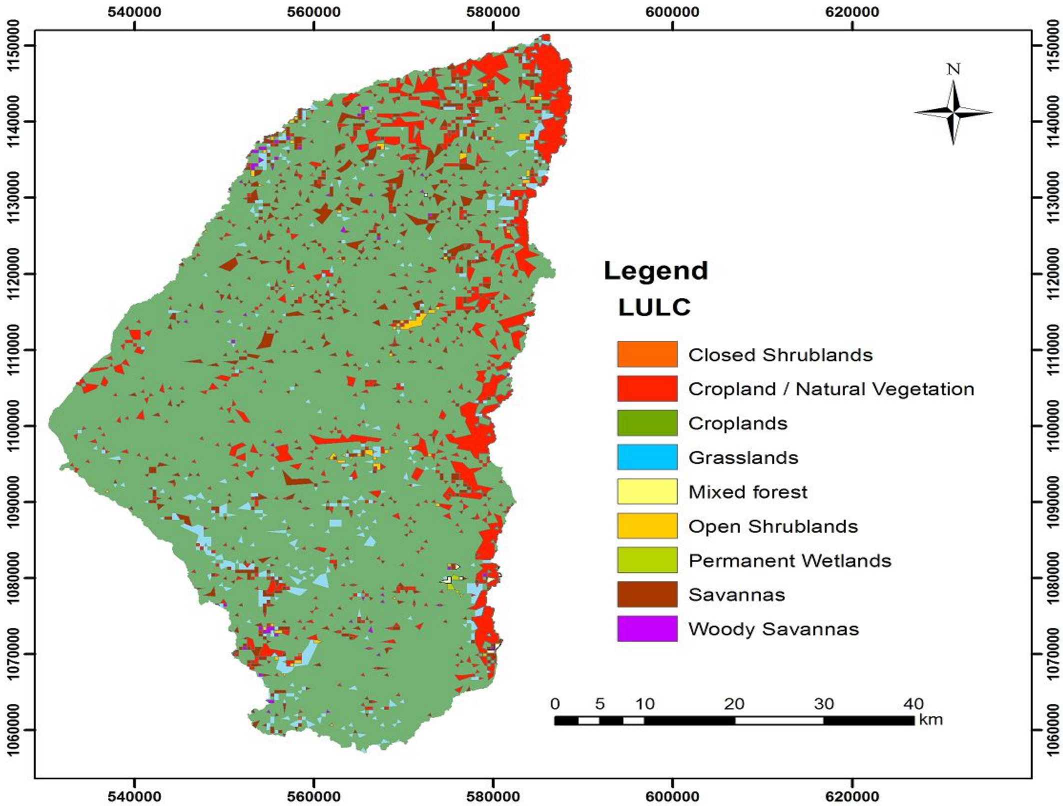

Figure 2. 4: land use land cover map of upper Jemma catchment

2.5. Soil

The nature of soil affects the relationship between runoff and infiltration rate which control the degree of permeability. The characteristics of soil depend on parent material, land escape, agricultural activities and land use practice (Nigussie Kebede, 2005). Geology and climate is the main component soil formation. According to the soil map, the upper Jemma catchment is covered by five soil types. These are Eutric Cambisols, Lithic Liptosois, Eutric Liptosols, Eutric Vertisols and Vertic Cambisols.

Eutric Cambisols: is accumulation of humus, soluble slat and clay and characterized by lack of horizon development good for agriculture. It is mainly found northern part and small portion in the eastern parts of the study area.

Lithic Liptosois: this soil type has shallow depth, overlay country rock, occurs in steep slope area, young in age and exposed to soil erosion (Development study associates and showel consult international 2005 as cited in Melkamu Adimaw 2019). It is the dominant soil type in the study area and mainly occurred in western, central and eastern part the study area.

Eutric Liptosols: is mainly occurred eastern part of the study area and the second largest soil type. It is common in eroding parts the area and found on top of hard rocks.

Eutric Vertisols: the soil formed in flat land and has deep depth. It is hard during dry time and sticky when get water. This soil type is found in the central and northern parts of the study area.

Vertic Cambisols: This soil type is found in the southern part of the study area. Vertic cambisols are shallow to very deep, clay loam to sandy loam formed from variable volcanic and sedimentary rocks (Development study associates and showel consult international 2005 as cited in Melkamu Adimaw 2019). The most productive soil on earth and intensively used for agriculture.

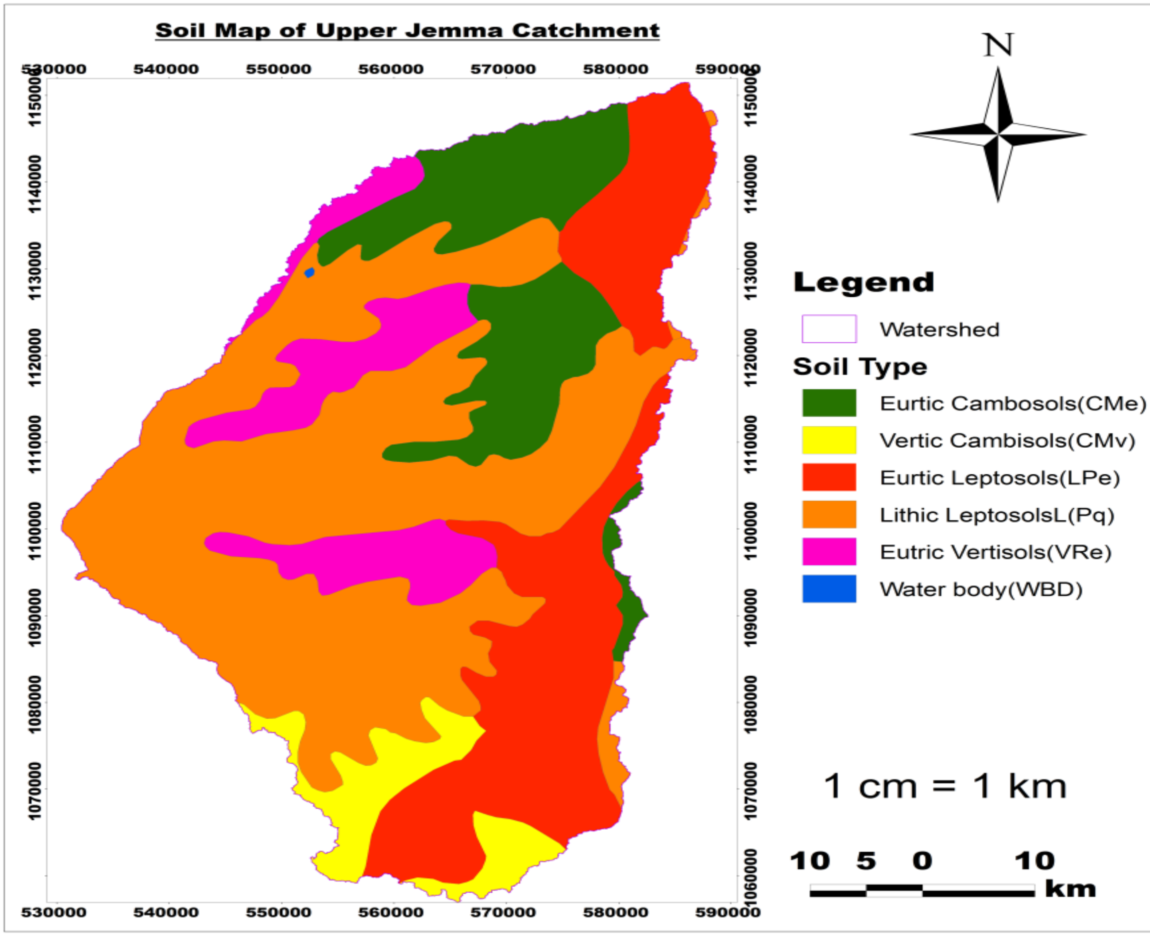

Figure 2. 5: FAO Soil map of upper Jemma river catchment

2.6. Population

Most Ethiopian people live in rural areas and form small agricultural plots. These Crop productions largely depend on rainfall. Most Ethiopians are subsistence farmers whose use of old farming techniques makes their land vulnerable to the effects of recurrent drought (Shitaye et al., 2007). According to the 2007 Ethiopian census, the total population of Jemma Sub-Basin was 1,605,876, and the growth rate of the population was 1.7 and average population density was 106person/km^2 (Gebrekidan Worku 2018). Now a day the population increase rapidly. The population number increase in the area it needs more water used for different activities. Population growth aggravates land degradation because a very high pressure on the land resources. In the study areas the dominant ethnic group is Amhara who speak Amharic. These populations are unevenly distributed and denser in the highlands than the lowlands. Most of rural householders in the basin agriculture (animal husbandry and crop production) are the main socio-economic activity to generate their means of income. Some of the inhabitants in the towns are governmental employment and the rest who engage themselves in small trade businesses. When we see the settlement conditions in the catchment area densely populated in urban residential areas like Debrebirhan, Molale, Mehal-Meda, Seladingay and other big villages but sparsely populated in most rural peasant association. Cultivation has covered most part of the area except some areas left as grazing land and steep slopes.

CHAPTER THREE

REGIONAL AND STUDY AREA GEOLOGY

3.1. Regional Geology

The geological units in Ethiopia fall into the following three main groups; the Precambrian basement, late Paleozoic to early tertiary sediments and the Cenozoic volcanic and associated sedimentary rocks (Mengesha Tefera et al., 1996). The oldest rock inside the country is Precambrian basement. The exposure is limited to marginal parts of the state like in the northern (Tigray), the southern (Sidamo and Bale) and the western (Wellega and Gojam). The different rocks produced the outcome of complex tectonic and metamorphic history during Proterozoic early Paleozoic times. The age of the basement rocks is considered to be Neoproterozoic, ranging from 850 to 550 Ma (Geni et al., 2009). It is either overlain by Mesozoic sedimentary succession, Paleozoic sediments, and Cenozoic volcanic, quaternary sediments or directly exposed to the surface. Structurally complex area and rock types such as metamorphic, igneous, and sedimentary rocks are crucial to understanding the geologic setting of the catchment (Mengesha Tefera et al., 1996).

The geological phenomenon occurred during Mesozoic Era accumulation and deposition of multi-layer sedimentary strata formed by transgression and regression of sea. Mesozoic sedimentary rocks are uncovered in the Blue Nile canyon and the gorges of its major tributaries. The succession is about 1200 m thick. It includes from the bottom to the top lower sandstone (Adigrat sandstone), the lower muddy sandstone (Gohatsion formation), Antalo limestone, the upper muddy sandstone (Mugger sandstone and gypsum) and the upper sandstone (Debrelibanos sandstone) exposed along the river gorge within the country. Paleozoic sedimentary rocks within the Blue Nile Basin might be due to uplift during the Paleozoic Era resulting in extensive erosion throughout this area (Geni et al., 2009).

After sedimentary event occurred volcano tectonic processes during Cenozoic Era. These rocks are from oldest to youngest, Ashangi, Aiba, Alajae and Tarmaber Megezez. Flood basalt formed the present geomorphologic configuration of Ethiopian highlands and plateaus.

Volcanic rocks cover the majority of Ethiopia's landmass, forming spectacular interconnected highlands and rift basins (Geni et al., 2009).

The regional geologic setting of upper Jemma catchments are situated to different rock units having different age of formation. The geology of the study area is represented by two litho-stratigraphic units. These are Mesozoic sediments and Cenozoic volcanic rocks with quaternary superficial deposits. Igneous rocks are an important source of groundwater in some regions. Extrusive igneous rocks (those that have erupted and formed on the land surface) have a greater capacity for water transmission and storage than intrusive igneous rocks (those that formed and cooled beneath the earth’s surface). Extrusive and intrusive igneous rocks can generally be distinguished by their texture and mineral composition. Extrusive igneous rocks are generally fined grained and have fewer distinguishable minerals than intrusive igneous rocks. Extrusive rocks are also known as volcanic rocks. They have erupted to the surface either through volcanic or fissures (Delleur et al., 1999).

3.2. Lithology

The description of lithological units were taken from individual geological reports and maps provided by several GSE mapping groups who carried out detailed (1:50,000) geological mapping in large area and including the study area over the last years. The Geology and litho-logy of various units was simplified to use the information for an interpretation of the hydro geological characteristics of the various geological units with the final aim to express them of a hydrological map and identify their hydro geological characteristics and ground water resources (Jiri Sima, 2009).

3.2.1. Paleozoic sedimentary Rocks

The Paleozoic sedimentary rocks are the Abay sandstone unit in Abay gorge, the sandstone top part alternates with siltstone, shale and mudstone. It is exposed at the confluence of the Jemma and Abay rivers in the western side of the study area below the altitude of 1,160 m above sea level (Jiri Sima et al., 2009).

3.2.2. Mesozoic Sedimentary rocks

The Mesozoic sedimentary rocks are uncovered in the highly dissected lowland at the western tip of the study area. The Mesozoic sedimentary rocks form cliffs in the lower reaches of rivers in the deep valleys. Based on the mineral composition and texture, these rocks are divided into five map-able lithological units, namely lower sandstone (Adigrat sandstone), gypsum, limestone, Mugger mudstone and upper sandstone (Debrelibanos sandstone) (Jiri Sima , 2009). Lower sandstone exposed at the basin of Jemma and Wonchit river valleys. It is mainly exposed lower valley of Jemma and its tributary (Derek wenz, Bersena, Chira, Chacha, Beressa, Adabay and Mofer-Wuha) in the western tip of the study area. It forms steep cliffs and is conformably overlain by Gohatsion formation. The lower sandstone has a maximum thickness of 241m in the area exhibiting a general trend of thickening towards the west. Gypsum exhibits different colors in the area. Limestone outcrops are mainly observed on the banks of the river valley. It forms cliffs and at a times gentle ridges. The maximum exposed thickness is 529 m in the shenkora cheka section. Mugher mudstone is forms gentle slopes in the lower valleys of the Jemma River and is only exposed in the northwestern part of the Inewari sub-sheet. The thickness of the mudstone is about 149 m. Upper sandstone unit exposed in the lower valleys of Jemma, Derek-wenz, Bersena, Chacha, Beressa, Adabay and Mofer-Wuha is found the Inewari and Sasit sub-sheets. It forms steep cliffs and stream cut exposures with a few road cuts. The maximum thickness of this unit is 433 m. The sandstone is medium grained with light red on fresh surface and reddish brown, yellowish brown, and pink brown upon weathering.

3.2.3. Cenozoic Volcanic Rocks

According to (Daniel Meshesha et al., 2010) Cenozoic volcanic rocks are grouped in to Tertiary and Quaternary volcanic rocks. The Cenozoic is mainly characterized by wide-ranging faulting accompanied by extensive volcanic movement and uplift. The outpouring of vast quantities of the basaltic lava accompanied by the eruption of large amounts ash resulted in a basaltic plateau often called trap series basalts.

The tertiary volcanic rocks are the main constituent of the Ethiopian plateau and covers large area; mostly exposed along the plateau (Debre-Birhan, Saya-Debir, Tarmaber, Sendafa, Mehal-Meda, Wenoda, Molale, Wegere, Sheno Weberi) and the NE-SW trending rift margin (Debresina, Ankober, Aliyu-amba, and Megezez). The rocks are mainly consisting of a thick succession of basalts and ignimbrites with sporadically distributed trachyte, rhyolite and scoria cones. (Daniel Meshesha et al., 2010).

Cenozoic volcanic in Northwestern Ethiopian plateau was started by eruption of Ashangi basalt during the Eocene- Oligocene and then followed by extrusion of Aiba basalts and Alajae formation during the Oligocene- Miocene. The Ashangi and Aiba pulses consist of dominantly basaltic whereas the Alajae Formation is represented by a bimodal rhyolite (ignimbrite) and basaltic volcanism. The upper Blue Nile basin contains the alkaline basalt and the fragmental materials enclosed by Cenozoic basalts and ashes. The Cenozoic basalt different has variation from place to place in mineralogical composition but in all types of basalt mainly contained olivine and pyroxenes with different amounts plagioclase.

3.2.4. Quaternary volcanic rocks and Quaternary sediments

3.2.4.1. Quaternary volcanic rocks

The quaternary volcanic rocks occupy the MER and the volcanic comprise fissural to central and vesicular to scoracious basaltic rock, ignimbrite and some trachyte. The quaternary lacustrine superficial deposits and fluvial-colluvial sediments covers the river channel and the basalt intermittently (Geni et al., 200). The ignimbrite is compact, hard and lithified rock, mostly found overlying the plateau basalt. This ignimbrite is gray to light gray, massive, mostly containing rock fragments of trachyte obsidian, tuffs, and scoria. The age of these acidic volcanic can also be estimated geomorphologic-ally. They form a slopping topography filling older relief formed during the quaternary. The ignimbrite thickness varies from 20 to 40 m. the younger basalt flow is restricted to the eastern part of the basin. It is directly overlain by Ash-flow tuffs but in extreme eastern areas it is overlain by ignimbrite. The basalt is weathered and developed characteristic of spheroidal weathering. Another sequence of ignimbrite is above areas lying east of Molale and around Gift Mariyam. There are more than three layers of such ignimbrite, intercalated with loose ash and basal lahars. The ignimbrite overlies the upper basalt but in the absence of the basalt flow it directly overlies the older ignimbrite. Ash-flow tuffs are restricted to the higher elevation or rift shoulders in the western rift areas exposed in the north, northeastern, and eastern parts of the basin. The ash-flow tuffs are gray to light gray, fine to medium grained and in places glassy rock, unconformable to the underlying rock. The ash-flow tuffs become softer and loose when weathered. When the rock is fresh it is smooth and shows sharp edges. It often shows polygonal fractures and also crude horizontal layering. It is 15 m thick or more and marks the top surface of the highland of the map area.

