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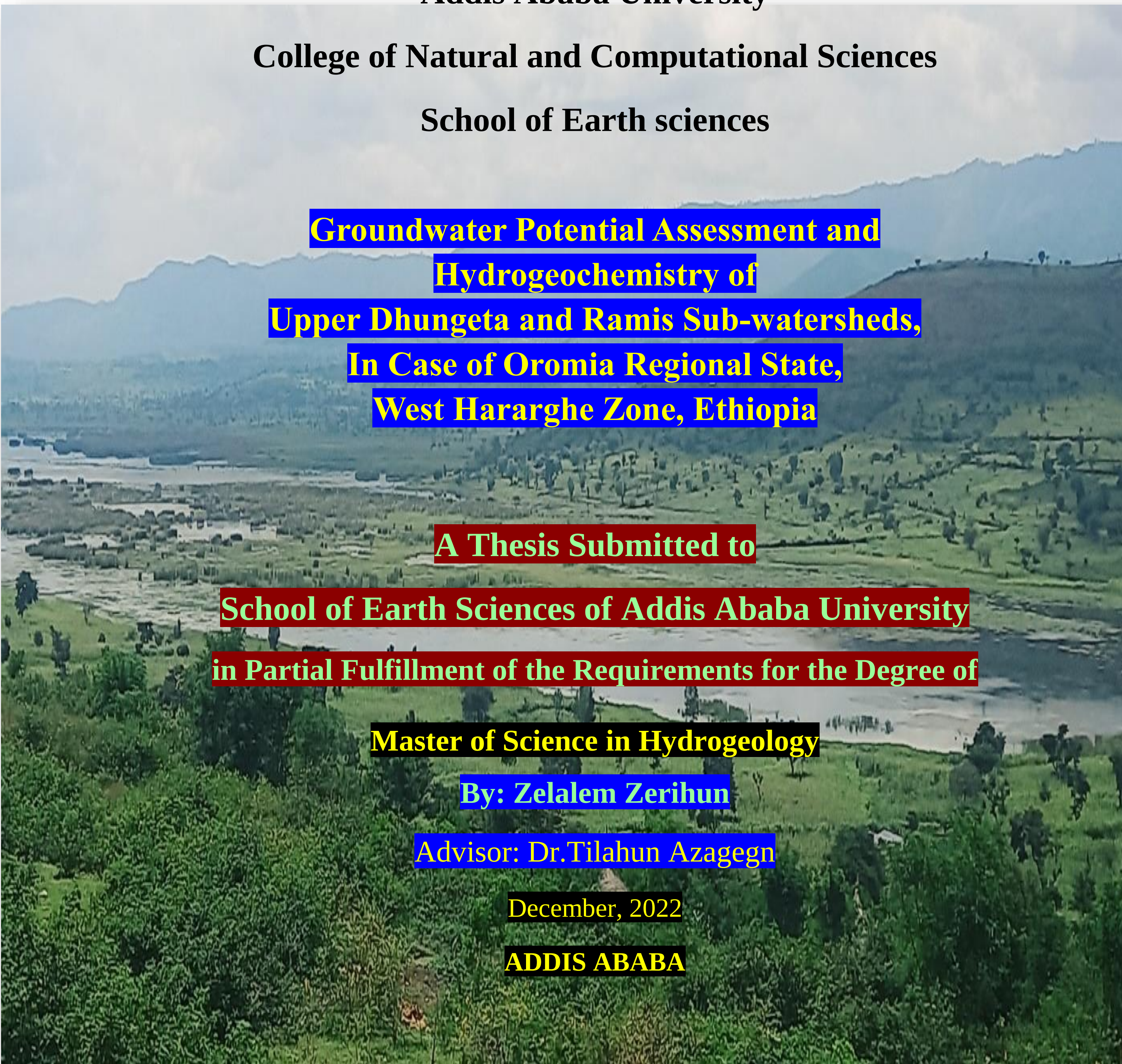

Addis Ababa University

College of Natural and Computational Sciences

School of Earth sciences

Groundwater Potential Assessment and Hydrogeochemistry of Upper Dhungeta and Ramis Sub-watersheds, In Case of Oromia Regional State, West Hararghe Zone, Ethiopia

A Thesis Submitted to

School of Earth Sciences of Addis Ababa University

in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Hydrogeology

By: Zelalem Zerihun

Advisor: Dr.Tilahun Azagegn

December, 2022

ADDIS ABABA

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Approved by the Board of Examiners:

Signature

Dr. _______________ (Examiner) ______________ Date_______________

Dr. _______________ (Examiner) ______________ Date______________

Dr. Tilahun Azagegn (Advisor) ______________ Date_______________

Declaration for Originality, Quality and Copy Right

I undersigned declare that this thesis is my original work for the requirement of the degree of Master of Science in Hydrogeology accomplished under the supervision of Dr. Tilahun Azagegn, School of Earth Sciences, Addis Ababa University, during the year 2021/22. My further declaration is that this work has not been presented and/or submitted to any other college, institution, or university for the award of any degree or Diploma. All the secondary data sources and materials used in the thesis work have been duly cited and acknowledged.

Zelalem Zerihun (MSc Candidate)

Signature________________________ Date: _____________________

Advisor: Dr. Tilahun Azagegn

Signature_______________________ Date: _______________________

Abstract

The main sources of water for domestic water supply of Bedesa, Gelemso, kara, wachu towns, Boke woredas and neighboring rural villages is Upper Dhungeta and Ramis Sub-watersheds where are found in the eastern escarpment of the rift valley on the upper part of Wabishebele river basin. Despite their importance, the hydrogeological and hydro geochemical system of the sub-watersheds is not well understood. This study was aimed to assess the groundwater resource potential and Hydrogeochemistry by identifying and characterizing the main aquifer types of the sub-watersheds, estimating the natural groundwater recharge, determining ground water flow directions, identifying geochemical evolution and suitability of the water in the sub-watersheds for different purposes. Well log data and hydraulic parameter values obtained from constant pumping test data were used to identify and characterize the aquifers in the sub-watersheds. For estimation of the natural groundwater recharge, soil water balance method was used. Groundwater flow directions also were determined from the groundwater contour map prepared by GIS software using groundwater level data. The study has indicated that there are three major types of aquifer types in the sub-watersheds namely Extensive and Moderately Productive Porous Aquifers, Extensive and Highly Productive Fissured Aquifers and Extensive and Moderately Productive Fissured Aquifer. From the computed meteorological data, the amount of water infiltrated to subsurface as a recharge was 101.2mm. Moreover, groundwater flow runs locally towards the low lands (Bedesa graben) which is considered as discharge area. Yet, regionally it flows from the west to east and southeast directions of the sub-watershed. Finally, Physical parameters measurement, and chemical analysis of water samples were analyzed to study the geochemical evolution of water in the area and the Ca-Mg-HCO_3 type is the dominant water type which indicates recharge area ground water with less time of residence and interaction with the surrounding rock/soil. Finally, by comparing with different standards and guidelines, Groundwater in the area is suitable for Domestic, Agricultural and Industrial purposes.

Key Words/Phrases: Groundwater Recharge, Flow Direction, Water Quality, Upper Dhungeta and Ramis Sub-watersheds

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Acronyms and Abbreviations

°C ……………………...Degree Celsius
µS/cm.……………….…Micro Siemens per Centimeter
AAWSA ………..……… Addis Ababa Water and Sewerage Authority
AEP …………………..…... Actual Evapotranspiration
BDL …... ………………. Below Detection Limit
BH………………………... Borehole
DEM ……………………... Digital Elevation Model
DR ………………………Direct Runoff
EARS ……………………... East African Rift System
EC ………………………Electrical Conductivity
EPA...………….………… Environmental Protection Agency
FAO……………………… Food and Agricultural Organization
GSE ....…Geological Survey of Ethiopia
GWL……………………… Groundwater level
GWR …………………… Groundwater recharge
ITCZ....………………..... Intertropical Convergent Zone
Km.…..…………….……… Kilometer
LD ……………….……Lithological Description
LMS ………………….….. Limestone
M …. ……………….………Meter
MER ……………..……… Main Ethiopian Rift
Mg/l ………………………Milligram per Liter
Mm/a ……………….…......... Millimeter per Annum
MM-DRF…………….….…Mean Monthly Direct Runoff
MM-PET ………………… Mean Monthly Potential evapotranspiration
MM-RF ………….…….… Mean Monthly Rainfall
MoWIE …………………… Ministry of Water, Irrigation and Energy
NMA ……………..……… National Meteorological Agency of Ethiopia
NMSA ……………..……. National Meteorological Service Agency
OLI/TIRS ………..………Operational Land Imager and Thermal Infrared Sensor
OWEDB ……………..……. Oromia Water and Energy Development Bearuea
PET ……………..………… Potential Evapotranspiration
PH ………………..………...Hydrogen-ion Activity
RF …………..………………Rainfall
SRTM……………….……...Shuttle Radar Thematic Mapper
SST …………………..……. Sandstone
SWL…………..….…….....…Static Water level
TDS ………….…….….……Total Dissolved Solids
UTM ……………………... Universal Transverse Mercator
VOL ……………….……..... Volcanic Formation
WFB ……………...….…. Wonji Fault Belt
WWDSE …………………...Water Works Design and Supervision Enterprise

CHAPTER ONE

Introduction

1.1. General Background

Without water, life on Earth would be impossible. In fact, the major characteristic that sets the Earth apart from other planets in the solar system is the presence of water. The capacity to access affordable, dependable water supplies for home, agricultural, and industrial use is essential for carrying out our daily tasks(Gumm *et al.*, 2016). In the system of natural water resources, groundwater plays a very important role. In home, agricultural, and industrial settings, it is the most dependable and safest source of water. Geology, lithology, Geomorphology, drainage density, rainfall, geological structures, slope, land use, land cover, and soil of groundwater regime all affect the occurrence, origin, movement, and chemical composition of groundwater(Gintamo, 2015).

In terms of satisfying domestic, agricultural, and industrial needs, groundwater serves as a vital life support to human being. Despite being unevenly distributed over the world, it is the largest source of fresh water available today.

According to (Kebede, 2005), groundwater supplies more than 90% of the water used for domestic and industrial supply in Ethiopia, but only a very minor percentage of the water used for irrigation, which is primarily made up of surface water. It jeopardizes the sustainability of groundwater resources for usage in the future, and bad assessment of recharge makes the situation much worse. Large amounts of surface water in Ethiopia's lakes and rivers are used to generate the majority of the nation's electricity through hydropower. There are plans for more hydropower capacity expansion, including the "Grand Ethiopian Renaissance Dam," which will eventually be the biggest hydroelectric power plant in Africa. However, the nation has also had numerous, catastrophic droughts, which have had serious effects such as famine, increased poverty, and civil upheaval. Groundwater was in high demand due to the agricultural sector's rapid expansion and the growing population. As a result, several boreholes are drilled, and groundwater is developed and used. Over pumping of groundwater resources has occurred in some areas as a result of extensive development plans, urbanization, and rapid population growth in the nation (Adem, 2012). The type of soil and rock through which the water passes, the degree of weathering and solubility of the mineral components of rocks and soils, the extent and duration of contact with rocks and soils, temperature conditions, the type of dissolved and suspended solutes that falls with precipitation, and anthropogenic factors are some of the factors that affect the amount of ionic species in natural waters (Ayenew, 2006).

The study area is one of the areas in Ethiopia that unplanned groundwater resource development activity is carried out with little consideration to groundwater resource potential and flow system. The study area, Upper Dhungeta and Ramis sub-watersheds, is currently serving as a groundwater source for domestic water supply mainly for Bedesa, Gelemso and Boke Tiko woredas in west Harerghe zone. But in the rural areas, the farmers are extracting groundwater for domestic and irrigation purposes. Therefore, it is important to assess the groundwater resource potential for sustainable utilizations of the resource.

1.2. Problem Statement

The increasing demand on groundwater resources and the complex nature of different aquifers requires accurate and reliable characterization and evaluation of groundwater dynamics and its recharge for sustainable groundwater management. The country Ethiopia is even now not made detailed studies of groundwater dynamics and recharge at large scale in spatial distribution. Majority of these studies are regional and concentrated some selected areas of the country.

Upper Dhungeta and Ramis Sub-watersheds is the area where groundwater is abstracted for Bedesa, Gelemso and Boke towns and surrounding kebeles in west Harerghe zone water supply. The demand of groundwater for urban and rural domestic water supply and irrigation is dramatically increasing from time to time. This resource is the key to the economic development in the area and hence the quantification of the groundwater recharge and hydrogeochemical study is necessary for the efficient and sustainable groundwater resource management.

There are also some unprotected springs and rivers in the Upper Dhungeta and Ramis Sub-watersheds that are utilized by Communities for a wide range of purposes throughout the year. The scarcity of these water sources, their quality related problems, and inequities in access for local beneficiaries makes intense competition for access and conflict among upstream and downstream users.

This research work intends to solve those problems and uncertainties by Characterizing aquifer type and properties, recognizing groundwater quality differences, and mapping the area's groundwater capacity through lithological, hydrogeological, geochemical studies using Several Bore hole and uniform pumping test data with field Observations in order to improve the scarcity of Water and Quality related problems and to solve different challenges which is faced to the sub-watersheds.

1.3. Objectives

1.3.1. General Objective

The main objective of the study is to evaluate groundwater resource potential and the hydro geochemistry of Upper Dhungeta and Ramis Sub-watersheds.

1.3.2. Specific Objectives

To estimate annual groundwater Recharge in the Sub-watersheds.

To characterize the major aquifer systems

To characterize the groundwater flow dynamics

To characterize hydro geochemical evolution in the Sub-watersheds

To identify suitability of the water in the sub-watersheds for domestic irrigation and industrial purposes.