3.2.4.2. Quaternary sediments

The general distribution of the quaternary deposits in the study area is localized to a gentle undulating plateau, slopes and along rivers in deep gorges. Quaternary lacustrine and fluvio-colluvial sediments and superficial deposits occur intermittently covering the basalt and filling river channels. Quaternary deposit covers large area with variable thickness from place to place. The alluvium along the major rivers like the Jemma and Wonchit is reworked and seems less compacted and relatively more porous. In the tributaries of the main rivers sediments consist of pebbles and cobbles devoid of smaller size materials. The elluvial and colluvial sediments (soil) cover large areas of plain. This unit is represented by black to reddish brown silty to clay fertile soil. It is highly ploughed by the local people it is formed by the weathering of the bed rocks, especially basalt and rhyolite (Jiri Sima et al., 2009).

3.3. Local Geology successions

According to (Serwit Amene and Tamrat Mojo, 1995) the geology of Jemma river valley, which is located in the Eastern part of the central highland of Ethiopia, is characterized by sharp escarpments, cut by shallow and deep gullies and stream channels. According to the previous works in the study area the description of geological reports and maps provided by several mapping groups by GSE in 2010.

The upper Jemma catchments are part of the central Ethiopian in northwestern plateau. The geology of investigated area was observed during field work along the accessible traverse during the field and reviews the previous geological maps. In this investigated area have different litho-stratigraphic units are found in different setup dominantly covered by volcanic rocks, sedimentary rock and recent sediments are common. From volcanic rocks (Kesem basalt, Seladingay-Debrebirhan Gorgo Ignimbrite, Tarmaber-Megezez basalt, Molale Ignimbrite)

3.3.1. Upper sandstone

Upper sandstone is exposed at the lower deep river gorge of Mofer-Wuha and Beressa. The unit has unconformable contact overlying by Ashangi basalt. The sandstone is white, pink, light gray fine to medium to coarse grain size referred to as amabradom/ debrelibanos SST. The upper sandstone is located in the western side of the upper Jemma catchment on the gorge main rivers. The sandstone is laminated to thinly bedded in the lower part and massive at the top. It also shows cross-bedding in the lower part.

3.3.2. Lower Basalt

The lower basalt is Ashangi basalt it covers small portion of the upper Jemma catchment and located in deep gorges of the Mofer wuha, Retmet, Shay and Beressa rivers in the western part. Lower basalt occurred between upper sandstone and middle basalt. The name Ashangi basalt is lower basalt in general. It is overlain by Alajae basalt and underline by upper sandstone. The unit forms the valley sections in the stream gorges and it is characterized by alternate layers of aphanitic and amygdaloidal basalt. The lower part of the unit is mainly aphanitic basalt, which shows spheroidal weathering in places. The middle part of this lava flow is medium grained, phorphyritic and sometimes amygdaloidal. The top part is dominated by aphanitic basalt. In these sections, it is overlain by pyroclastic rocks of the Alajae sequence. The thin basalt succession of the unit underlies the Aljae basalt. The unit is characteristically strongly weathered, intensely fractured, and friable and rarely vesicular. Thin paleo soils and inter bedding sediments are observed in between lava flows. The unit is highly fractured and jointed.

3.3.3. Middle Basalt

Middle basalt is Kesem basalt or Aljae basalt covers part of the western and central part of the area and exposed on the gorge of Mofer-Wuha and Beressa deep down river valley. It is located between middle basalt and lower trachyte. The Kesem basalt highly fractured sporadically weathered, columnar jointed and dominantly aphanitic to phorphyritic in texture. It is forms cliff structure on the side of the river gorges dark to gray color and fine grain size. The aphanitic Kesem basalt dominantly plagioclase groundmass this plagioclase basalt exposed on the upper part of aphanitic basalt cliff forming. Aphanitic basalt is fine grained, the most abundant, dark gray to black (fresh color) and bluish (weathered color) (Daniel Meshesha et al., 2010). The unit forms relatively low laying topography on the plateau, cliffs in the river gorges on Mofer-Wuha. The contact with the underling Ashangi (lower) basalt is marked by reddish brown pale soil ignimbrite tuff is followed (overlay) by alternate beds of aphanitic and amygdaloidal basalt, which is again followed by ignimbrite.

3.3.4. Lower trachyte

Seladingay-Debrebirhan gorgo Ignimbrite is mainly exposed in Seladingay area it extends in different parts like Debrebirhan, Ankober, and Aliyu-amba. The rock contact underlined by Kesem basalt and over lined by Tarmaber-Megezez basalt. It have medium to coarse grained size texture and it forms gentle to steep cliff structure, highly consolidated and welded tuff, brown gray to light gray color (Daniel Meshesha et al., 2010). It comprises rhyolite, tertiary sediment, aphanitic basalt, tuffaceous sediment, ash and agglomerate. This rocks light gray, brownish gray to gray color (fresh color) and dull/dark gray (weathered color) highly consolidated to welded tuff and bedded with fracture, vertical and columnar joints. It holds rock fragments of rhyolite and basalt ranging up to two centimeter in diameter elongated fibrous glass but the quantity of rock fragments considerably variable from place to place.

Molale ignimbrite covers large area flat gentle plane, including Molale area and Mehal-Meda. This Ignimbrite found in between Alajae (underlying) and Tarmaber-Megezez (overlying) formation. The ignimbrite out crops always interlay-red with basalt and exposed indifferent horizons moderately to strongly stratified. This rock has different thickness and different grain size from fine to coarse grain size with variable colors light-gray, dark-gray and yellowish gray color strongly compacter rock (Solomon Gerra, et al., 2010). The unit fine grained and slightly and moderately weathered. The ignimbrites are phorphyritic with quartz and K-feldspar phenocyrsts with obsidian fragments. The rhyolitic tuff is dominantly black fine to medium grained, columnar jointed with well-developed vertical to inclined joint sets. Olivine phorphyritic basalt is dominantly exposed between Meleya and Molale localities. It forms a hill and discontinuous boulders. The basalt is black with medium to coarse grained. The geology of the area is dominated by tertiary volcanic rock of highland which is characterized by degree of weathering and fracturing and alluvial deposits. Lower trachyte the combination of Seladingay-Debrebirhan gorgo Ignimbrite (Tidg) and Molale Ignimbrite (Tmi)

3.3.5. Tarmaber-Megezez Basalt (Ttb)

The Tarmaber-Megezez basalt exposed Tarmaber, Mezezo, Ankober and parts of highland area and mountain converge. The rocks sharp contacts with underling by Seladingay-Debrebirhan gorgo Ignimbrite and over lined by surface. Tarmaber-Megezez basalt contains fine, medium to coarse grained, dark gray (fresh color) to light/reddish/dark/yellowish brown (weathered color) aphanitic to phorphyritic basalt. It is characterized by different phases of basalt flow separated by reddish pale soil and reddish brown scoracious basalts (0.5-8m) thick (Daniel Meshesha et al., 2010). Columnar basalt was found in Jemma river gorge and characterized by columnar joints on the side of the river and also found in upper part of the area. This columnar basalt commonly found between the sedimentary rocks and vesicular basalt. The formation of vesicular basalt mainly weathered and altered.

Plate 1: columnar joint of Tarmaber basalt

3.3.6. Eluvium Soil (Qel)

The eluvium soil mainly occurrence of on the plateau and escarpment of flat lying and gentle topography. It is the result of the gradual weathering of ignimbrite, basalt and rhyolite. Different rock fragment of basalt, rhyolite and ignimbrite within the eluvium soil. It is silt to clay size light/dark gray to reddish brown fertile soil. It is highly cultivated by the local peoples (Daniel Meshesha et al., 2010). Eluvium soil occurred in southern and central part of the study area on the right side of Seladingay to sasit road.

Superficial deposits are the result of different weathered rocks product like Ignimbrite, rhyolite basalt bedrocks and deposited in flat lying and gentle slopes area. It is good for agricultural activities and groundwater reservoir during rainy seasons. The residual deposits have different grain size from fine to coarse overlaying on the ignimbrite, rhyolite and basalt bed rocks it has dark gray to reddish colors.

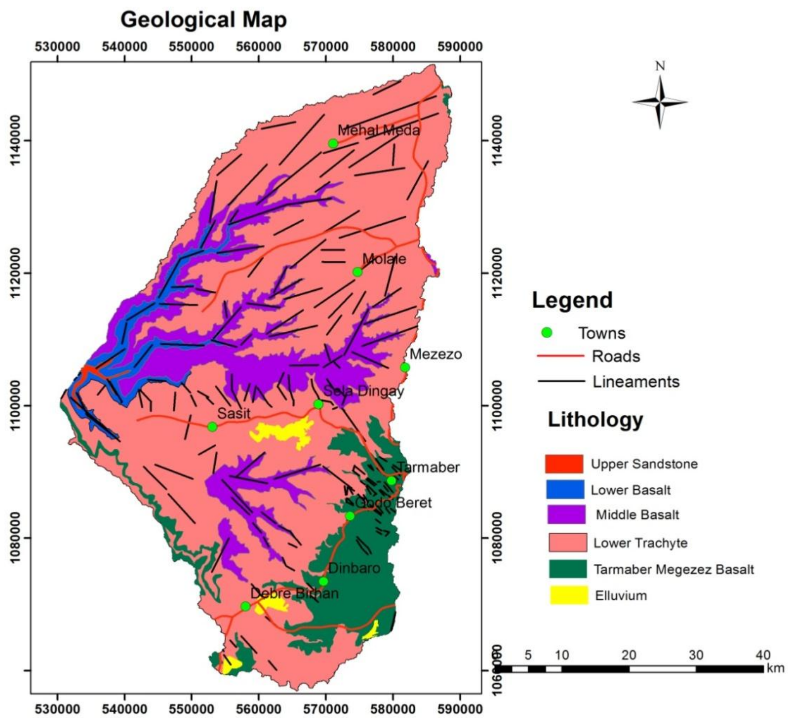

Figure 3.1 Simplified Geological map of the study area (GSE, 2010)

3.4. Structure

The cause for geological structures is deep tectonic activities either regionally or locally which can change the morphology of the earth through time. Aerial photographs studies, satellite image interpretations and filed observations were exposed the faults, lineaments, fractures and joints characterize and observed in the study area. Most of the structures in the study areas are observed around the rivers and streams. Those geological structures are play an important role in controlling groundwater flow paths, occurrence, storage and for groundwater movement like a conduit (high hydraulic conductivity) and also it may cause negative impact on groundwater flow direction as a barrier (low hydraulic conductivity) and also bad effects during constructions of dams and buildings and after finished developmental activities. Some of the structures in the study are fault, lineament, and fracture, joint and bedding

Faults- there are two types of faults; the first one is a normal fault with N-S and NNE-SSW orientation which is part of the upper boundary of the western afar margin. It extends to the northeast (Mezezo) and (Ankober) and continues beyond the study area.

Lineaments- the lineaments in the area are concentrated in the central and northern parts and have a dominant NW-SE orientation and lesser extent E-W and NE-SW. the main rivers and their major tributaries follow the traces of these lineaments and extend up to 10-15 km.

Fractures- the ignimbrite and rhyolite are affected by irregular fracture with varying trends. The fractures are seldom filled by soil.

Joints- the joints are dominantly columnar with some irregular and tectonically induced types of the vertical and horizontal ones. The columnar joints are five to six faced and closely spaced with typical arrangement and reach up to 80 m in height forming very steep cliffs.

Planar bedding and lamination- planar beddings and laminations are found mainly in Mesozoic sandstone and tertiary sediments. Some cross beddings are also observed in the upper tertiary sediment.

CHAPTER FOUR

HYDROMETEOROLOGY

4.1. General Background

Hydrometeorology is the most important discipline which deals with the movement of water and water vapor in the atmosphere which associations both hydrology and meteorology (Raghunath, 2006). The hydro meteorological information is important to establish the water balance of the basin for increasing and managing its water resources**.** Important hydro-meteorological elements are the precipitation, solar radiation, humidity, evaporation, evapo-transpiration, soil moisture, air temperature, water levels (groundwater and surface water level) and stream discharge (Raghunath, 1987).

4.2. Hydro-metrological parameters

There are nine metrological stations within and around the study area but the meteorological stations are unevenly distributed in the basin. Metrological data records from 1985 - 2018 have been used supplementing for the missing and non-continuous records. Among the nine stations Yegem and Zemero station out of the basin adjacent to it but the rest seven stations are found within the catchment. From those nine stations Debrebirhan and Mehal-Meda metrological stations are class-A station. First class or class-A stations are measured all parameter such as rainfall, temperature, wind speed, relative humidity and sunshine hours. Molale and Gudoberet stations are measured the rainfall and temperature but the rest stations are measured only rainfall. The metrological data collected from different stations include rainfall, temperature, relative humidity, wind speed and duration of sun shine.

Table 4.1 metrological station within and around the catchment

Stations	Year		Coordinate		Ppt	T	RH	SHr	WS	
	From	To	Longitude	Latitude						
Debrebirhan	1985	2018	39.5	9.633333	*	*	*	*	*	1*
Mehal-Meda	1985	2018	39.66025	10.3146	*	*	*	*	*	1*
Molale	2010	2018	39.66139	10.12142	*	*				2*
Gudoberet	1987	2018	39.66667	9.75	*	*				2*
Debresina	1985	2019	39.75	9.866667	*					3*
Yegem	2003	2019	39.8	10.26667	*					3*
Wegere	2007	2018	39.55	10.15	*					3*
Zemero	1987	2016	39.45542	10.22994	*					3*
Seladingay	2006	2018	39.61667	9.95	*					3*

1* Records the precipitation, temperature, relative humidity, sunshine hour and wind speed

2* Records the precipitation and temperature, 3* Records to precipitation only

4.3. Precipitation Data Analysis

The term ‘precipitation’ covers all forms of drop water being released by the atmosphere, including snow, hail, sleet and rainfall to reach the earth surface (Davie, 2008). In the study area rainfall is the main form precipitation in the upper Jemma catchments. It is the output or result of hydrologic process through an amalgamation/combination of circumstances when water vapor changes back to the liquid state through the process of condensation to form clouds and change in to rainfall (Meseret Adeko, 2005). Precipitation in the study area is controlled mainly by the direction of the moisture bearing wind, elevation, topography and temperature. The study area is found in the tropical regions of central Ethiopian western highland plateau. This investigated area catchment is the eastern part of the Blue Nile Basin (BNB) which has a bimodal rainfall regime with the short rainy season (belg) lasting from February to May and the long rainy season (kirmt) lasting from June to September (Roth, et al. 2018). The water resource of the Jemma sub-basin is also highly dependent on rainfall. This means the difference in rainfall may trigger wonderful impacts on the water resource base and agricultural production of the sub-basin (Gebrekidan Worku et al., 2019).

4.3.1. Rainfall patterns of the study area

Rainfall/ precipitation measurement on station is a point observation and may not be used as a representative value for the entire area under consideration (basin or catchment) (Tenalem Ayenew and Tamiru Alemayehu, 2001). Precipitation is all types of moisture reaching to earth surface from the atmosphere used in hydrology include sleet, hail, Snow and rain derived from atmospheric vapors. Table 4.2 long terms mean monthly rainfall (mm) of the nine stations in and around the basin

Table 4.2 Mean monthly distribution of RF (mm) within and around the study area

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Debrebrhan	10.59	17.92	45.54	54.35	42.24	54.57	307.58	278.67	84.43	18.70	5.95	4.31	924.84
Mehal Meda	15.24	24.15	58.75	49.82	38.08	47.39	282.67	270.97	61.25	17.21	8.69	4.90	879.11
Gudoberet	15.19	13.49	40.03	57.15	66.12	82.58	408.62	380.97	127.93	49.43	16.23	6.52	1264.26
Molale	1.65	5.97	44.82	46.51	36.14	66.93	251.11	199.21	56.94	17.93	3.74	0.81	731.76
Debresina	68.31	46.69	119.62	160.55	130.94	81.29	370.22	446.31	190.59	112.35	88.14	70.55	1885.55
Yegem	11.47	17.99	78.57	95.46	81.92	80.39	370.24	366.42	129.28	33.33	20.40	7.48	1292.95
Wegere	2.63	12.37	25.05	49.14	36.31	58.07	306.72	281.40	71.80	21.19	6.11	5.60	876.38
Zemero	23.56	11.77	65.30	62.13	50.58	76.85	277.77	267.80	88.63	12.53	8.89	7.85	953.67
Seladngay	9.21	8.80	28.58	56.84	50.68	97.62	401.39	403.21	106.21	30.79	15.24	11.59	1220.17
Mean	**17.54**	**17.68**	**56.25**	**70.22**	**59.22**	**71.74**	**330.70**	**321.66**	**101.90**	**34.83**	**19.27**	**13.29**	**1114.30**

Table 4.3 Average annual rainfall of the study area

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual R.F
17.54	17.68	56.25	70.22	59.22	71.74	330.7	321.66	101.90	34.83	19.27	13.29	1114.3

The precipitation bar graph displayed the maximum rainfall and the minimum rainfall recorded in the month of July and December respectively. The majority of the rainfall in the basin is obtained during the summer time (Kiremt) June, July, august and September which covers 74% of the total annual rainfall and the minimum rainfall records are in the months of January, February, November and December which covers only 6% of the annual rainfall. The rest 20% of the annual precipitation recorded in the months of March, April, May and October. The mean monthly rainfall intensity of the area is clearly illustrated in the graph shown below.