1.4. Significance of the Study

The outcome of this research will give a contribution for both the scientific society and the general community**.** Understanding groundwater resource potential and the Hydrogeochemistry of the sub-watersheds is crucial for proposing the maximum benefit from the aquifer(s) found in the sub-watersheds without affecting the aquifers. Quantifying the sub-watersheds groundwater potential help us a base for further groundwater exploration and development. Besides based on the newly generated data during this research work, it will be used as a basic input for related studies that will be conducted in the future.

In addition to the classification for drinking and irrigation the analysis of the chemistry of groundwater is useful for understanding of movement and direction of groundwater flow as well as recharge and discharge area. The usefulness of groundwater for various purpose can be established based on the type and concentration of the dissolved solutes.

The concentration and composition of soluble salts in water will determine its quality for various purposes (human and livestock drinking, irrigation of crops, etc.). The quality of water is, thus, an important component with regard to sustainable use of water for irrigated agriculture, especially when salinity development is expected to be a problem in an irrigated agricultural area. (Shahid, Zaman and Heng, 2018).

1.5 Previous Work

Published articles concerning the hydrogeology and Hydrogeochemistry around the study area are scarce, which means Upper Dhungeta and Ramis Sub-watersheds is less studied. And even most of the published literature obtained are for nearby watersheds and basins including Haramaya lake basin and they are related with works of a general nature and specific publications have not been available that are concerning geology, hydrogeology and hydrochemistry.

Some previously conducted research in the study area and around the vicinity on the hydrological, hydrogeological, hydro geochemical, geological and structural evolution include Hydrogeological map of Bedesa Sheet (NC 37-16) which is compiled by (GSE, 1988). In the study, factor affecting the groundwater occurrence, the productivity of aquifer and Hydro chemical characteristics of groundwater are explained.

Zenebe Bogale conducted a research on Groundwater Resource Potential Assessment: A Case of Bedesa-Gelemso Sub-Watersheds. In its study the recharge in the sub-watersheds by using water balance method was 148mm/year (Bogale, 2016).

1.6 Methodology and Material used

1.6.1. Methodology

To accomplish this research, a lot of time and effort was put into gathering relevant primary and secondary data from concerned institutes and previous studies. In general, all the activities performed in this study can be classified into three phases.

Pre-field work phase: - was the first phase, which included field planning for thesis work, as well as arranging the equipment and materials required for the thesis work: -

- Secondary data such as meteorological data (precipitation and temperature) were collected from the National Meteorological Agency of Ethiopia (NMA);
- A theoretical framework and contents that will be incorporated in the proposed study was collected, developed and conceptualized;
- Field equipment including GPS, topographic map, geological maps, hydro-geologic map and hydro-geochemical, sampling equipment and other materials that will helpful during the field work were Prepared;
- Hydro meteorological data, well completion reports, pumping test data and hydro geological logs were collected from different institutions and organizations.
- Chemical Laboratory result data are collected from ODA (Oromia Development Association), West Hararghe zone water and energy office and Oda Bultum woreda water and energy office.

During field work phase was the second phase of this research work. Under this phase the following activities were conducted: -

- Geomorphological, geological and hydro geological setting and map of the area in terms of lithological description and identification of geological structures like faults and joints which may act as a conduit for groundwater and contaminant flow was made.
- Water samples, physical and chemical characteristics including total dissolved solids (TDS), major and minor ion proportion were analyzed.
- Photos of the representative geological exposures and representative geological rock samples were taken

Post-field work: was the process in which the entire thesis work was completed in the office, and the phase in which the collected primary and secondary data were interpreted, discussed, and presented and it includes the following activities: -

- Collection of additional data from different source, Processing satellite imagery and DEM data for understanding geological, Geomorphological, hydrological, and geographical features.
- Analysis and interpretation of field inventoried and collected hydrogeological, geological, meteorological and hydrometric data
- Water sample chemical analysis result data interpretation and presentation. By combining the previous hydrochemical data collected from different institutions/organizations and literature, water types, quality and sources of their constituents of groundwater was determined.
- Characterization and classification of lithological units based on their hydraulic parameters, Preparation of geological, hydrogeological and hydro chemical maps were conducted.
- Meteorological data taken from NMA (national meteorological agency) of Ethiopia contains some missing data. These missing data were filled with the inverse distance method.

1.6.2. Materials used

The following materials, equipment and different software's and applications were used to achieve the above-mentioned goals:

- Topographic, Geological and hydrogeological map sheets with relevant and available scale were used as base map in the field to mark the lithologies, their contacts and trends and to develop detailed geological and hydrogeological maps of the area.
- GPS**:** was used for recording the location (Geographic coordinates) of sampling sites, for finding travel direction, and to know the elevation of the area above mean sea level.
- Various computer software's (ArcGIS 10.8, Global Mapper 17, Surfer 10, aquifer test,

Graphics piper plot) and Microsoft offices including word, and excel.

Software's applied for this study were:

ArcGIS: location maps, climate map, soil map, land use and land cover maps, geological and hydrogeological map, drainage map and hydrochemical distribution map were prepared using ArcGIS Software.

Aquachem 2014.2: In the fields of hydrogeology and groundwater analysis, Aquachem Software is very powerful tools for visualizing the relative abundance of common ions in water samples. It used for hydrochemical analysis and water type classification and preparing different hydrochemical graphs which simplify the interpretation in terms of ionic dominance and water quality. Piper and Wilcox diagram were used for representing and comparing water quality analyses in the watershed.

A flowchart depicting the generalized approach of the research work is shown below

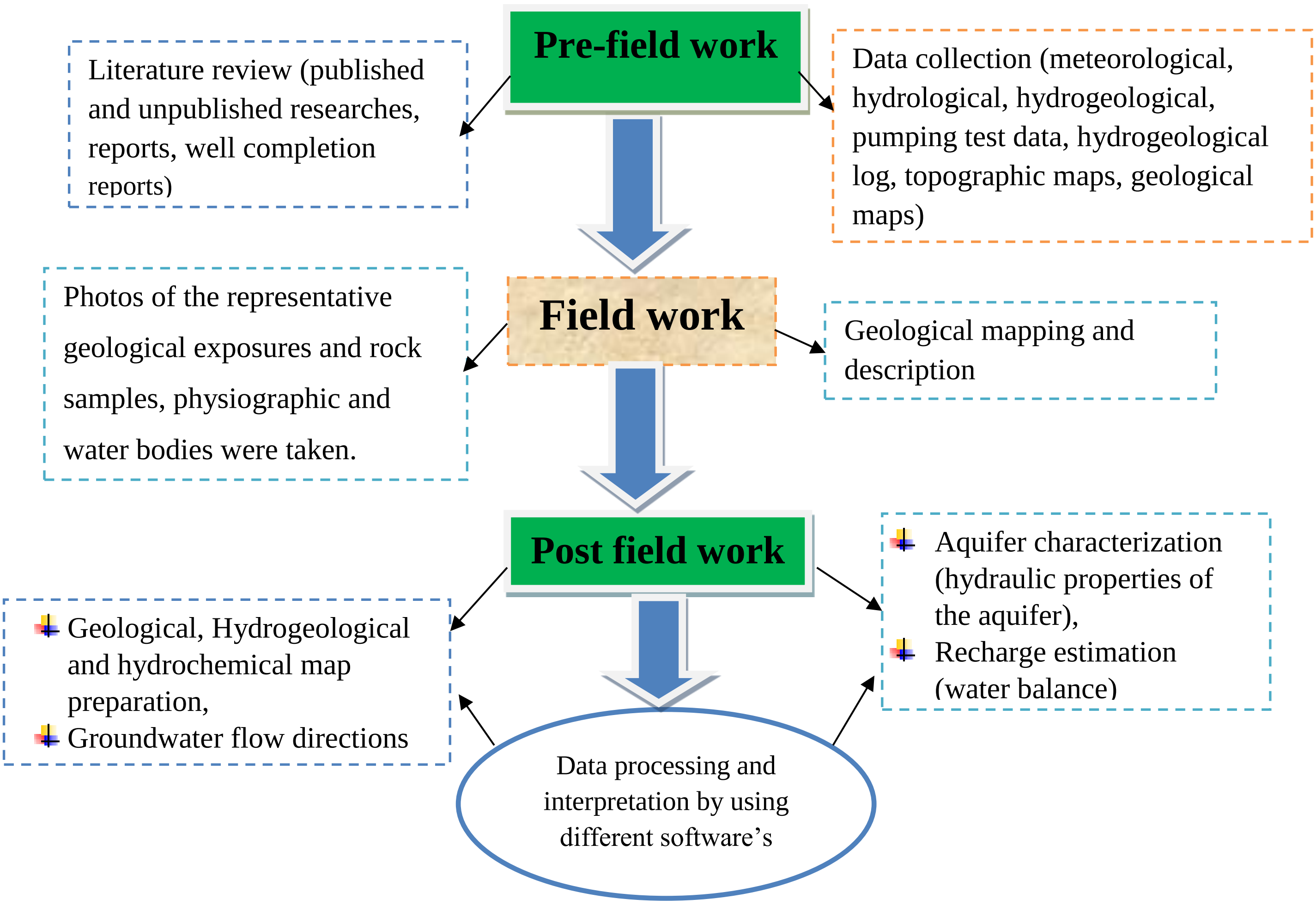


Figure 1. 1 Activity Flow Chart

CHAPTER TWO

Literature Review

2.1. Ground water Potential in Ethiopia

Ethiopia's groundwater potential is affected by diverse topography, climate, and soil types as well as complicated geological formations (Gebregziabher, 2012). Recent research suggests that groundwater reserves may be far larger than the standard estimate of 2.5 billion cubic meters (BCM). Kobo, Raya, and Adaa Bechoo studies for irrigated agriculture indicate that regional aquifers are deep and water circulation spans surface basin boundaries. Groundwater reserves in the Kobo Girana Valley alone are thought to be in the range of 2.5 BCM, 7.2 BCM, and 965 MCM (Gebregziabher, 2012).

Groundwater Resources Potential Assessment in the Alamata Sub-basin, Northern Ethiopia, was studied by Berhie (2006). Based on the transmissivity values determined using several methods in the Aqiutest software, he has categorized the potential of the local aquifers as high (>500m^2/day) to weak (0.5–5 m^2/day). He came to the overall conclusion that the Alamata Sub-basin has good groundwater potential from a hydrogeological and chemical standpoint, and the high potentiality aquifers were primarily discovered on the western side of the valley. He also calculated annual groundwater recharge about 120 Mm^3/year, which was confirmed using manual estimates and groundwater modeling.

(Adem, 2012) conducted a research on the evaluation of groundwater resources and sustainable management in the Adelle and Haromaya Dry Lake Catchment, Eastern Ethiopia. Groundwater is the only significant source for residential and irrigation needs in the Adelle-Haromaya region, claims (Adem, 2012). Since Lake Haromaya's death, the Adelle-Haromaya dry lake watershed has been characterized by significant groundwater exploitation(Adem, 2012). Despite having a small catchment area, the study region contains a variety of rock types with ages ranging from Precambrian to more recent unconsolidated deposits. The area's main aquifer system is housed in the unconsolidated strata. Using the water balance approach, he calculated the total amount of water needed to recharge the aquifer system at 10.06 MCM per year and the annual groundwater discharge at 13.78 MCM. He concluded by stating that the catchment's aquifer system is overused and that overall groundwater abstraction exceeds recharge and the safe yield.

In the South Rift Valley of Ethiopia, (Gintamo, 2015) evaluated the groundwater potential using integrated GIS and remote sensing techniques. In his research, an effort was made to identify and categorize potential groundwater zones in the Bilate River catchment of the South Ethiopian Rift Escarpment, located in SNNPR, using integrated remote sensing and GIS techniques. Thematic layers for lithology, geomorphology/landform, drainage density, lineament density, rainfall, soil, slope, and land use/land cover were prepared using the Landsat ETM+ imagery and ArcGIS software. (Gintamo, 2015) claims that four separate groundwater potential zones—"high," "moderate," "low," and "poor"—were discovered.

Alluvial plains, lacustrine sediments, fracture valleys, and valley fills are associated with high potential zones, and these regions also share a low slope and a high lineaments density. The research area's eastern section of the Bilate River, as well as a few tiny sections in the north and valley escarpment, are located in the moderate groundwater potential zone. Structured hills and escarpments, which contribute significantly to high run-off, are primarily found in low zones. At contrast, areas with low fragmented undifferentiated per-alkaline Dino formation, obsidian, and pitch stone are found in mountain summits, plateaus, and escarpments with steep cliffs. Based on the data from existing water sources in the study area, he validated the results of the groundwater potential zoning map and came to the final conclusion that the combined GIS and remote sensing techniques are very effective and useful for identifying groundwater potential zones.

(Belay, 2009) conducted research on Ethiopia's Lake Beseka. For the hydrogeological assessment of the research area, she used hydrochemistry, isotope hydrology, recharge estimation (water table fluctuation, earth modeling, and chloride mass balance), and groundwater modeling (using MODFLOW) methodologies. She explained how the intricate tectonic and volcanic processes in the Ethiopian rift valley produced volcanic-tectonic structural depressions that served as the locations of several rift valley lakes. According to her calculations, seepage of groundwater into Lake Beseka accounts for 51% of the total water input. The model estimated the seepage to be 33.8Mm^3 per year. As Eleni Ayalew Noted, "It is clear from the recharge estimation that replenishment of the groundwater system occurs from infiltration of local precipitation in the watershed." But the annual recharge is only expected to be 17.4 Mm^3. Therefore, the groundwater recharge that periodically tops up the aquifer system within the lake watershed is insufficient to account for the growth of Lake Beseka. The model calculated that annually, 30.45Mm^3 of groundwater flows laterally beyond the surface borders into the lake watershed's aquifer system. This lateral influx may be connected to recharge from the mountains. Changes in the volume of this groundwater, which initially flows to the Lake Watershed and subsequently to Lake Beseka, are most likely related to the growth of Lake Beseka. Due to the geologic context of the research area, tectonically induced change of the groundwater regime in the area may have led to an increase in the discharge of the hot springs that continuously flow into the lake.