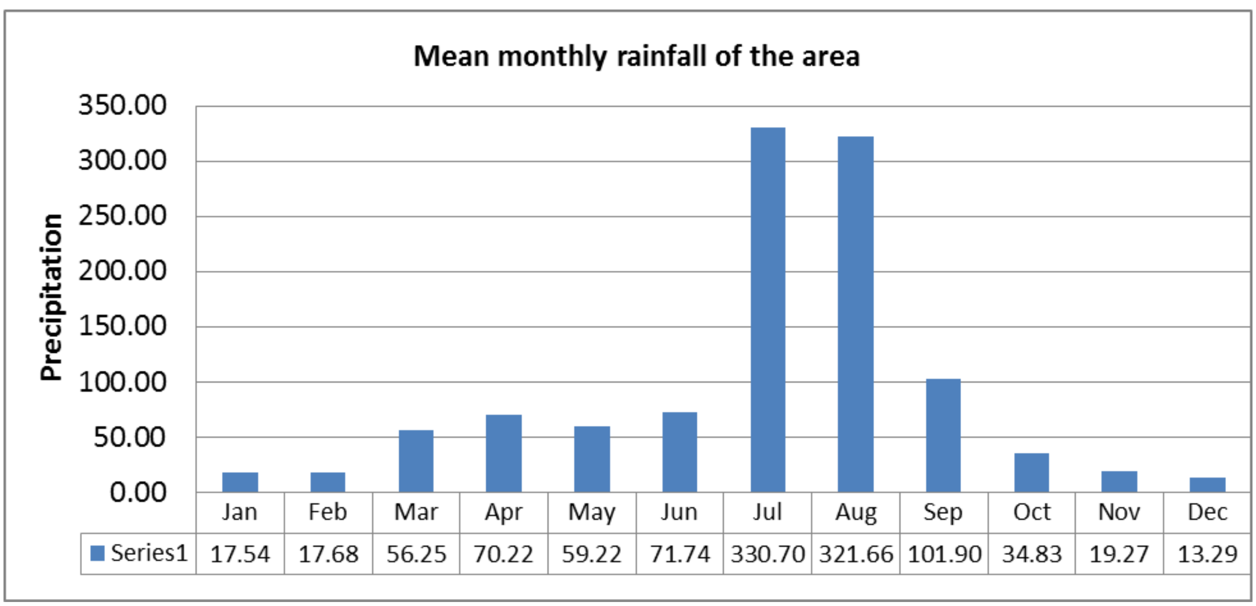

Figure 4.1: Mean monthly rainfall distribution from nine stations in upper Jemma catchment

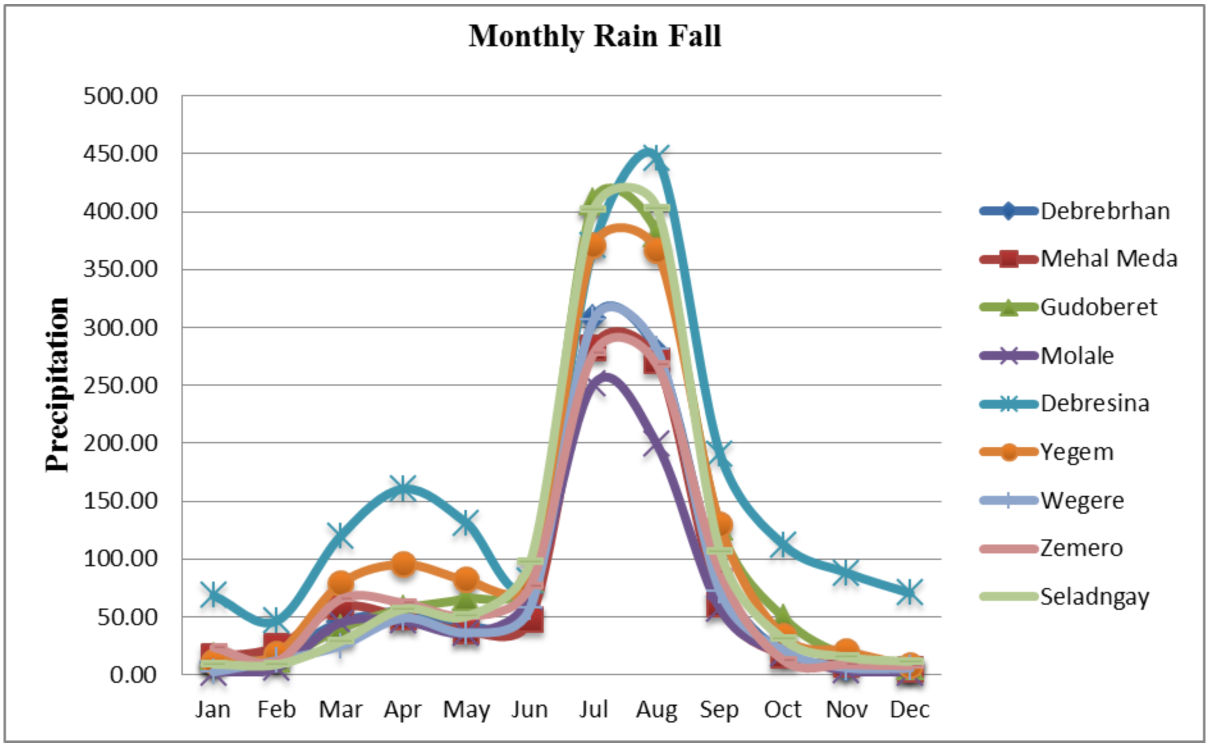

Figure 4.2: Spatial and temporal distribution of rain fall

4.3.2. Determination of areal depth of precipitation

There are three different method to determine the average areal depth of rainfall in a catchment area those are arithmetic mean method, Thiessen polygon method and Isohyetal method.

Arithmetic mean method: the arithmetic is the simplest and most widely used measure of mean/average or sum of numbers. This method is reliable in flat topography and the rain gage stations are closed and evenly distributed. Arithmetic mean method is chosen over Isohyetal and Thiessen polygene method because relatively uniform and evenly distributed gauge evenly. However the elevation control the precipitation but Debresina station located at lower elevation (2800m) than Molale station (3046m) but the annual precipitation is higher in Debresina (1885.55mm) than Molale (731.76mm) respectively.

Arithmetic mean method is the sum of all numbers divided by the number of items mathematically

$$\mathbf{Pave = \Sigma P1/n}$$

Where, Pave = average rainfall over the area,

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

n = number of rain-gauge stations in the area

The aerial depth of rainfall calculated using arithmetic mean result is 1114.30mm

Thiessen polygon method: this method provides for non uniform rain gauge stations distribution by determining the weighting factor for each area. The annual rainfall resulted in Thiessen polygon method is 1050.587mm. Sea the table 4.4 and figure 4.3

Table 4.4 Thiessen polygon method annual rainfall

Station	Area(ai)	Area tot(A)	ai/A	Annul PPT	Weighted PPT
Gudo-Beret	433	3249	0.13	1267.62	164.7909
Yegem	163	3249	0.05	1292.95	64.64754
Molale	360	3249	0.11	731.76	80.49387
Seladingay	820	3249	0.25	1220.17	305.0422
Debresina	113	3249	0.03	1885.55	56.56645
Debre-Birhan	372	3249	0.11	924.84	101.7322
Zemero	225	3249	0.07	952.99	66.70941
Wegere	444	3249	0.14	876.38	122.6931
Mehal-Meda	319	3249	0.1	879.11	87.91111
				Annual	1050.587

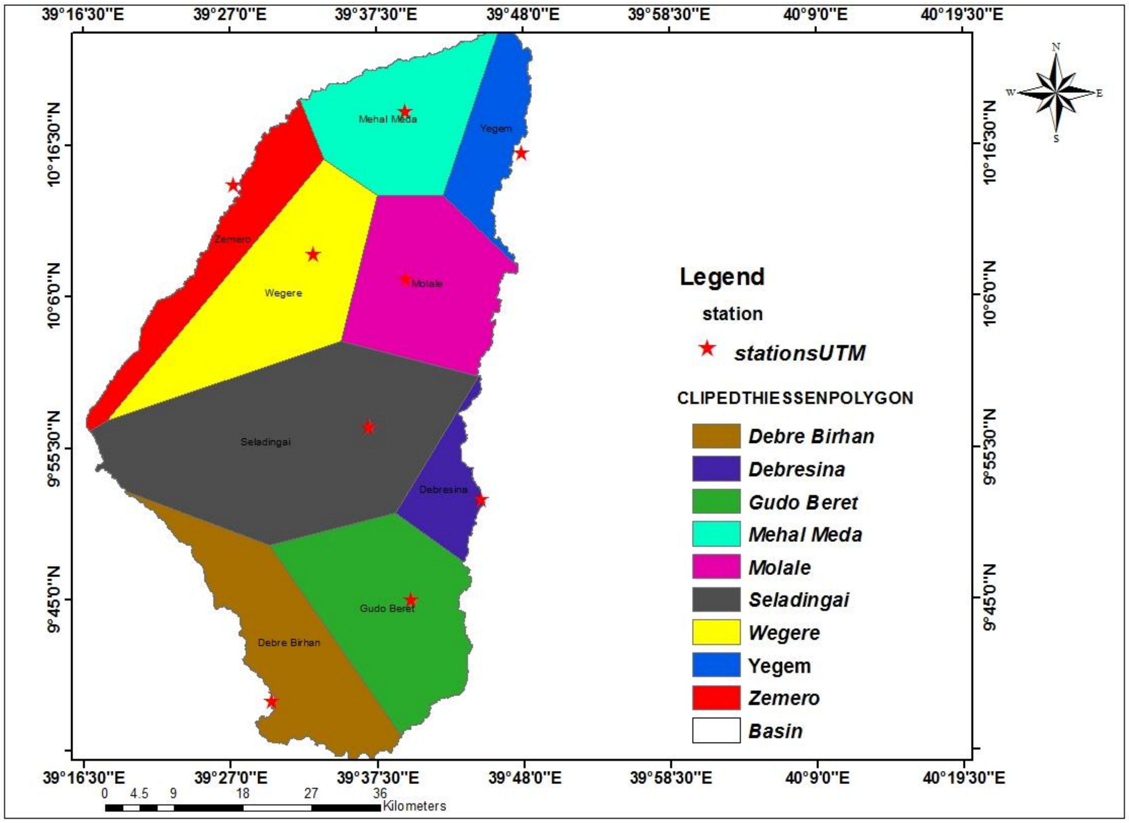

Figure 4.3: Thiessen polygon map

Isohyetal method: this method uses topographic and other data to yield reliable estimates with equal precipitation analogous to contour lines on the topographic map. The average rainfall between two successive Isohyetal taken the average of the two Isohyetal values are weighted with the area between the isohyets summed up and divided by the total area gives the average depth of the rain fall over the entire basine. The annual precipitation calculated by this method is 1089.5mm/year.

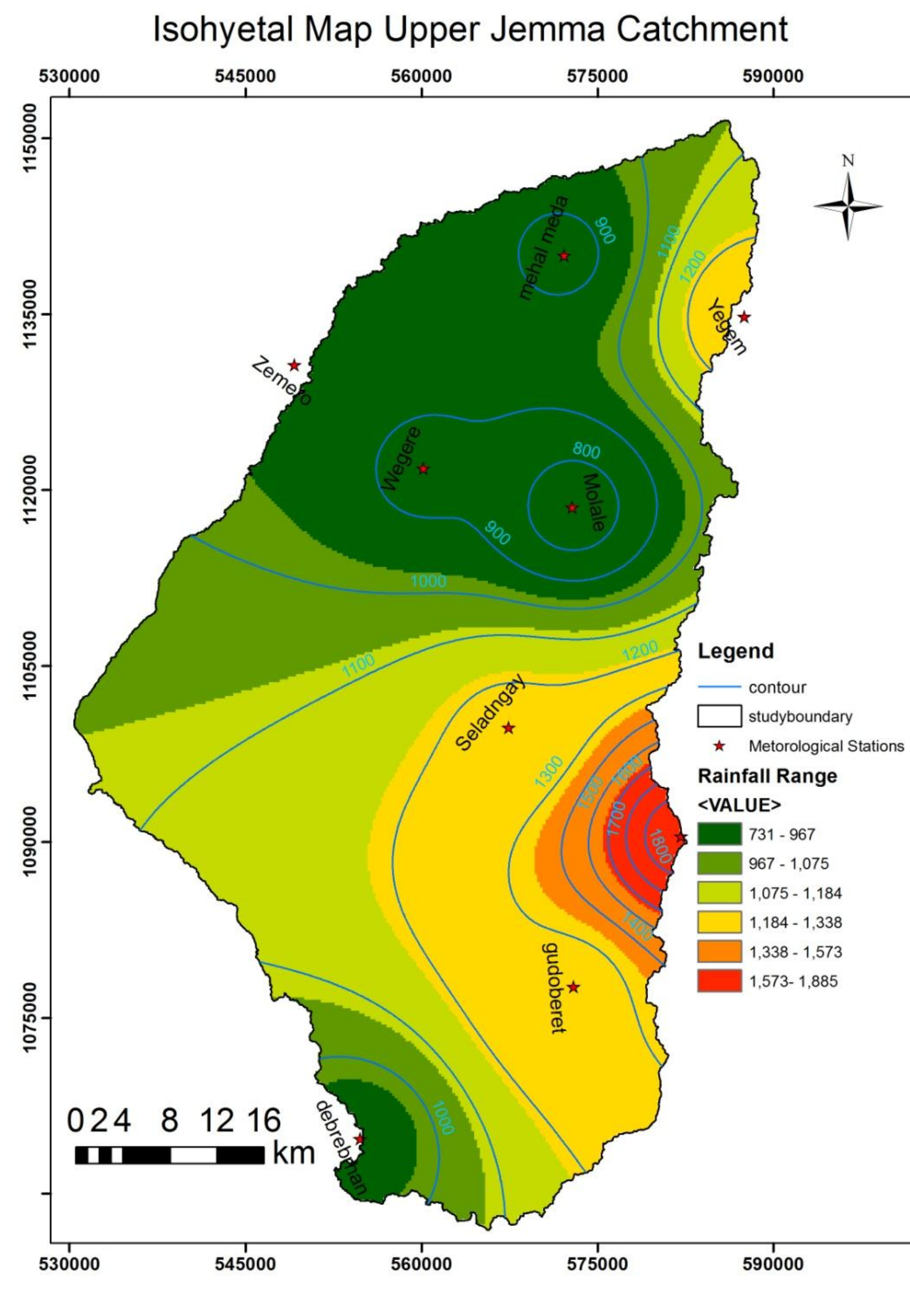

Figure 4.4: Isohyetal map upper Jemma catchment

4.3.2. Rainfall characteristics

4.3.2.1. Distribution rainfall with time and space

In Ethiopia, the main rainy season is from June to September (summer), which is referred to as Kiremt in Ethiopian. Minor rainfall is likely from March to May (spring), and this period is known locally as Belg (Gebrekidan Worku et al., 2019). The amount of precipitation falling over a location varies both spatially and temporally (with time). The influences precipitation both static (altitude, side, slope) and dynamic (weather) influence (Davie 2008). Precipitation process in nature is subjected to spatial and temporal variation. The temporal variability in rainfall has brought about two main seasons dry time and wet time in the area. Even if having dry and wet time we can-not predict with certainty what would be the precipitation for any given period in future. The magnitude of the rainfall can be estimated only with some probability attached to them. The rainfall data analysis has obtained over a long period in the past would help to make reasonable estimation for rainfall to be used in various developmental activities (Meseret Adeko, 2005).

The annual rainfall distribution in the study area is not uniform which ranges from 731.76 mm to 1885.55 mm. The highest rainfall is recorded in Debresina station and the lowest rainfall record in Molale station. The highest rainfall recorded in the month of August (446mm) and the minimum rainfall is record in the month of December (0.81mm). The rain fall in the basin is mainly controlled by moisture laden wind ward side, temperature and mountain barriers. The rainfall amount and frequency are higher on the wind ward side of the orographic and mountain barriers (Tenalem Ayenew and Tamiru Alemayehu, 2001). The rainfall amount increase with altitude even though the altitude of Debresina station lower than Molale station but annual rainfall higher than Molale and other stations due to wind ward side and mountain barriers.

According to rainfall coefficient (RC) the annual months are classified in dry months and rainy months by mean monthly rainfall and the total annual mean rainfall of the area.

RC = 12pm/pa

Where, RC = rainfall coefficient (unit less)

Pa = annual total rainfall of the area

Pm = mean monthly rainfall

Dry months (RC < 0.6) and rainy months (RC > 0.6) this rainy months can be further classified as small and big rain. Small rain (0.6-0.9), and big rain (>1.0) this big rain also further dived in to moderate (1-1.9), high (2-2.9) and very high concentrations (>3)

Table 4.5 Rain fall coefficient

months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Pm	17.54	17.68	56.25	70.22	59.22	71.74	330.70	321.66	101.90	34.83	19.27	13.29	1114.30
R.C	0.19	0.19	0.61	0.76	0.64	0.77	3.56	3.46	1.10	0.38	0.21	0.14	
	Dry	Dry	small rain	small rain	small rain	small rain	Very high rain	Very high rain	Moderate rain	Dry	Dry	Dry	

4.3.2.2. Rainfall relations with altitude

The relationship between the altitude and the rain fall in the study area indicates are variable for every station. Rainfall data obtained from nine metrological stations for the study area from 1985-2018 years data. The amount of rainfall and frequency are greater on the windward side of the mountain (Tenalem Ayenew and Tamiru Alemayehu, 2001 as Cited in Nigussie Kebede, 2005). In general trend the altitude increase the rainfall also increase in most area but in the study area is the reverse. There are nine rain gauge stations are found within the basin and around the basin. The basin has almost good spatial distribution of rain gage stations are evenly distributed. The mean annual rainfall correlation with respective altitude is shown in table 4.6.

Table 4.6 Elevation and mean annual rain fall

Stations	Elevations	Annual Av R.F
Debrebirhan	2750	924.84
Mehal-Meda	3084	879.11
Gudoberet	2600	1264.26
Molale	3046	731.76
Debresina	2800	1885.55
Yegem	2940	1292.95
Wegere	2890	876.38
Zemero	2850	953.67
Seladingay	2870	1220.17

4.4. Temperature

Temperature is quantified of coldness or warmness of any things with reference to some standard value. It is the most important meteorological variables that have a capacity to influence evaporation from surface water body, from shallow groundwater, from bare soil, and from interception leaves. The temperature of a given surroundings is much more dependent on the topographical setup, geomorphologic location and mainly the altitude the area located.

The temperature in the study area is measured at four stations these are Debre-Birhan, Mehal-Meda, Molale and Gudoberet station. The long term records of mean monthly minimum and mean maximum values of temperature of each stations shows slight difference.

Table 4.7 Monthly maximum mean, minimum mean and average temperatures variability

Station	Column1	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Debrebrhan	Max	19.89	20.74	20.94	20.82	21.56	21.97	18.61	18.20	18.91	18.90	19.00	19.15
	Min	4.76	6.11	7.71	7.86	7.37	7.51	8.81	8.75	7.08	3.69	2.62	3.26
	Averag	12.32	13.42	14.33	14.34	14.46	14.74	13.71	13.47	13.00	11.29	10.81	11.20
Mehalmeda	Max	18.98	19.50	19.19	18.88	19.25	19.93	17.45	16.85	17.11	16.53	17.19	18.35
	Min	5.90	7.10	7.85	8.18	8.46	8.10	8.09	8.08	7.81	6.26	5.25	5.37
	Averag	12.44	13.30	13.52	13.53	13.86	14.01	12.77	12.46	12.46	11.39	11.22	11.86
Gudoberet	Max	18.25	18.52	18.76	18.37	18.62	19.14	17.17	17.08	17.10	16.41	16.77	17.15
	Min	7.28	7.83	8.37	8.55	9.08	9.02	8.09	8.08	8.23	7.40	6.79	6.82
	Averag	12.76	13.18	13.56	13.46	13.85	14.08	12.63	12.58	12.66	11.91	11.78	11.99
Molale	Max	20.28	21.43	21.41	21.74	21.53	22.41	22.98	23.28	23.02	21.21	21.58	21.97
	Min	9.18	10.04	10.51	11.38	11.21	11.08	11.11	10.51	10.83	10.42	9.98	9.58
	Averag	14.73	15.73	15.96	16.56	16.37	16.74	17.04	16.90	16.92	15.81	15.78	15.78

The average annual long term values of temperature within the study area/ upper Jemma catchment ranges from 12.40 ^{0}C to 14.89 ^{0}C with a mean annual value of the catchment is 13.72 ^{0}C.

Table 4.8 mean monthly temperatures of the four stations

Station	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Debrbrhan	12.32	13.42	14.33	14.34	14.46	14.74	13.71	13.47	13.00	11.29	10.81	11.20
Mehalmeda	12.44	13.30	13.52	13.53	13.86	14.01	12.77	12.46	12.46	11.39	11.22	11.86
Gudoberet	12.76	13.18	13.56	13.46	13.85	14.08	12.63	12.58	12.66	11.91	11.78	11.99
Molale	14.73	15.73	15.96	16.56	16.37	16.74	17.04	16.90	16.92	15.81	15.78	15.78
Average	13.07	13.91	14.34	14.47	14.64	14.89	14.04	13.85	13.76	12.60	12.40	12.71

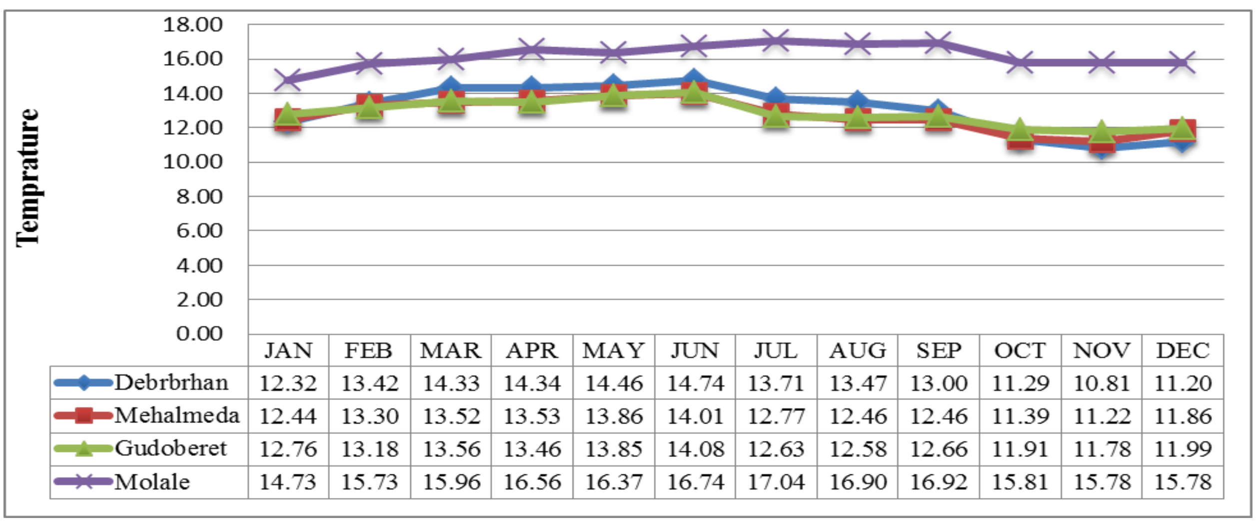

Figure 4.5: average temperature four stations

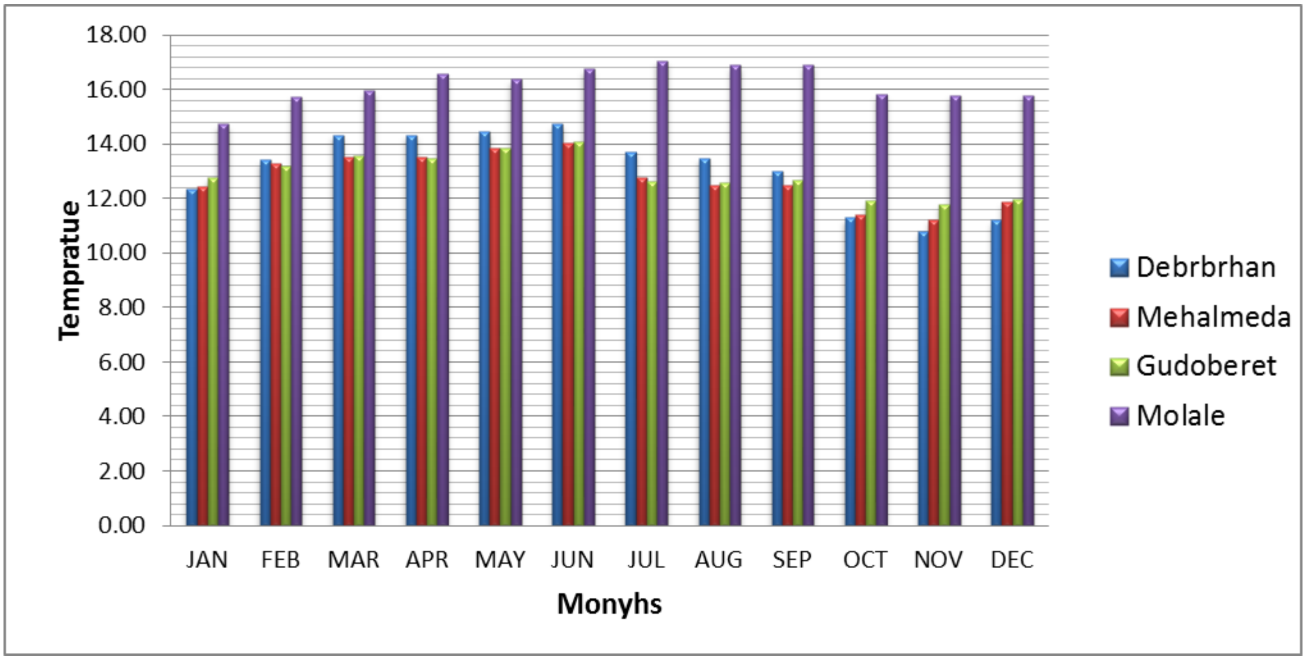

Figure 4.6: average temperature of Debrebirhan, Mehal-Meda, and Gudoberet and Molale stations

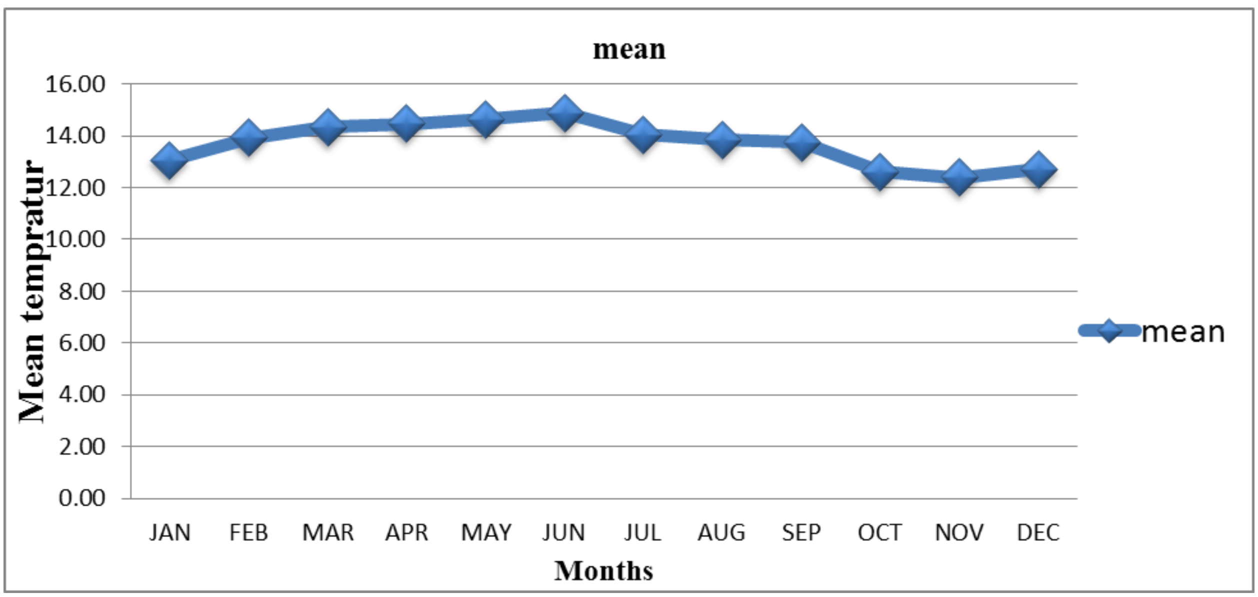

Figure 4.7 Mean monthly temperature of the study area

As observed in the above graph, the maximum temperature is observed during May and June, whereas, the minimum temperature was recorded from September to January.

4.5. Relative Humidity

Relative humidity has the relative amount water vapor or moisture in the air. Water vapor is the gaseous state of water but invisible in the atmosphere to the amount needed to saturate the air at the same temperature. It is the ratio of water vapor density to the saturation water vapor density. The relative humidity of the area has 63%

$$\text{Relative humidity} = \frac{\text{Actual vapor density}}{\text{Saturation vapor density}} * 100$$

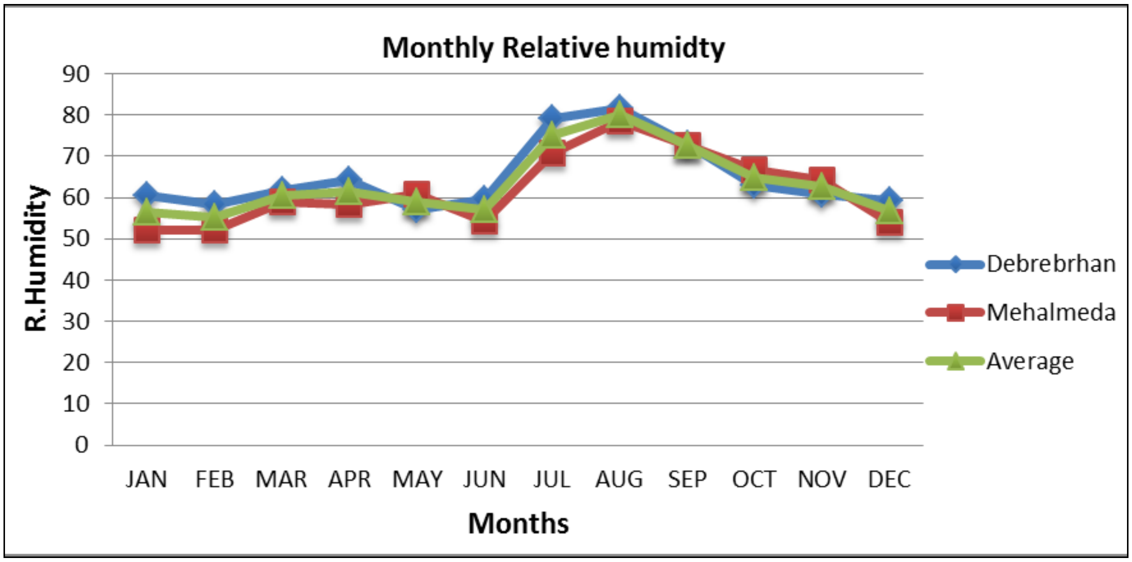

Figure 4.8: mean monthly relative humidity graph of Debrebirhan and Mehal-Meda

4.6. Wind speed

Wind speed is a fundamental atmospheric quantity caused by moving air from higher pressure to lower pressure. One of the factors of evaporation is wind speed, the decrease of wind speed resulting in non-removal of saturated vapor that affects evaporation rate. The wind speed of Debre-Birhan and Mehal-Meda station reaches its pick in March and May respectively and the wind is relatively become quiet in the month of August and July respectively. The annual mean wind speed on the area from maximum and minimum monthly mean is 2.13m/s.

Table 4.9 mean monthly wind speed of Debrebirhan and Mehal-Meda

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Debrebirhan	2.38	2.57	2.62	2.29	2.35	2.10	1.48	1.40	1.56	1.65	1.97	2.26
Mehal-Meda	1.93	2.24	2.29	2.46	2.87	2.39	1.64	1.65	2.18	2.61	2.25	2.05
Average	2.15	2.40	2.45	2.37	2.61	2.25	1.56	1.52	1.87	2.13	2.11	2.15

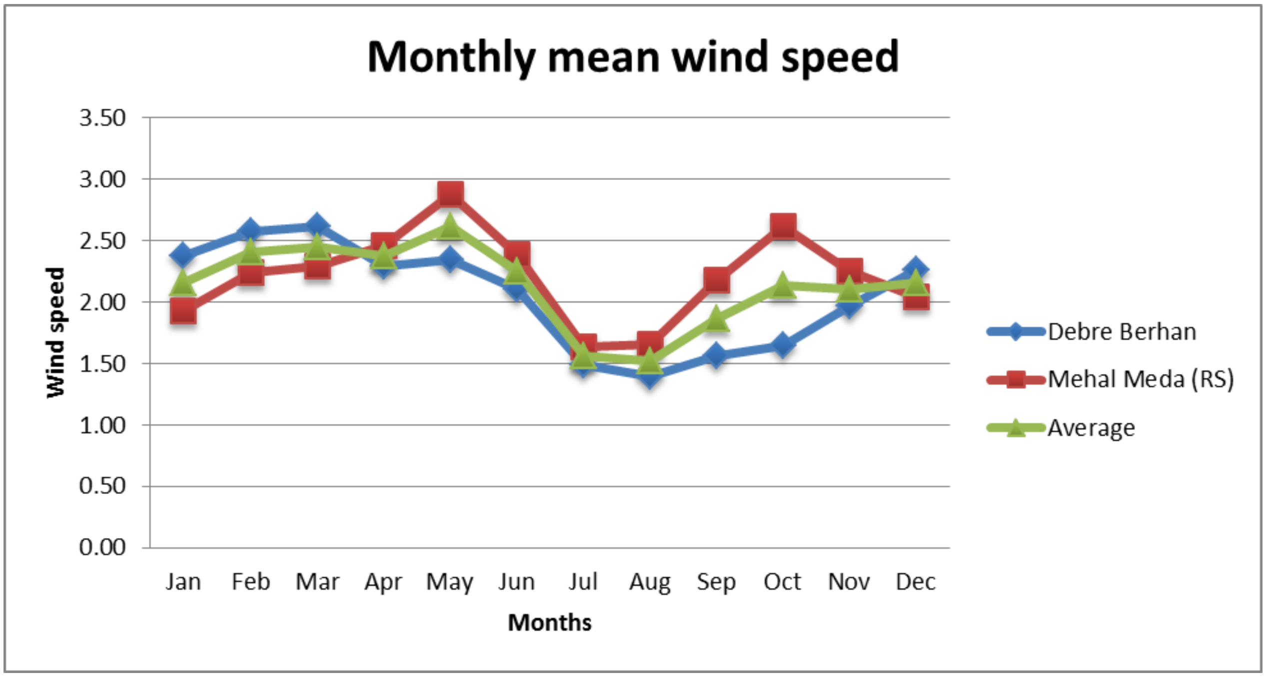

Figure 4.9: monthly mean wind speed

4.7. Sunshine hour

Sunshine hour is the time in hours of sunshine in day and direct relation with evaporation. When the day is cloudy, the sunshine hour decreases similarly evaporation decrease with the existing of other meteorological factors. When the day is shiny the evaporation increases. The maximum sunshine hour recorded in the study area in the month of January and December but minimum record in July and august.