Using data from continual pumping tests and well logs obtained from boreholes, the groundwater potential assessment in the Haromaya watershed in eastern Ethiopia was utilized to identify the main water-bearing formation and describe the aquifer (Tadesse, Bheemalingeswara and Abdulaziz, 2010). According to (Tadesse, Bheemalingeswara and Abdulaziz, 2010), there are three categories for aquifers depending on their permeability potential and size: (1) Extended and shallow aquifers with moderate to high potential and inter-granular porosity and permeability (alluvial and lacustrine sediments) (3) limited and shallow aquifers with intergranular and fracture porosity and permeability, and with low potential. (2) limited and shallow aquifers with fracture and/or karstic porosity and permeability, and with moderate potential (sandstone and limestone) (granite). They have discussed how to characterize aquifers using different hydraulic characteristics and if groundwater is suitable in terms of quality and productivity.

(Abate, 2010) did research on the Dire Dawa region's hydrogeological system. He found that the principal aquifers in the Dire Dawa area are limestone and sandstone formations, and that the alluvial deposits of the Afar Depression are porous, widespread aquifers with a relatively shallow groundwater table.

(Teferi, 2009) used isotope hydrology to perform his research on the hydrogeologic state of the Ilala-Aynalem catchments, with special attention paid to the variation in the chemical features of the aquifers. Although the water ages in the Aynalem sub-catchment were noticeably varied, in general, recent rainwater is used to recharge the boreholes in the catchments. Through an integrated geophysical examination, (Tesfagiorgis *et al.*, 2011) research work in the Aynalem well field sought to identify cracks and faults. He concluded that the majority of the fractures and faults found are oriented in a NW-SE pattern, much like the regional structures. He made the point that the research area's geological structures, such as faults, fractures, and lithologic contacts, are crucial to the flow and occurrence of groundwater.

(Ahmed Hassen, 2018) states that the main source of recharge for the groundwater of the Shinile plains is precipitation that is frequently experienced on the south boundary marking highlands, along with some inferred groundwater influx from nearby areas related to the Awash River and its adjacent aquifer systems, at the southwest and northern sections of the Shinile zone. For the Dire Dawa Administration Council Integrated Resource Master Plan Project, the groundwater assessment work in the Dire Dawa area was carried out by (Gebretsadik, 2011). Using data on groundwater level fluctuation over the course of one hydrological year (July

2006–July 2007) for the study region, (Gebremikael and Dawod, 1970) estimated the groundwater recharge of the Dire Dawa. In the neighborhood of the Abadir camp, an average annual recharge value of 42.6 mm was determined, compared to 42 mm in the Gofa Sefer area. In the Gofa Sefer and Abadir regions, respectively, this recharge represents 6.6% and 6.7% of the total annual precipitation. The catchment region received 34.24 mm/yr of recharge annually. Based on analysis of the groundwater point inventory, it was determined that the escarpment at Dire Dawa had a groundwater potential of about 4.8 Mm3/year (151.7 l/s), and the area at the foot of the escarpment, where the Haseliso well field, the future source of water for Harar town, is located, was considered to have a high groundwater potential.

2.2. Characterization of the Aquifer

(Shekhar, 2017) defines an aquifer as a geological formation that has the capacity to retain and convey groundwater in sufficient amounts to enable its commercial use. The examination of an aquifer's three-dimensional structure, hydraulic and transport qualities, and chemical is known as aquifer characterisation (Maliva, 2004). According to (Davidson and Wilson, 2011) aquifers are described in terms of hydraulically important properties such hydraulic conductivity (K), porosity (n), or any other relevant quantity. Since surface-level aquifers are unrestricted, rainwater can immediately recharge them. If they are buried by sediments, they are refilled by slow leaking from nearby aquifers. Rainfall percolates down from the water table to the surface sediments. It then proceeds to flow by gravity through central, intermediate, and regional flow networks inside the aquifers (Harold F. et al., 2015). Less than five kilometers separates the flow routes in local flow systems. They tend to occur more frequently in upper aquifers than in lower aquifers or basements that include unconfined fractured rock. These aquifers respond quickly to changes in rainfall, mining, or land use. Groundwater in a local system has a very little residence time before it is released into surrounding streams (Shekhar, 2017). Ground-water accessibility is influenced by the size, quantity, and degree of pore space connections within the aquifer material. An aquifer's ability to store and convey ground water is influenced by these features. The porosity of a rock or soil is the proportion of void space to its total volume (a measure of how much ground water an aquifer can hold). Permeability, a quality that is mostly determined by the size and connectivity of pore spaces within a material, has an impact on a material's ability to transfer fluids (Khadri & Moharir, 2016). Water transmission qualities of an aquifer are referred to as hydraulic conductivity and transmissivity. An aquifer's hydraulic conductivity, which measures how quickly water flows through it, is typically reported in gallons per day across a one-square-foot cross section with a constant hydraulic gradient (Akaerue, 2020). Transmissivity is equal to the hydraulic conductivity times the saturated thickness of the aquifer. The storage coefficient is a measure of an aquifer's capacity for storage (Tse and Amadi, 2010).

Single well tests are more common than aquifer tests with observation wells since the pumping test can be carried out on the production well without using an observation well. Step-drawdown tests, a type of single well test, are used to evaluate a well's effectiveness and fundamental capabilities. Even though Transmissivity can be calculated from a single well test, Storativity is exaggerated (Dinu et.al, 2017).

Pumping tests, well lithological logs, comprehensive hydrogeological field surveys, data gathered from a variety of sources, and inferred information from hydrochemical data all help to classify and characterize aquifers and their hydraulic properties, including groundwater recharge and discharge conditions (Tamilnadu, 2010).

2.3. Groundwater quality

The 2016 Ethiopia Socioeconomic Survey found that 66 percent of Ethiopians drink water from upgraded sources, with distribution differing according on where they live. The most popular improved sources in rural regions are protected springs, tube wells, and dug wells, with 59 percent of the population using them. Additionally, source type varies by area; in Addis Ababa, practically all households reported using improved sources, whereas 72% of Tigray's households reported so (CSA, 2017).

There are few statistics available regarding Ethiopia's overall groundwater quality. From the ones that are known, it is evident that the quality is extremely variable, ranging from fresh waters in many of the springs originating from the crystalline basement rocks (such as those in the Ansokia Highlands (Aberra, 1990) to more salty waters in some regions of the Rift and the sedimentary formations of the plains. The majority of the available public data relates to the Rift's water quality. It is clear from this that geothermal waters with abnormally high concentrations of fluoride and/or total dissolved salts have an impact on the groundwater in the Rift zone. Fluoride is thus acknowledged to be a significant issue, particularly for the communities residing within the Rift. The breakdown of evaporite minerals (the byproducts of evaporation) in some sedimentary strata is the cause of the observed elevated salinity in several groundwaters from deposits in the south, south east, and north-eastern regions of the country.