Table 4.10 Mean monthly sun-shine hours (hr/d) of Debrebirhan and Mehal-Meda

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Debrebirhan	9.32	8.69	7.85	7.19	7.83	6.54	4.28	4.63	5.93	7.48	8.84	9.16
Mehal-Meda	9.05	8.80	8.44	8.06	8.90	7.33	4.53	5.45	7.99	9.03	8.93	9.54
Average	9.19	8.75	8.15	7.62	8.36	6.93	4.40	5.04	6.96	8.25	8.89	9.35

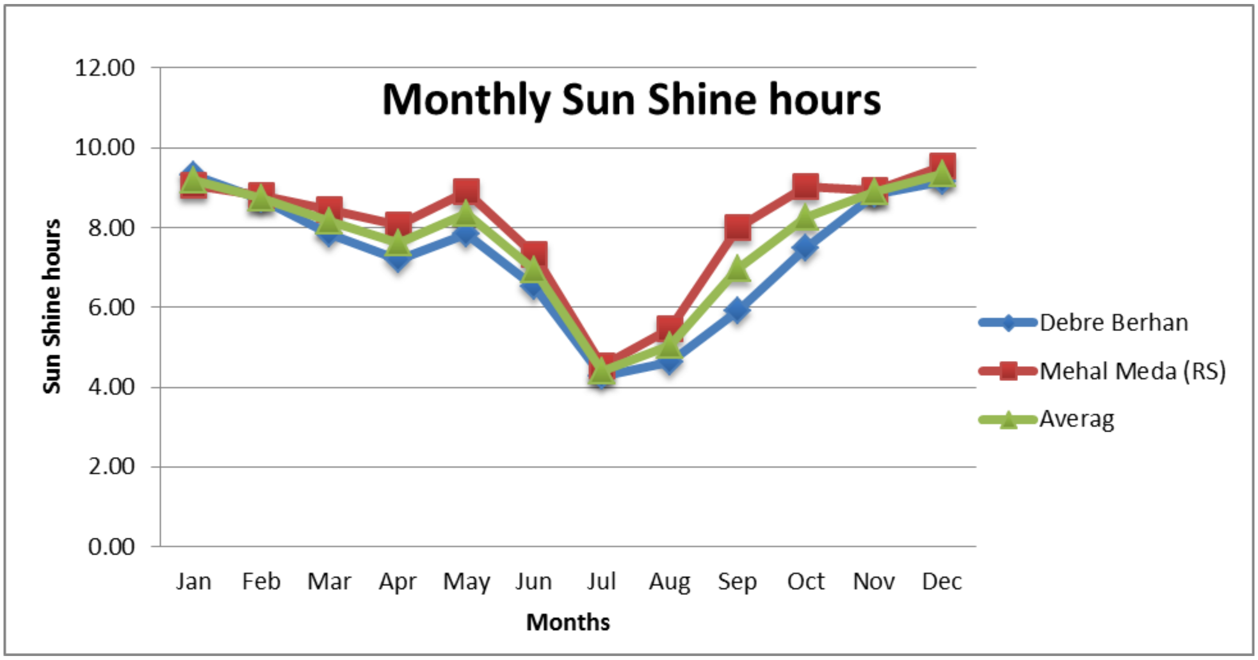

Figure 4.10: Monthly sunshine hours

4.8. Estimation of Evapotranspiration

Evapotranspiration (ET) is the combined process of transpiration from vegetation and evaporation from bare soil and free water surfaces. It is the total water loses from a cropped (irrigated) land due to evaporation from the soil and transpiration by the plants or used by the plants in building up of plant tissue (Raghunath, 2006). It is a natural process where water vapor is transferred from land surface and vegetation by evaporation and transpiration processes respectively. It is a key process of water balance and also an important element of energy balance. This process is the controlling factor in the water cycle and energy transport among the biosphere, atmosphere, lithosphere and hydrosphere.

The quantitative understanding of Evapotranspiration is one of vital practical importance in several respects over the long term. The difference between Evapotranspiration and precipitation is the water available for human use and management. Direct measurement of evapotranspiration is difficult and cannot measure directly. The array of method has been developed that estimates evapotranspiration based on measured quantities.

4.8.1. Estimation of Potential Evapotranspiration (PET)

Potential Evapotranspiration (PET) is the Evapotranspiration from the short green vegetation when the roots are supplied with unlimited water covering the soil. It is usually expressed as depth over the area (Raghunath, 2006). Potential Evapotranspiration is the maximum loss of water through Evapotranspiration. Even though there are different formula for calculating Evapotranspiration, for the purpose of this research work Penman method has been used. The results of the PET calculation are displayed in table 4.11. The potential evapotranspiration of the upper Jemma catchment resulted 1365.3mm/year.

4.8.2. Estimation of Actual Evapotranspiration (AET)

Actual Evapotranspiration (AET) is used to describe the amount of Evapotranspiration that occurs under the existing soil moisture (Thornthwait, 1994 as cited in Melkamu Adimaw 2019). It depends on unsaturated soil moisture condition and affected by vegetation such as plant type and stage of growth (Freeze and Cherry, 1979 as cited in Nigussie Kebede, 2005). Actual evapotranspiration is the amount of evaporation that occurs under field condition. If the area has abundant moisture in the soil, the actual evapotranspiration rate is equal to potential evapotranspiration. When the soil moisture contents are limited and vegetation unable to abstract enough water from the soil, then actual evapotranspiration becomes less than the potential evapotranspiration. The relationship between AET and PET depends upon the soil moisture content in the area.

If there is no rain to replenish the water supply, the soil moisture gradually become depleted by the demands of the vegetation to produce a soil moisture deficit (D). As soil moisture deficit increases, the AET become increasingly less than PET. The value of soil moisture deficit and AET vary with soil type and vegetation (Shaw, 1988 as cited Nigussie Kebede, 2005).The Actual Evapotranspiration of the catchment is calculated using Thornthwait and Matter method soil water balance model.

Most of the study area is covered by cropland and the vegetations are shallow rooted crops (peas, beat, carrot and spinach) and moderately deep rooted crops (corn, cereals). The soil texture from clay, clay loam, and silt loam to sandy grain size with available water capacity from 10-30% and the root depth extend from 0.25 to 0.6m and the available water capacity of root zone from 50 to 125 mm. So the monthly water balance of upper Jemma catchment for a soil with an average available water capacity of 25% and available water capacity of root zone (mm) is 100. The soil is clay loam under shallow rooted crops (spinach, peas, beats, carrot, etc) with a rooting depth of 0.4m. The actual evapotranspiration of the upper Jemma catchment is resulted 745.77 mm/year.

Table 4.11 summary of analyzed hydro-meteorological data of upper Jemma catchment

mm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
PP	17.54	17.68	56.25	70.22	59.22	71.74	330.7	321.66	101.9	34.83	19.27	13.29	**1114.3**
PET	113.4	125.1	126.9	125.1	130.5	123.3	91.5	92.4	107.4	111.6	108.3	109.8	1365.3
P-PET	-95.86	-107.42	-70.65	-54.88	-71.28	-51.56	239.2	229.26	-5.5	-76.77	-89.03	-96.51	-251
ACPWL	-363.67	-471.09	-541.74	-596.62	-667.9	-719.46			-5.5	-82.27	-171.3	-267.81	
SM	2.5	0.8	0.4	0.2	0.1	0.07	100	100	94.5	43.2	17.5	6.5	
ΔSM	-4	-1.7	-0.4	-0.2	-0.1	-0.03	99.93	0	-5.5	-51.3	-25.7	-11	
AET	21.54	19.38	56.65	70.42	59.32	71.77	91.5	92.4	107.4	86.13	44.97	24.29	**745.77**
RO							119.6	114.63					**234.23**

4.9. Groundwater Recharge

Groundwater recharge is the downward movement of water flow from recharge area to join the groundwater table. It is the reminder of runoff and ET from the precipitation. Clear distinction should be made between the potential and the actual recharge. In actual recharge, the amount of water that reaches water table and adds to the ground reservoir is important. The actual one occurs only after sufficient rainfall occurrences after saturation of unsaturated zone. It depends on infiltration, precipitation, climatic factors, and geological features. The amount of groundwater recharge depends in the amount of precipitation, temperature, land terrain (slop gradient), land cover (vegetation) and types of rocks (permeability). There are different types of recharge some of them are direct and indirect recharge. Direct recharge is the entrance of rainwater without transformation to the surface flow, which occurs mainly in the upper parts of the basins where the rainfall happens most frequently. Indirect recharge is due to runoff water which occurs outside the rainfall influenced areas. So it results from percolation to the aquifer following surface flow, poundings, and lakes.

Groundwater recharge is one of the most difficult components of the hydrological cycle to estimate, but it is generally very important for future economic improvement. Knowledge about groundwater recharge and discharge is significant for effective management of groundwater resources (Genet Mathewos, 2017). Rainfall is the major source of recharge to groundwater especially in the upper Jemma catchment. Part of the rain water, which falls on the ground, is infiltrated into the soil and part of this infiltrated water is utilized in filling the soil moisture deficiency while the remaining portion percolates down to reach the water table, which is termed as rainfall recharge to the aquifer.

4.10. Groundwater Recharge Estimation

Recharge estimation is one of the most significant hydrologic component calculations in arid regions, where rainfall variations are periodic and irregular. The important factor is the estimation of the rate of recharge which represents the volume of water per unit area during a unit time. The factors affecting the recharge are: Rainfall, Climate, Soil, Moisture, Topography, Geology, Vegetation, structure and land use land cover.

For recharge estimation techniques two components are important these are the area coverage and the infiltration rate. Estimation of the amount of recharge to the sub-surface is key role for efficient and sustainable management of groundwater resources. Soil moisture water balance method have been used the recharge, Surface runoff and Actual Evapotranspiration (AET) can be easily computed.

Precipitation in the catchment partly becomes runoff, some part is evapotranspiration and the remaining may infiltrate in to the ground. Annual groundwater recharge was estimated by determining the product of annual precipitation, estimated annual runoff and estimated actual evapotranspiration. More accurate estimates of groundwater recharge for a specific groundwater body is more complex.

Water balance can be determined by calculating the groundwater input, output and storage changes of water in the study area. The general formula of water balance is given by

Inflow = out flow ± change in storage.

$I = O \pm \Delta S$

$P + Gi = AET + SRO + R + GO \pm \Delta SG$

Where; P = precipitation,

Gi = groundwater inflow,

AET = actual evapotranspiration,

R = Recharge,

SRO = surface runoff,

Go = groundwater outflow,

ΔSG = change in groundwater storage,

The annual change of water storage assumed to be zero for an aquifer under steady sate condition because the assumption is made that the inflow (Gi) and outflow (Go) amount are balance or equal. The water balance equation of the study area as follow

To estimate of groundwater recharge using water balance method/equation of the catchment

$R = P - AET - SRO$ Where,

R - Groundwater recharge

P - Mean annual precipitation in mm/year

AET - Estimated Annual actual Evapotranspiration in mm/year

SRO - estimated annual runoff in mm/year

Therefore, Annual Groundwater recharge of the study area is

R = P – AET - SRO

R= 1114.3 mm/year - 745.77 mm/year - 234.23mm/year

R=134.3mm/year

The Annual recharge of the study area is 12% of total annual precipitation

Therefore, the amount of recharge in the upper Jemma catchment is calculated **134.3mm/year** and AET and SRO are **745.77mm/year** and **234.23mm/year**.

4.11. Surface Hydrology

The surface runoff is the excess water that flows over the land when soil is infiltrated to full capacity. It is a major component of the hydrologic cycle and generated by rainfall in our country. The interaction between precipitation and surface runoff is highly dependent on metrological factors, the physical geology and topography of the area. Portion of the runoff that moves over the land surface to reach the smaller channels is called overland flow. The overland flow has small length and depth and the small channels join and form large streams finally reach the basin outlet. Stream flow is highly variable with time due to precipitation amount during high rainfall time have high stream discharge and rainfall can result rising rivers in the watershed (Karamouz et al., 2013).

Beressa, Mofer-Wuha, Retmet and Shay rivers are the major perennial rivers in the Upper Jemma catchment. This catchment drains almost all streams are emerging from eastern high land areas. Central part of the study area drained by Mofer-Wuha and Retmet River and The northern parts and the southern parts of the basin are drained by Shay and Beressa River respectively. The main drainage pattern in the area is dendrite and parallel to sub parallel patterns are common in the highland mountain side. The catchments has different order river network and deep river cut are observed in the western direction of the study area.

CHAPTER FIVE

HYDROGEOLOGY

5.1. General Background

The hydrogeological framework of the Ethiopian volcanic terrain and associated sedimentary deposit are complex for the movement and occurrence groundwater storage (Tenalem Ayenew et al., 2008). The Abay basin subdivided in to 16 sub basins based on the major rivers in the basin (ABA 2016). Jemma River is one of those sub-basins and the study area locate in the upper part Jemma river basin.

The study area is covered by volcanic rocks which have extremely variable hydro-geological characteristics. The hydrogeology of an area depends on the precipitation amount, landform, slope, climate condition, soil type, land cover, grain size, geological structure, degree of weathering and fracturing. Geological, meteorological and geomorphologic setup of the study area strongly controls the movement, distribution and occurrence of groundwater. As a result the circulation and storage capacity of these rocks depend on the nature of porosity, permeability of aquifer and the degree of weathering and fracturing of rocks. The porosity of the rock may have high permeability is largely a function of secondary structures like fractures and faults develop in the rock mass (Tenalem Ayenew and Tamiru Alemayehu, 2001). In upper Jemma catchment essential aquifer is localized in the weathered and fractured volcanic rocks, alluvial-colluvial sediments filling intermountain graven, alluvial deposits dominated by volcano-clastics and gravels along major river courses and paleo-soils within the trap series volcanic layers and inter-bedded loose pyroclastic materials and reworked breccias/agglomerates with in basic and acidic lava flows (Tenalem Ayenew et al., 2008).

To understand the hydrogeology of the area it is essential to first understand the litho-logic characteristic of geological units, their mode of occurrence, the depth of ground water table and the flow direction, distribution and magnitude of spring discharges, fracture setting of the rocks. In the study area, general groundwater exploited by springs, hand dug wells, pumping wells and evapotranspiration. A lot of springs in the study area discharge from groundwater to the land surface through faults, contacts, fractures, depression and low land/graben. The other way of groundwater discharged in the area is from the shallow wells and existing deep boreholes. There are many springs, hand dug wells, shallow wells and small number of boreholes abstracted ground water for the use of domestic and irrigation purposes.

Geological and hydro-geological data were collected in the field after having the secondary data. Geological field investigation was concentrated more in differentiating the rock units for groundwater importance such as, degree of fracturing of the rock units, extent of weathering, degree of cementation & cementing materials, thickness of the formations, grain size, shape and sorting. Hydro-geological information in the field is locating the water points, observing the distribution, and measurement of discharge of wells and springs.

Meteorological effect on groundwater occurrence; precipitation is the main factor for the presence of surface and subsurface water. Rainfall is the major input source for the infiltration and the recharge of groundwater. Especially in the study area, rainfall is the main source of recharge. When areas have high annual rainfall will have high groundwater potential. If an area has long-lived, frequent and less-intensity of rainfall has got high infiltration to the groundwater but if area with has short lived, infrequent and very intense rainfall it aggravate surface runoff and reduce infiltration.

Geologic effect on groundwater occurrence; the geological formation with structures controls the presence, storage, circulation and movement of groundwater. If the formation highly weathered, fractured, faults, joints, porous, well sorted and large grain size can store and transmit groundwater. In general the geology has paramount for governing the amount, movement and storage of subsurface water.

Topographic effect on groundwater occurrence; The geomorphologic setups of the area determine the amount of infiltration and recharge to groundwater. If the area is flat and gentle slope increases the infiltration to the subsurface and promotes recharge to the groundwater and decrease runoff. If the area is steep slope and rugged topography aggravate surface runoff but retard the groundwater recharge. Most of the study area rugged topography and steep slope increase runoff rather. Look plate 2 the topographic land of the area below this.

Land use land cover affect the occurrence of groundwater; the types of vegetation, vegetation cover and soil types determine and control the amount of recharge to the groundwater and the chemistry of groundwater. When the area has thick soil cover, these areas having deep rooted vegetation will increase infiltration and reduce runoff. If the areas bare lands and thin soil cover promotes runoff and surface erosion. In this regard most of the study area is covered with thin soil and rugged topography so it increases surface runoff and erosion rather than deep percolation. Even though areas covered by plants the population pressure increase deforestation and promote surface erosion and runoff. The cumulative effect of human intervention, geology and undulated topography aggravate overflow in the study area

Generally the groundwater potential depends on geological, topographical, meteorological elements, land use land cover, degree of weathering and fracturing basalt, elluvial sediment and alluvial deposit extent with thickness. Due to this reasons groundwater potential in the study area vary from place to place (from low, medium and high depends on the degree of weathering and fracturing of basalts and elluvial and alluvial sediments extent with thickens)

5.2. Aquifer Characterization

Aquifer is a geologic formation that contains sufficient saturated permeable materials to yield of significant quantity of water to the well or spring in economical quantity. It is a geological media mainly a function of geological material, sediment grain size, degree of sorting, degree of weathering and fracturing. Any aquifer characterized by the subsurface geology, structural features, Lithology, weathering and hydrogeological nature formations.

Groundwater without uncertainty occurs in geological formation (Fetter, 2014). Hydro-geological study explains the occurrence or absence, origin, movement, and chemical constituents of shallow and deep groundwater movement directly or indirectly depending on the types of litho-logical formation, geological structure, geomorphology/landforms, rainfall, slope of the area, drainage density, land use land cover and soil types of the area (Reys Asfaw, 2016). The occurrence, distribution and availability of groundwater should be evaluated in terms of the distribution of aquifers and aquitards and the distribution of the hydro-geological properties of the rock framework, hydraulic continuity (Abera Gonfa, 2018). Springs those found in an area directly related to the geological structures formed by different natural and artificial activities.

Good aquifer must be sufficiently permeable with interconnected pore space and fissures and with enough storage to yield groundwater. Groundwater bearing potential related to porosity, geological structures, grain size and sorting, fractured and weathered zone in the rock mass.

In the upper Jemma catchment the main aquifers identified in the study area based on field observation, the existing well data and hydrogeological investigation are elluvial sediment, alluvial deposit along the streams, valley deposit and flat land area, weathered and fractured basalt in the rock mass is good for groundwater potential.

Elluvial and Alluvial deposits; are good formation for shallow (unconfined) groundwater reservoir potential zone. These formations increase the recharge of groundwater infiltration and percolation. Alluvial sediments are deposited at the base of the mountain and the side of the river transported from the adjacent highland area and deposited with variable thickness. This formation has high discharge but it difficult formation for drilling. Eluvium sediments are located in central and southern parts of the study area and this formation has good shallow groundwater reservoir.

Weathered and fractured basalt: most of the study area covered by volcanic rock with fractured and weathered basalt and fractured and weathered trachyte with ignimbrite rhyolite. The degree of fracturing and weathering are variable from place to place. Several springs emerged from these types of formation with different yield of springs. In the study area so many hand dug wells, shallow wells and a few deep wells are drilled in this aquifer. The productivity of the wells was variable yield related to degree of fracturing and weathering for shallow/ unconfined aquifer and for deep/confined multi layer aquifer the productivity related to penetration depth and degree of weathering and fracturing.

Field observation is very important to identify the aquifer productivity and hydrogeological characteristics of the area. During field work observe the hydrogeological nature of the rocks like degree of fracturing and weathering of rock unit, sorting and shape of grain size, degree of cementation and the magnitude, distributions of spring discharge, lithological well log, hydrogeological observations used for classify groundwater potential area and the aquifer productivity.

5.3 Aquifer Classification

The geological units of the study area classified into aquifers and aquitards based on the geological description, qualitative and very limited quantitative (yield of springs and hydraulic characteristics of boreholes) data. Aquifers are classified according to their productivity, physical properties of rocks and sediments, based on field observation, discharge, and spring distribution, degree of weathering, fracturing, faulting and topographic location. The groundwater potential zone of upper Jemma catchment is explained as follow.

5.3.1. Extensive and Highly Productive Porous Aquifers

The porous aquifers are represented by alluvial and elluvial material of a Quaternary age in the study area with porous permeability. The groundwater occurs between pore spaces in the unconsolidated and semi consolidated materials. The availability of the groundwater in the unconsolidated materials depends on the grain size, shape, sorting, cementing material and thickness of the deposition. The eluvium is mainly distributed over the plateau area and at the foot of mountains chains. The alluvial sediment consists of different grain size such as sand, silt and gravels with variable size. Gravel and sand have high storing and transmitting capacity for shallow groundwater.

The highly productive porous aquifers cover only small portion in the study area. This aquifers flows mainly intergranular (unconsolidated materials) includes alluvial and elluvial sediment aquifers. Eluvium mostly found in plateau area occupying gentle sloping and flat lying topography. These materials were gradual weathered product of basalt, ignimbrite, trachyte and rhyolite forms a tick cover of regolith. There are fragments of basalt, ignimbrite and rhyolite within the elluvial soil. A lot of hand dug wells used for the purposes of community water supply. Generally the eluvium is the most important hydrogeological unit in the catchment mainly for shallow groundwater sources. The transmissivity values of the aquifers are variable it ranging from 10.8 to 224.6 m^2/day with an average of 129.766. The springs and boreholes are in this aquifer yields from 4 l/s to 15 l/s with an average of 9.2 l/s.

5.3.2. Extensive and Highly Productive Fissured Aquifers

Aquifers with fissured permeability: - the occurrence of groundwater in sedimentary and volcanic rocks depends on the type of permeability formed during and after the rock formation. The fractured and weathered parts of the volcanic and sedimentary rocks increase the groundwater flow and storage. In the study area the volcanic rocks are highly weathered, fractured and jointed parts can store and transmit a relevant amount of the groundwater.

The Tertiary basalts, which is lower, middle and upper aquifer units and Mesozoic sandstone is categorized under this high productive aquifers. The flows mainly through regularly developed systems of fissured and joints sedimentary and volcanic rocks. These aquifers are common in Tarmaber-Megezez basalt, Alajae basalt and Ashangi basalt and Mesozoic sedimentary rocks are upper sand stone and sediments. The aquifers are found in different morphological positions and are disturbed with different levels of tectonic features. The main aquifers of this group are described below.

5.3.2.1. The Upper Sandstone (MSST)

The upper sandstone aquifer mostly uncovered in the lower valleys of the Jemma and its tributaries (Beressa and Mofer Wuha). It has well developed primary and secondary permeability. Recharge to this aquifer mainly comes through the overlying Tertiary volcanic rocks and also recharged by perennial rivers and their tributaries. Rainwater penetrates to greater depth to saturate this aquifer. From the water point inventory data and previous studies, many springs emerge at the contact between the sandstone and underlying Mugger mudstone. The yield of springs varies from 0.07 to 20.2 l/s with an average of 3.2 l/s.

5.3.2.2. Middle basalt/Kesem basalt (Tkb)

Middle basalt commonly known as Alajae basalt or Kesem basalt is mainly distributed in the lower sections of the Beressa, Bersena and Mofer wuha river valleys. It is vesicular at the top, flow banded in the middle and massive at the bottom. It is highly faulted and fractured, irregularly to columnar jointed, and spherical weathered, which enhances the permeability of the aquifer. No water points are observed from this aquifer on the map sheet however, from regional and detailed hydrogeological studies the yield of wells is from 30 l/s up to 60 l/s and depth of wells is 300 m to 380 m. Some springs with a discharge of up to 2.7 l/s emerge from this aquifer.

5.3.2.3. Tarmaber Megezez basalt (Ttb)

The Tarmaber Megezez also known as upper basalt is shield volcano that overlies Molale trachyte and intensely weathered and altered to bentonite and other clay minerals. These basalts have an average yield of wells of 10 l/s and spring of 6 l/s, and are aquifers with very good secondary porosity, and permeability. They form a series of linear ridges and high mountains but in some areas gentle undulating topography. These basalts are tectonically affected by the NNE-SSW trending normal faults, which follow the rift propagation. These structures enhance the recharge conditions of the area and, in addition to the intensive development of fractures, weathered rock and joints in this unit; create favorable condition for their good permeability. This unit has scoracious lava flow nature and favorable for groundwater storage and movement. The aquifer is recharged directly by rainfall and the infiltration from porous aquifers developed in Quaternary sediments and covering the plateau area.. Many springs emerging from this unit are controlled by fractures or faults intersecting topographical depressions. The springs emerge at the contact between this unit and underlying les permeable volcanic rock. Those springs are located around Gudoberet and Keyt on the left down side of the main asphalt road have high discharge on average 20 l/s and 50 l/s respectively.

5.3.3. Moderately Productive Aquifers with Mixed Fissured and Porous Permeability

Aquifers with mixed (porous and fissured) permeability aquifers are moderately to highly productive aquifers with porous and fissured permeability to wells and springs. The mixed aquifers are the combination of porous and fractured developed in fissured ignimbrite, rhyolite, trachyte, basalt and porous Tertiary sediments intercalating volcanic rocks on the plateau. These types' aquifers are found in Seladingay-Debrebirhan gorgo-ignimbrite

Sela-Dengaye_Debrebirhan_Gorgo-Ignimbrite/Trachyte/Rhyolite/Tertiary sediment aquifers of the plateau with an average discharge of well =10 l/s and spring = 1.3 l/s are mainly exposed at Seladingay and Debrebirhan. They have sharp contacts with the overlying (Tarmaber-Megezez,) and underlying middle (Kesem) basalts. These volcanic plateaus of the Alajae formation comprise ignimbrite, rhyolite, Tertiary sediment, tuffaceous sediment, aphanitic basalt, agglomerate and ash. The ignimbrite forms gentle to steep cliffs, elongated ridges and sporadically distributed isolated hills. The aquifers are recharged by infiltration of rainfall and infiltration from porous aquifers developed in Quaternary sediments covering the plateau and nearby rivers. The data from boreholes drilled in the Debrebirhan area show how significant the contribution of permeable Tertiary sediments to the yield of wells. Usually, fresh basalt, ignimbrite, rhyolite, and trachyte are low permeable lithological units; however, the presence of the porous sediments in between lava flows forms a body that can accumulate a large volume of groundwater by drainage of the surrounding fissured aquifers and contributes to the yield of wells. These fissured and mixed aquifers of the plateau represent the most important hydrogeological unit of the area. Many water points were inventoried from these aquifers with discharge of springs from 0.02 l/s to 12.75 l/s and yield of wells from 4 l/s up to 17 l/s. the transmissivity of the aquifer varies from 0.05m^2/day to 200m^2/day.

5.3.4. Aquifers with local and limited groundwater resources

Aquitards/Aquicludes with very limited/no-groundwater resources common in fresh and massive rock area, ashes are slightly weathered considered very low permeability. Even the fractured rocks are filled with secondary materials reduce the permeability the rocks. Minor aquifer with local and limited groundwater resources Molale tuff (ignimbrite and trachyte) are found the peak of the plateau. Molale rhyolite tuffs (Tmi) and trachyte cover a broad area in central and northern parts of the study area. This unit is fine to medium grained size and slightly too moderately weathered. Molale rhyolitic tuff is rarely fractured and has low potential to store and transmit groundwater (Fedlu Hassen et al., 2017). Generally trachyte has low permeability even if faulted, the fault filled by clay minerals. Even though many wells are drilled in the area most of them are abandoned and dry but a few wells were having low discharge.

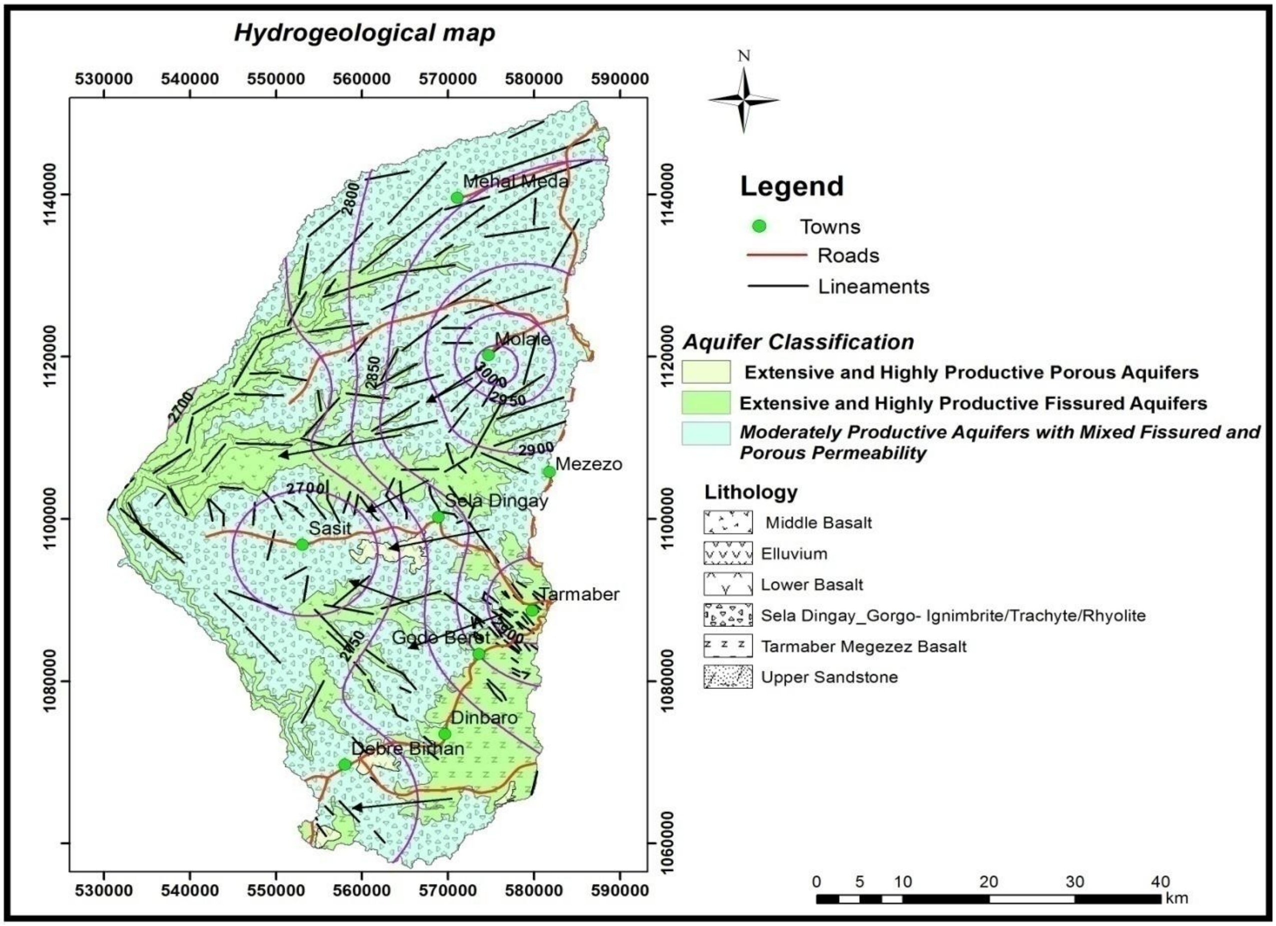

Figure 5.1: hydrogeological map of the study area (adopted from GSE, 2010)

As shown in the figure above that groundwater flow direction in the study area coincides with the topography and the surface water flow direction. The flow controlled by two factors, partly the structures and partly the geomorphology of the area. The local groundwater flow direction variable from place to place depending on local topography.

Usually the recharge areas were located in high elevation and this area has deep unsaturated zone between the land surface and water table. The amount of recharge is controlled by the amount of precipitation, topography, existing temperature, vegetation (land cover), slope gradient (land terrain) and permeability of the rocks. The precipitation of the catchment is controlled by the elevation and relatively high amount of precipitation observed in the elevated plateau and mountain area. Eastern, north eastern and south eastern highlands are. The main recharge areas of the catchment of the catchment because high precipitation common in these areas. Topographically high areas precipitation and loss from ephemeral streams are the main sources of the recharge.

Groundwater flow direction

Groundwater movements were from recharge area (highland) to Discharge area (lowland) or from high elevation to low elevation area by gravity following surface topography like streams and rivers. It moves below surface like surface water but the movement is very slow. The movement of groundwater highly depends on geomorphology, geology and structures. The local groundwater flow directions vary from place to place depending on local topography and structural arrangements. In the study area groundwater flows from eastern to western direction following surface topography look the hydrogeological map of figure 5.1.

Groundwater discharge

The discharge areas were located at lower elevation and relatively the water table either close or at the earth surface in discharge areas (Fetter, 1994 as cited in Ketema Wogari, 2006). During the field, the discharge areas selected by looking vegetations, structure and surface water. Most of the springs emanated from highland tertiary volcanic rocks through topographic breakage and structures. The groundwater abstraction by boreholes drilling for community water supply another means of discharged. Generally the discharge area is located in central and western parts of the study area.