According to (Tekle-Haimanot et al., 2006), high groundwater fluoride levels are the main cause of the rift valley's poor water quality. When they analyzed 1438 samples of water, they discovered that 24.2% of them had fluoride amounts over the recommended maximum of 1.5 mg/l by the WHO. The drainage basin's natural elements (geological, topographical, meteorological, hydrological, and biological aspects) have an impact on how the composition of surface and subsurface waters vary throughout the year based on runoff volumes, climate patterns, and water levels.

Groundwater quality in the Arba-Minch Area was evaluated by(Bekele *et al.*, 2019). He said that the region was highly heterogeneous and anisotropic, with a range in the aquifer's daily transmission rate of 2 to 532.3 m^2.

Tesfaye Chernet (1993) evaluated the groundwater recharge/discharge conditions as well as the hydrochemical features of the natural fluids that were gathered from various sources. According to Tesfaye Chernet, the water resources in the highlands are categorized as having good chemical quality with TDS less than 500 mg/l, whereas the water resources in the lowlands are categorized as having variable chemical quality with TDS 500-1,500 mg/l and even 1,500-3,000 mg/l.

Bicarbonate with TDS less than 1,000 mg/l on the escarpment and highlands was the water type described by Hapteab, Z. and Jiri, S. (1986) in the Dire Dawa area (a sheet near to the Bedesa area). A significant amount of precipitation is received in the area, and the water type and low TDS indicate reasonably quick groundwater circulation. Along the primary surface water split between the Awash and Wabe Shebelle rivers, there are no more than 500 mg/l of total dissolved solids.

Based on two water sampling campaigns (37 and 178 samples), the WWDST (2003) assessment of water quality found excellent water quality for drinking water, with the exception of high sulfate content, hardness, and nitrate content in various water sites, mainly in the southeast. When using groundwater that circulates in limestone and gypsum for irrigation in agriculture, high salinity and a high sodium absorption ratio (SAR) present challenges. High groundwater salinity can also be caustic and cause scaling issues. Sulfate level peaked at 3,336 mg/l and chloride content peaked at 3,130 l/s, respectively. The Wabe Shebelle basin's overall tendency for rising TDS was determined and goes from northwest to southeast.

In order to determine if groundwater in the Modjo river basin is suitable for irrigation and drinking, Kawo and Karuppannan (2018) collected and analyzed groundwater samples.

The Water quality index (WQI) and Sodium Adsorption Ratio (SAR) were used to assess the consistency of drinking and irrigation water, and the vast majority of samples show that groundwater is suitable for both uses.

CHAPTER THREE

Description of Upper Dhungeta and Ramis Sub-Watersheds

3.1. Location and Accessibility

The study area, Upper Dhungeta and Ramis Sub-watersheds is part of Wabe Shebelle River basin. As shown in Figure 3.1., it is located in Oromia regional state at the Eastern part of the country, and is about 390km far from Addis Ababa, the capital city of Ethiopia. Geographically the study area lies between 40° 28' 5.28" E to 40° 54' 22.95" E longitude and 8° 40' 5.27" N to 8° 59' 36.90" N latitude or in UTM coordinates of 661530m E to 709578 m E and 958474m N to 994688m N. The area covers about 753.2km^2 and its ground elevation ranges from 1355-2710m.s.l.

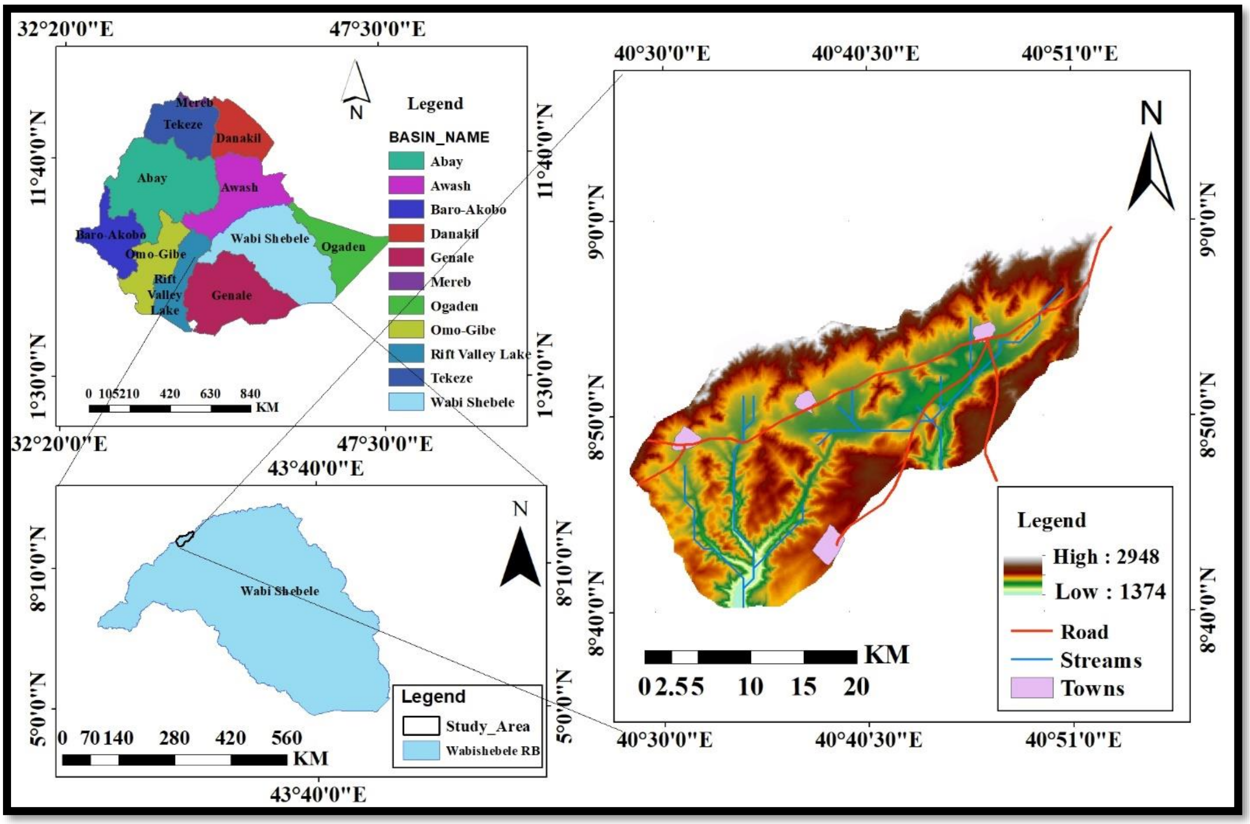


Figure 3. 1. Location map of the study area

3.2. Physiography and Elevation of Upper Dhungeta and Ramis Sub-watersheds

These sub-watersheds' topography varies in slope from low to steep, and it is undulating. The drainage network of the study area has been shaped by the area's steep slopes, hills, and mountains. In the northern and northeastern regions of the study area, higher slope range is the predominantly defining feature. Slope sections with a moderate gradient make up the majority of the study area's central region.