CHAPTER SIX

HYDROCHMISTRY

6.1. General

The chemical composition of the groundwater is derived from different sources of solute and determined by soil minerals, rock composition, travel distance, length of time and geological formation. The hydrochemistry of the research area first understand the geology, distance of recharge and discharge area, the movement and occurrence of groundwater on the basis of major ionic components. In general the hydrochemistry of the investigated areas are distinct difference from highland to lowland and the shallow and deep aquifer system because of the chemistry of groundwater is controlled by rock-water interaction during groundwater flow from recharge area to discharge area and from surface to sub-surface depth reservoir, travel distance and age of rock and water (Tenalem Ayenew et al., 2008). So the interaction between groundwater and geologic materials determine the water quality. The hydro-chemical data is very important information to study the different water samples and to limit the consumption for various purposes.

Groundwater chemistry influenced by natural process and human activities (like agriculture, industries). The volcanic rocks forming aquifers in the study area are represented by various types of basalts and ignimbrites. The groundwater of the highland and escarpment area is suitable for drinking without further treatment. Generally in volcanic highland area the groundwater and surface water have good quality for domestic and irrigation.

6.2. Measure and characterize in-situ water quality

Water samples were collected from the investigated area during field work to measure physicochemical parameters at different water points. These water samples are representative and reliable samples from different water source of the catchment area. For this research 18 water samples were collected and measured the physicochemical parameters. Among these 18 water samples; eight samples from shallow wells, two samples from deep wells and the rest eight samples from springs and hand dug wells. During field work in-situ measurement were made for temperature (T), pH, electrical conductivity (EC), and total dissolved solids (TDS).

Table 6.1 in-situ measured data/water point data

ID	UTM N	UTM E	Locality	Z [m]	Spring/well	Lithology	Field Temp	Field EC	Field pH	TDS
S1	566612	1111315	Alga-Dingay	2874	Shaloww well	volcanic	19.1	275	6.74	178.75
S2	575312	1118553	Dasa	3042	Shaloww well	volcanic	20	271	6.74	176.15
S3	552382	1115777	Girgra	2741	Shaloww well	volcanic	25.4	253	6.58	164.45
S4	565655	1125909	Toramesk	2934	Shaloww well	volcanic	18.7	242	6.92	157.3
S5	561245	1138330	Tsehay Sina p.s	2933	Shaloww well	volcanic	18	165.1	6	107.315
S6	571169	1141039	Tsiftsaf	3057	Spring	volcanic	18	311	6.79	202.15
S7	565160	1097540	Barmeda w1	2870	Deep well	volcanic	20	131.9	6.18	85.735
S8	568216	1100647	Wasiya	2868	Spring	volcanic	18.4	94.8	6.6	61.62
S9	574497	1082767	Weyn-Abchu	2976	Spring	volcanic	18.4	94.8	6.6	61.62
S10	571511	1076092	Gum-Wuha	2920	Spring	volcanic	17.7	119.5	6.57	77.675
S11	570431	1074959	Shema-matebiya	2852	Spring	volcanic	17.5	143.8	6.75	93.47
S12	562907	1072827	Beryo p.School	1208	Shaloww well	volcanic	20	141.3	6.37	91.845
S13	562018	1074235	Aba-Hora	2759	Spring	volcanic	20	130.9	6.34	85.085
S14	561895	1074556	Doyo-Ager	2732	Spring	volcanic	19.2	109.5	6.03	71.175
S15	560029	1061185	Laymilky/Qiqe	2864	Spring	volcanic	19.2	104.5	6.84	67.925
S16	572958	1066589	Girgira/Ribrb	3115	Hand Dug Well	volcanic	15.7	84.5	6.57	54.925
S17	572398	1065845	Abilamoch	3106	Shaloww well	volcanic	14.9	337	6.59	219.05
S18	555477	1067455	AquaSafe Fac W1	2768	Deep well	volcanic	19.5	245	6.73	159.25

6.3. Physicochemical parameters

Physicochemical parameters of water samples were measured on the field. The measured parameters are temperature (T), electric conductivity (EC), pH and total dissolved solids (TDS) were made. The water quality and suitability for specific use like domestic, irrigation and industry.

6.3.1. PH (Hydrogen ion activity)

The pH is a measure of how acidic or basic water and ranges from 0 to 14, with 7 is neutral. The hydrogen ion concentration of the water is measured by PH. The PH values less than 7 indicate acidity where as a pH greater than 7 indicate a base. For drinking water the PH value ranges between 6.5 and 8.5 is usually measured acceptably in WHO guideline.

The pH value in the study area ranges from 6 to 6.91 measured at field in situ measurement. The lowest pH value record in sample (S5) Tsehay-Sina primary school shallow well and the relatively high pH records in (S4) Tora-mesk shallow well. Relatively high pH values on the north eastern and southern parts of the catchment.

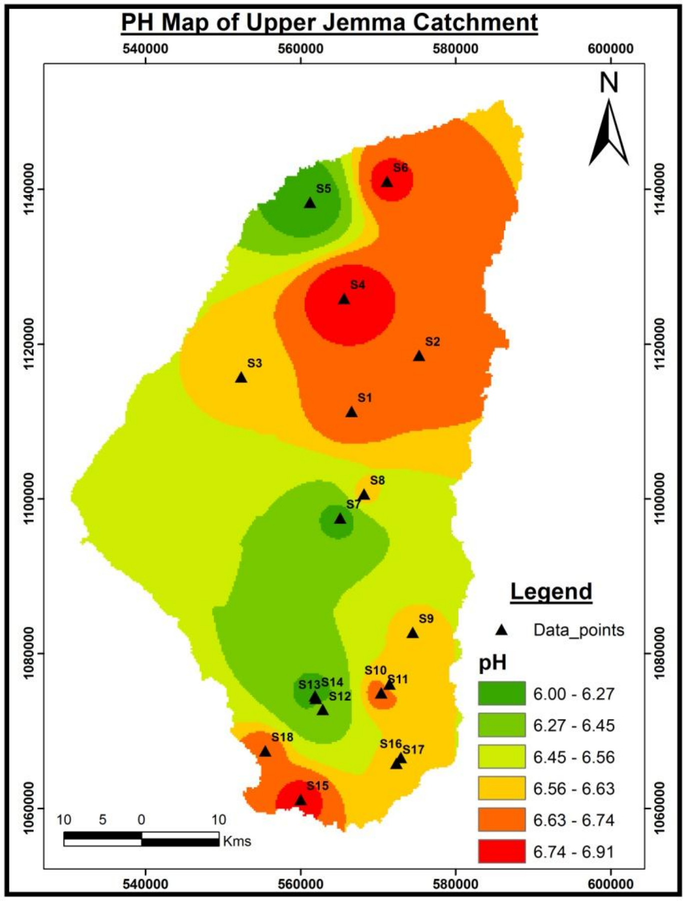

Figure 6.1: pH map of upper Jemma catchment

6.3.2. Temperature

The water temperature is mainly controlled by weather, climate and volcanic activity in the ecosystem. The water temperature is an essential property that determines water suitability for human use, agriculture, industrial activity and aquatic ecosystem existence. The temperature of water extremely affects aquatic organisms; state of nature, dissolved oxygen and characteristic of the water. The following parameters such as color, odor, turbidity and pH, EC are also affected by temperature directly or indirectly (Ketema Wogari, 2006).

Temperature mainly influences biological activity and the speed of chemical reaction as well as the concentration of the reactant, the products, and solubility of gases in the water.

The temperature of water sample in the study area ranges from 14.9 ^{o}C to 25.4^{o}C during in situ measurement on the field. The lowest temperature (14.9 ^{o}C) records in Abilamoch shallow well site (S17) and the highest temperature (25.4 ^{o}C) records in Girgira shallow well site (S3) at the western side of the catchment. The western part of the study area has high temperature and south eastern parts of the area show low temperature.

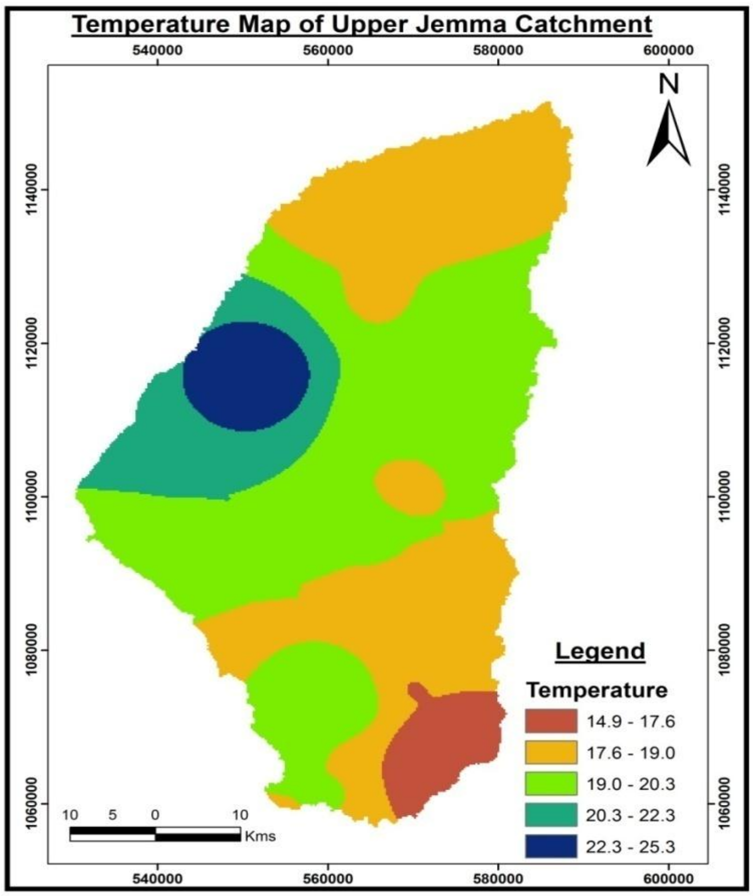

Figure 6.2 Groundwater Temperature map of upper Jemma catchment

6.3.3. Total Dissolved Solids (TDS)

Total dissolved solids (TDS) describe all solid materials in a solution or mineral salts are dissolving in water. It characterizes the sum of concentration of all dissolved constituents in a water sample. They are a number of dissolved organic components found in natural water and the units of TDS usually measured in mg/l. In groundwater major cat-ions are sodium, calcium, magnesium and potassium and the major anions are carbonate, bicarbonate, sulfate and chloride. These major constituents contribute to total dissolved solids. In addition to these miner constituents are boron, iron, nitrate, fluoride, strontium and manganese. The classification of water based on total dissolved (TDS) value (Freeze and Cherry, 1979).

Table 6.1 classification of water based on TDS (Freeze and Cherry, 1979)

Water types	Total dissolved solid
Fresh water	0 – 1000
Brackish water	1000 – 10,000
Saline water	10,000 – 100,000
Brine water	>100,000

In the study area the measured values of TDS in-situ result ranges from 55.8 to 217.2 mg/l. The measured value of all samples in the upper Jemma catchment is less than 1000mg/l. According to (Freeze and Cherry, 1979) classification all samples under fresh water (0-1000) range. Based on the TDS value; the groundwater in the study area is fresh water for drinking looks table 6.3.

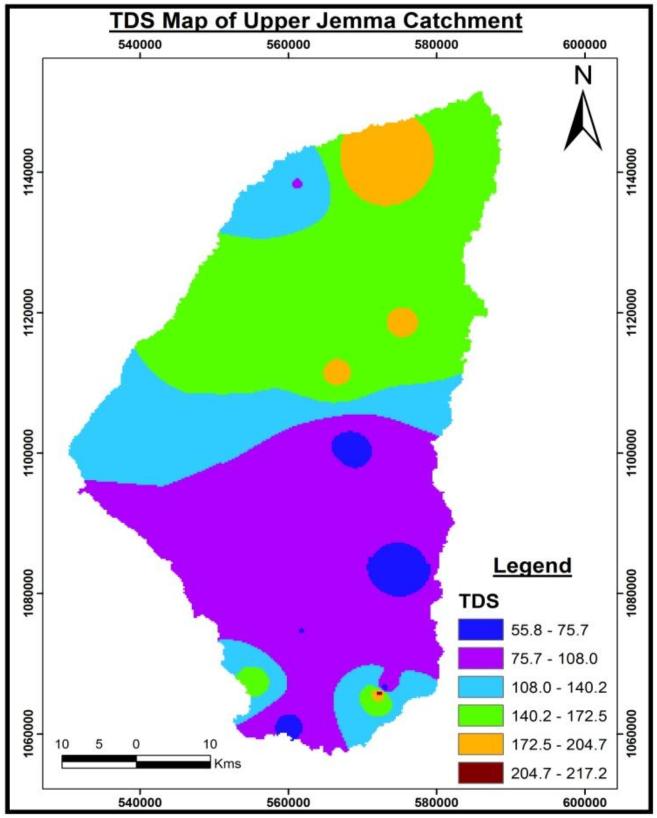

Figure 6.3 TDS distribution map of Upper Jemma catchment

6.3.4. Electrical Conductivity (EC)

The electrical conductivity of water is an indirect measure of dissolved constituents and presence of chemical components. The presences chemical constituents and dissolved salts in water and that have ability to conduct electricity. The electrical conductivity and total dissolved solid has close relation. The dissolved salts more in the water the value of the electrical conductivity higher. The units of EC expressed in terms of µS/cm.

The rock minerals are dissolved during the movement of groundwater along the formation from recharge area to discharge area and the water enriched by various chemical compounds. The volcanic rocks forming aquifers in the study area are represented by various types of basalts and ignimbrites.

The electrical conductivity of the Upper Jemma catchment ranges from 85.8μS/cm to 334.2μS/cm. The northern and northeastern part of the study area is characterized by relatively high electrical conductivity because the anthropogenic influence of the Mehal-Meda and Molale towns.

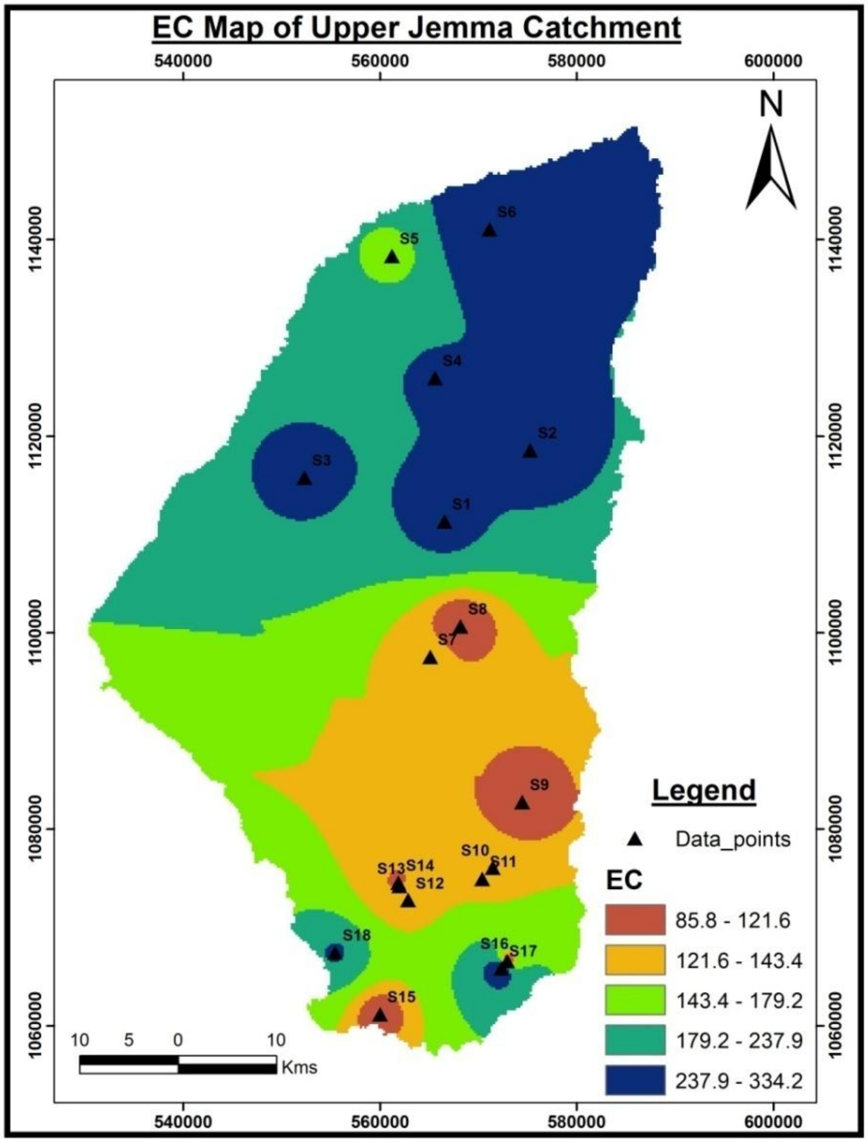

Figure 6.4: EC distribution map of Upper Jemma catchment

CHAPTER SEVEN

RESULT AND DISCUSSION

7.1. Groundwater Resource Evaluation

To understand the instruction between surface and groundwater different physical and chemical instruction methods are used but in the upper Jemma catchment analysis of different Meteorological, geological, hydrogeological and geo-morphological physical parameters were used. The rivers flow from eastern highland to western lowland on the study area. The basin has high rain fall during summer and dry during winter time. Therefore high amount of rain fall in the upper Jemma catchment during summer saturate the subsurface and flows down without losing the initial discharge rather gaining downstream. But during long dry winter time the groundwater table decline below the rivers bed channel and the rivers start to feed the groundwater as losing streams.