The mountain in the north and northeast is the primary recharging location from which various drainages are flowing to the plains and ultimately drain to its downstream part of the sub watersheds. Homecho, Jawis, Tiro, Hewena, and Awsaid, in that order, are the names of the principal streams in the study area. The maximum, minimum and average Elevation of the study area is 2948m, 1374m and 2161.5m respectively as shown in the next figure 3.3.

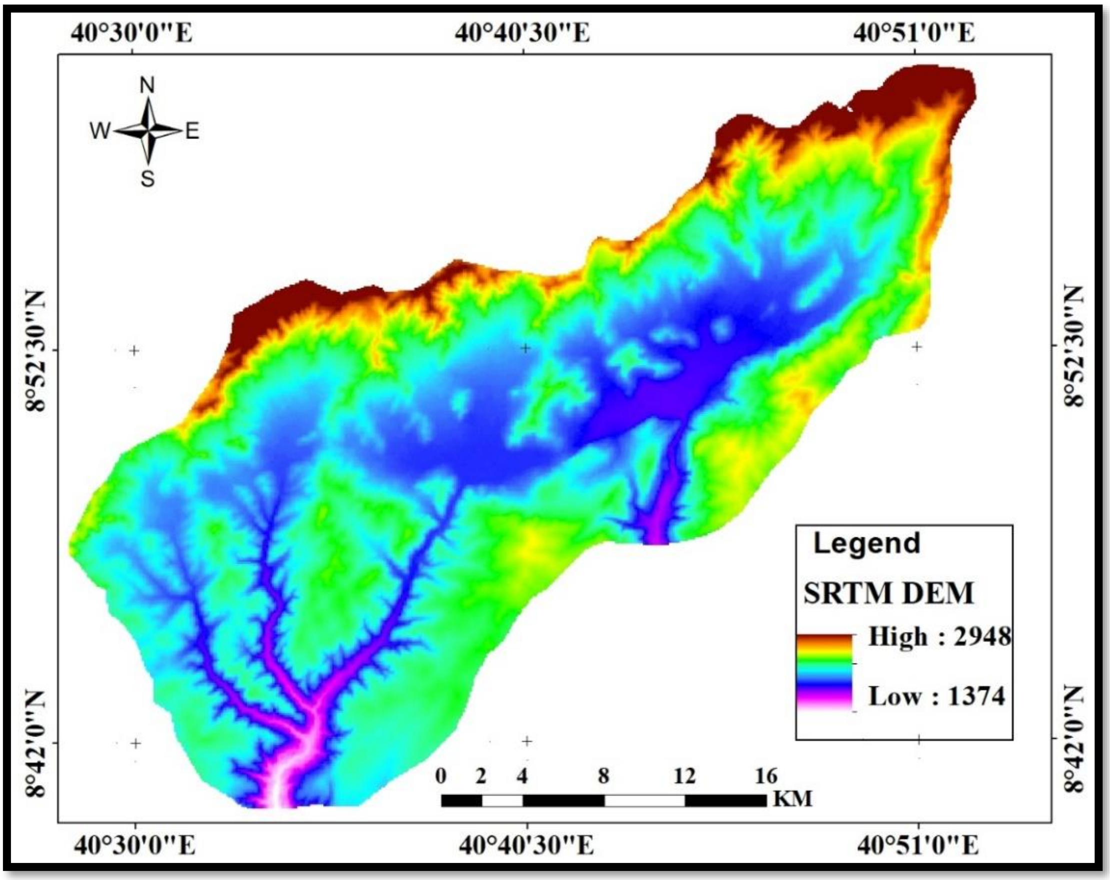


Figure 3. 2 SRTM Dem of the study area

3.3. Drainage Characteristics of Upper Dhungeta and Ramis Sub-watersheds

Many seasonal and perennial tributaries feed the Upper Dhungeta and Ramis Sub-watersheds that originates mainly from the upper parts of the watershed. The mountain in the north is the main recharging area from which several drainages are flowing to the plain land and finally drain to its downstream part of the sub watersheds. The sub-watersheds drainage system is characterized by three major water bodies: Lakes, rivers and stream. The major rivers and streams in the study area are Jewis, Midhegdu, Homecho, Tiro, Hewena and Awsaid.