7.2. Annual Precipitation of the Area

There are three different method used to calculate the average areal depth of precipitation in any catchment area those are arithmetic mean method, Thiessen polygon method and Isohyetal method. In these three methods gets nearly similar or slightly different results in Arithmetic, Thiessen polygon and Isohyetal methods was resulted 1114.3mm, 1050.587mm and 1089.5mm/year respectively. For this research arithmetic mean method is chosen over Isohyetal and Thiessen polygene method because evenly distributed rain gage station. However the altitude control the precipitation Debresina station located at lower elevation (2800m) than Molale station (3046m) but the annual precipitation is higher in Debresina (1885.55mm) than Molale (731.76mm) respectively

The precipitation bar graph displayed the maximum rainfall and the minimum rainfall recorded in the month of July and December respectively. The majority of the rainfall in the basin is obtained during the summer time (Kiremt) June, July, august and September which covers 74% of the total annual rainfall and the minimum rainfall records are in the months of January, February, November and December which covers only 6% of the annual rainfall. The rest 20% of the annual precipitation recorded in the months of March, April, May and

October. The mean monthly rainfall intensity of the area is clearly illustrated in the graph shown below.

Table 7.1 seasonal rainfall percent of upper Jemma catchment

Precipitation (%)	Months of the year
70%	June, July, august and September
20%	March, April, May and October
6%	January, February, November and December

7.3. Groundwater Recharge Estimation

Precipitation in the catchment partly becomes runoff, some part is evapotranspiration and the remaining may infiltrate in to the ground. Annual groundwater recharge was estimated by determining the product of annual precipitation, estimated annual runoff and estimated actual evapotranspiration. Groundwater recharge is the reminder of runoff and ET from the precipitation. Rainfall, climate, soil, topography, geology, soil, structure and land use land covers are affect the groundwater recharge. The area coverage and the infiltration rate are very important for recharge estimation techniques. Soil moisture water balance method has been used for recharge estimation, Surface runoff and Actual Evapotranspiration (AET) can be easily computed and analysis can be made through over the outputs.

The water balance represents the hydrogeological gains and losses of a given system over a specific period (Tenalem Ayenew and Tamiru Alemayehu, 2001). Water balance can be determined by calculating the groundwater input, output and storage changes of water in the study area. The general formula of water balance is given by

Inflow = out flow ± change in storage.

$I = O \pm \Delta S$

$P + Gi = AET + SRO + R + GO \pm \Delta SG$

Where; **P** = precipitation,

Gi = groundwater inflow,

AET = actual evapotranspiration**,**

R = Recharge,

SRO = surface runoff,

Go = groundwater outflow,

ΔSG = change in groundwater storage,

The annual change of water storage assumed to be zero for an aquifer under steady sate condition because the assumption is made that the inflow (Gi) and outflow (Go) amount are balance or equal. The water balance equation of the study area as follow

To estimate of groundwater recharge using water balance method/equation of the catchment

R = P – AET - SRO   Where,

R - Groundwater recharge

P - Mean annual precipitation in mm/year

AET - Estimated Annual actual Evapotranspiration in mm/year

SRO - estimated annual runoff in mm/year

Therefore, Annual Groundwater recharge of the study area is

R = P – AET - SRO

R= 1114.3 mm/year - 745.77 mm/year - 234.23mm/year

R=134.3mm/year

The amount of groundwater recharge in the upper Jemma catchment calculated using water balance method (WBM) which resulted 134.3mm/year. From the annual precipitation 1114.3mm/year of the area 12% recharged to the groundwater system. The rest 88% of the precipitation removed by surface run off and evapotranspiration. In the study area have high run off during the rainy season due to the steep slope and rugged topographic nature of the recharge area.

7.4. Characterization the Aquifer System

Aquifer is a geological media mainly a function of geological material, sediment grain size, degree of sorting, degree of weathering and fracturing. Any aquifer characterized by the subsurface geology, structural features, Lithology, weathering and hydrogeological nature formations. Good aquifer must be sufficiently permeable with interconnected pore space and fissures and with enough storage to yield groundwater. Groundwater bearing potential related to porosity, geological structures, grain size and sorting, fractured and weathered zone in the rock mass.

Elluvial and Alluvial deposits; are good formation for shallow (unconfined) groundwater reservoir potential zone. The porous aquifers are represented by alluvial and elluvial material of a Quaternary age in the study area with porous permeability. These formations increase the recharge of groundwater infiltration and percolation. Alluvial sediments are deposited at the base of the mountain and the side of the river transported from the adjacent highland area and deposited with variable thickness. This formation has high discharge but it difficult formation for drilling. Eluvium sediments are located in central and southern parts of the study area and this formation has good shallow groundwater reservoir.

The groundwater occurs between pore spaces in the unconsolidated and semi consolidated materials. The availability of the groundwater in the unconsolidated materials depends on the grain size, shape, sorting, cementing material and thickness of the deposition.

Weathered and fractured basalt: most of the study area covered by volcanic rock with fractured and weathered basalt and fractured and weathered trachyte with ignimbrite rhyolite. The degree of fracturing and weathering are variable from place to place. Several springs emerged from these types of formation with different yield of springs.

The porous aquifers are represented by alluvial and elluvial material of a Quaternary age in the study area with porous permeability. The groundwater occurs between pore spaces in the unconsolidated and semi consolidated materials. The availability of the groundwater in the unconsolidated materials depends on the grain size, shape, sorting, cementing material and thickness of the deposition. The eluvium is mainly distributed over the plateau area and at the foot of mountains chains. The alluvial sediment consists of different grain size such as sand, silt and gravels with variable size. Gravel and sand have high storing and transmitting capacity for shallow groundwater

The upper sandstone aquifer mostly uncovered in the lower valleys of the Jemma and its tributaries (Beressa and Mofer Wuha). It has well developed primary and secondary permeability. The Middle basalt commonly known as Alajae basalt or Kesem basalt is mainly distributed in the lower sections of the Beressa, Bersena and Mofer wuha river valleys. It is vesicular at the top, flow banded in the middle and massive at the bottom. It is highly faulted and fractured, irregularly to columnar jointed, and spherical weathered, which enhances the permeability of the aquifer. This rock discharge has from 30 l/s up to 60 l/s and depth of wells is 300 m to 380 m. Some springs with a discharge of up to 2.7 l/s emerge from this aquifer.

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7.5. Measure and Characterize In-Situ Water Quality

Water samples were collected from the investigated area during field work to measure physicochemical parameters at different water points. These water samples are representative and reliable samples from different water source of the catchment area. For this research 18 water samples were collected and measured the physicochemical parameters. Among these 18 water samples; eight samples from shallow wells, two samples from deep wells and the rest eight samples from springs and hand dug wells. Physicochemical parameters of water samples were measured on the field. The measured parameters are temperature (T), electric conductivity (EC), pH and total dissolved solids (TDS) were made.

The pH value in the study area ranges from 6 to 6.91 measured at field in situ measurement. The measured pH values water is less than seven and more acidic nature because of the acidic rock more in the area. The lowest pH value record in sample (S5) Tsehay-Sina primary school shallow well and the relatively high pH records in (S4) Tora-mesk shallow well. Relatively high pH values on the north eastern and southern parts of the catchment.

The temperature of water sample in the study area ranges from 14.9 ^{o}C to 25.4^{o}C during in situ measurement on the field. The lowest temperature (14.9 ^{o}C) records in Abilamoch shallow well site (S17) and the highest temperature (25.4 ^{o}C) records in Girgira shallow well site (S3) at the western side of the catchment. The western part of the study area has high temperature and south eastern parts of the area show low temperature. The western part of the study area has high temperature because of deep circulation.

The study area has measured values of TDS in-situ result ranges from 55.8 to 217.2 mg/s. The measured value of all samples in the upper Jemma catchment is less than 1000mg/l. According to (Freeze and Cherry, 1979) classification all samples under fresh water 0-1000 range. Based on the TDS value; the groundwater in the study area is fresh water for drinking looks table 6.1. In most parts of the study area has low TDS value because presence high rainfall and local groundwater flow.

The rock minerals are dissolved during the movement of groundwater along the formation from recharge area to discharge area. The volcanic rocks forming aquifers in the study area are represented by various types of basalts and ignimbrites. The electrical conductivity of the Upper Jemma catchment ranges from 85.8µS/cm to 334.2µS/cm. The northern and northeastern part of the study area is characterized by relatively high electrical conductivity because the anthropogenic influence of the Mehal-Meda and Molale towns and relatively high temperature and wind speed.

7.6. The Groundwater Discharge

The groundwater discharge areas were located at lower elevation and relatively the water table either close or at the earth surface in discharge areas (Fetter, 1994 as cited in Ketema Wogari, 2006). During the field discharge areas selected by looking vegetations, structure and surface water. In the elevated plateau and undulated highland area groundwater discharged as a spring, seepage on the depression and sub-surface flow to the rivers. Most of the plateau springs emerge from tertiary volcanic rocks through topographic breakage and other fault systems. Most of the springs emanated through weathered and fractured parts of the volcanic rocks at the topographic breakage and intermountain depression. The groundwater abstraction by boreholes drilling for community water supply another means of discharged. Generally the discharge areas of the upper Jemma catchment located in central and western parts of flat land, gentle slope and valley bottom of the study area.

Groundwater is replenished by precipitation, when it rains some of the water flow in the form of run off to streams, some evaporates, and some recharges aquifers. This process depends on the climate, Physiography and geology of the area and unevenly distributed in both quantity and quality. Groundwater occurs nearly everywhere in the world at different depths ranging from land surface to about 2000 ft below the land surface and it is stored and transmitted through aquifers.

The chemical composition of the groundwater is derived from different sources of solute and determined by soil minerals, rock composition, travel distance, length of time and geological formation. Groundwater chemistry influenced by natural process and human activities (like agriculture, industries). The volcanic rocks forming aquifers in the study area are represented by various types of basalts and ignimbrites. The groundwater of the highland and escarpment area is suitable for drinking without further treatment. Generally in volcanic highland area the groundwater and surface water have good quality for domestic and irrigation.

CHAPTER EIGHT

CONCLUSION AND RECOMMENDATION

8.1. Conclusion

The study area is located on upper Jemma catchment in Blue Nile basin at the north western margin of main Ethiopian rift particularly in Amhara National Regional State, North Shewa Administrative Zone in central Ethiopia and part of Jemma sub basin. The administrative zone town is Debre-Birhan which is located 130 km distance from Addis Ababa which is the capital city of Ethiopia and Molale town is located 124 km distance from Debre-Birhan town towards north direction.

The study area covered 3250 sq.km and having an average elevation ranges from 1556m to 3708m above mean sea level. The main objective of the study was to evaluate the groundwater resource and calculate the recharge by analyzing the available meteorological data. The annual precipitation of the basin calculated from long term mean monthly rain fall data is 1114.3mm/year.

The amount of groundwater recharge in the upper Jemma catchment calculated using water balance method (WBM) which resulted 134.3mm/year. From the annual precipitation 1114.3mm/year of the area 12% recharged to the groundwater system. The actual evapotranspiration (AET) and SRO are 745.77mm/year and 234.23mm/year respectively. The rest 88% of the precipitation removed by surface run off and evapotranspiration. In the study area have high run off during the summer season almost 74% of the rainfall drop during this rainy season. The methods and approaches has been conducted pre-field, field work and post fields and the following methods and materials were used

According to (Serwit Amene and Tamrat Mojo, 1995) the geology of Jemma river valley is located in the Eastern part of the central highland of Ethiopia characterized by sharp escarpments, cut by shallow and deep gullies and stream channels. According to the previous works in the study area the description of geological reports and maps provided by several mapping groups by GSE in 2010. The upper Jemma catchment is part of the central

Ethiopian in northwestern plateau. The geology of investigated area was observed during field work along the accessible traverse during the field and reviews the previous geological maps. In this investigated area have different litho-stratigraphic units are found in different setup dominantly covered by volcanic rocks, sedimentary rock and recent sediments are common. From volcanic rocks (Kesem basalt, Seladingay-Debrebirhan Gorgo Ignimbrite, Tarmaber-Megezez basalt, Molale Ignimbrite)

The major rivers in the study area are Mofer-Wuha, Awel Beressa, and Wizer & Shay River (around Mehal-Meda). The upper Jemma Rivers and most of the tributaries are perennial. These rivers and its tributaries are drained from the highland area to the lowland area that is from eastern, northeastern and southeastern parts of the catchment to the western direction of the outlet and link toward the Jemma River through steep gorges. The upper Jemma catchments are characterized by different drainage system like Rivers and streams are parallel to sub-parallel and dendritic to sub-dendritic drainage pattern which follow the fractures and weak zones. All rivers and streams in the study area join Jemma River which is one of the Maine tributary of Abay basin. These rivers are flooded during the rainy seasons but reduced their thickness in the dry season.

Kesem basalt locates on the gorge of Mofer-Wuha River and Beressa River deep down stream drainage system. The Kesem basalt highly fractured sporadically weathered, columnar jointed, and dominantly aphanitic to phorphyritic in texture. It is forms cliff structure on the side of the river gorges dark to gray color and fine grain size. The aphanitic Kesem basalt dominantly plagioclase groundmass this plagioclase basalt exposed on the upper part of aphanitic basalt cliff forming (Daniel Mesesha et al., 2010). Aphanitic basalt is fine grained, the most abundant, dark gray to black (fresh color) and bluish (weathered color).

Seladingay-Debrebirhan gorgo Ignimbrite mainly exposed in Seladingay area it extends in different parts like Debrebirhan, Ankober, and Aliyu-amba. The rock contact underlined by Kesem basalt and over lined by Tarmaber-Megezez basalt. Consolidated to welded tuff and bedded with fracture, vertical and columnar joints. It holds rock fragments of rhyolite and basalt ranging up to two centimeter in diameter elongated fibrous glass but the quantity of rock fragments considerably variable from place to place.

The Tarmaber-Megezez basalt exposed Tarmaber Mezezo, Ankober and parts of highland area and mountain converge. The rocks sharp contacts with underling by Seladingay-Debrebirhan gorgo Ignimbrite and over lined by surface.

The geological units of the study area classified into aquifers and aquitards based on the geological description, qualitative and very limited quantitative (yield of springs and hydraulic characteristics of boreholes) data. Aquifers are classified according to their productivity, physical properties of rocks and sediments, based on field observation, discharge and distribution of springs and pumping test data of the deep wells.

The occurrence of groundwater in sedimentary and volcanic rocks depends on the type of permeability formed during and after the rock formation. The fractured and weathered parts of the volcanic and sedimentary rocks increase the groundwater flow and storage. In the study area the volcanic rocks are highly weathered, fractured and jointed parts can store and transmit a relevant amount of the groundwater.

The porous aquifers are represented by alluvial and elluvial material of a Quaternary age in the study area. The groundwater occurs between pore spaces in the unconsolidated and semi consolidated materials. The availability of the groundwater in the unconsolidated materials depends on the grain size, shape, sorting, cementing material and thickness of the deposition. The eluvium is mainly distributed over the plateau area and at the foot of mountains chains. The alluvial sediment consists of different grain size such as sand, silt and gravels with variable size. Gravel and sand have high storing and transmitting capacity for shallow groundwater.

Mixed permeability aquifers are moderately to highly productive aquifers with porous and fissured permeability to wells and springs. The mixed aquifers are the combination of porous and fractured developed in fissured ignimbrite, rhyolite, trachyte, basalt and porous Tertiary sediments intercalating volcanic rocks on the plateau. These types' aquifers are found in Seladingay-Debrebirhan gorgo-ignimbrite

Aquitards/Aquicludes with very limited/no-groundwater resources: - this is common in fresh and massive rock area, such as trachyte, Molale rhyolite tuff, ignimbrite tuff; ashes are slightly weathered considered very low permeability. Even the fractured rocks are filled with secondary materials reduce the permeability the rocks.

8.2. Recommendation

The general objective of the study groundwater potential evaluation of upper Jemma catchment based on the available data, field observation and the research result the following recommendations are given below.

In order to protect the surface and groundwater pollution gives aware to the rural community and farmers properly utilize the fertilizer and pesticide during agricultural activities.

Most of the study areas are rugged and steep slope topography construct the terrace/shelf and plant the trees to reduce soil erosion and surface run off.

Most of the rural community uses spring, hand dug well and shallow well for domestic purpose, these water sources were not enough discharge. So the governments support and drill deep wells and solves the water shortage of water in the community.

The drilling companies properly develop the shallow wells until clean water discharged and properly construct the head work after development because most of the shallow wells are not properly functional even the functional wells have not clean water discharge.

In order to enhance infiltration rate and maximize groundwater potential, land and water resources conservation activities should be practiced in extremely degraded land of the catchment.

The government constructs river gage station in the outlet of major rivers in the catchment and properly recorded the data in proper manner for the futures and the coming researchers.

It needs further groundwater investigation and fined groundwater potential area for the community because of population number increase with living standards, so they need additional water sources.

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