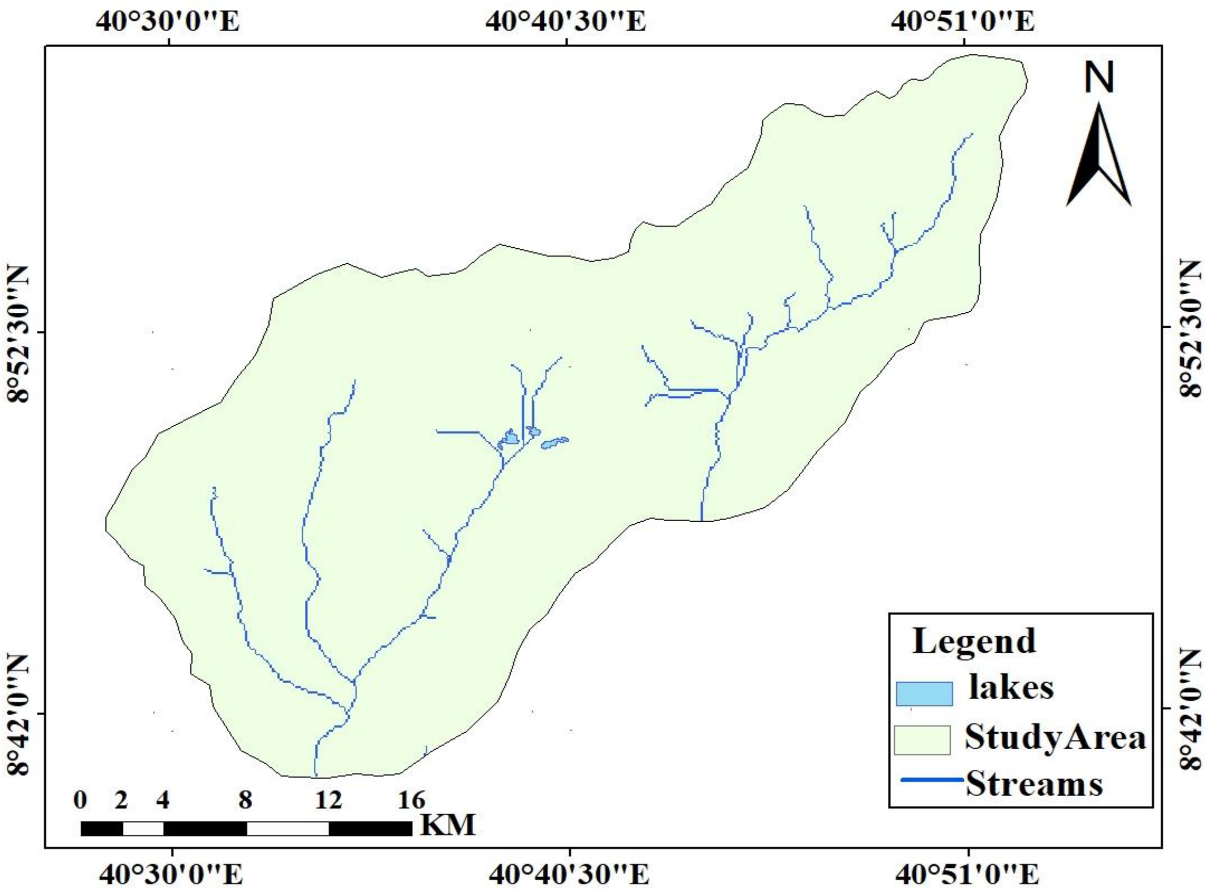


Figure 3. 3 Drainage map of the study area

3.4. Climate

The lowlands of Ethiopia have a semi-arid desert environment, whereas the southwest has a humid and mild (temperate) climate (Beyene, Lettenmaier and Kabat, 2010). High intra- and inter-annual rainfall variability in Ethiopia was also noted by (Klein, 2001). Ethiopia's average annual rainfall ranges from 141 millimeters in the country's dry eastern and northeastern borders to 2,275 millimeters in the southwest highlands (Berhanu, Seleshi and Melesse, 2014). Ethiopia's diverse rainfall patterns and spatial climate variations are largely influenced by the various topographical and geological features of the nation (NMSA 1996; Zeleke et al. 2013). From the middle of June until the beginning of September, Ethiopia experiences one significant wet season known as Kiremt, during which the majority of northern Ethiopia experiences precipitation (up to 350mm/month).

Traditionally by relating altitude and temperature, there are five climatic zones in Ethiopia namely: Wurch (cold climate at more than 3000m a.m.s.l), Dega (temperate like climate high lands with 2500-3000m a.m.s.l), Weina Dega (warm, 1500-2500m a.m.s.l), Kola (hot and arid type areas less than 1500m a.m.s.l) and Bereha (hot and hyper-arid type) climates (NMSA, 2001).

Table 3.1 meteorological stations in the study area

Station	year	UTM X	UTM Y	Z	Mean Annual RF (mm)	Mean Annual Temperature (^{O}C)
Gelemso	2002-2017	40.525	8.80933	1739	962.7	20.3
Bedesa	2002-2017	40.7712	8.90833	1703	1056.8	20.5
Asebe Teferi	2002-2017	40.8715	9.0725	1792	848.7	21.4

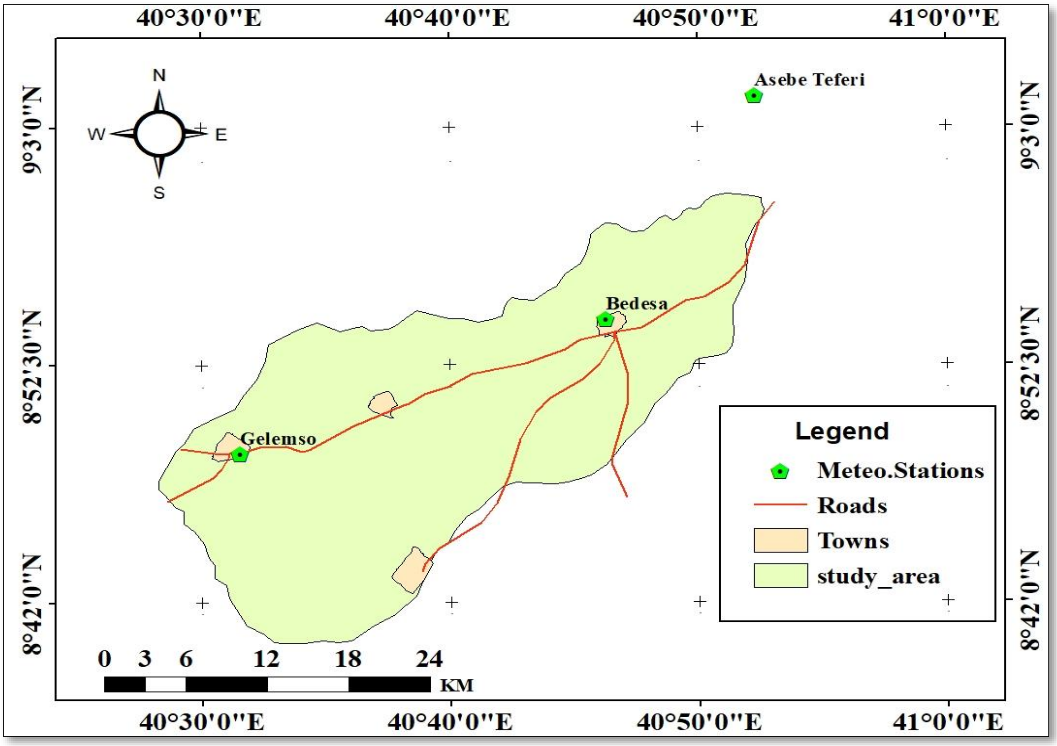


Figure 3. 4 Meteorological station map of the area

3.5. Soil and Vegetation Cover

Soil and vegetation cover reflect the basic climatic condition of the area as well as the regional and site specific geological, geomorphological and erosion characteristics.

3.5.1. Soil

The development of soils is mainly dependent on the type of rock from which they are derived and the condition of the depositions. The highlands (northern part of the area) is dominated by shallow black to gray silty soil derived from the basaltic rock. Besides, the northern tip of the area there is a limited development of black silty to clay soil resulting from the weathering of basaltic rock. Relatively gentle sloping and plain areas are covered by brownish silty soil derived from the erosion and transportation of upper sandstone. The river valleys and their main tributaries of the area are covered by silty to sandy soil and alluvial depositions.

The black cotton soil with common hexagonal cracking covers the Bedesa graben and mostly originates from the weathering of volcanic rocks in the northern highlands. This soil is composed of silty to gravely sized materials and is 4–6 m thick (as observed from Jewis Dug well) in the central and northern parts of the graben nearby Bedesa and Kara towns. The sandy size soil with red color covers the area around Gelemso town and its southern surroundings. Short stream channels deeply cut this soil that has a thickness of 3–6 m along these channels. Sandy soil covers sandstone exposures and is very susceptible to erosion. The limestone covered areas are characterized by unconsolidated clay to silty soils.

The soil map of the area has been extracted from the FAO digital soil map of the world (DSMW) and Harmonized World Soil Database at 1:5 million scale. In the study area the following dominant three soil types are prepared (Fig. 3.6) Luvisols (which includes Vertic Luvisols), black cotton soil (vertisols which includes Eutric Vertisols) and lateritic soil (leptosols which includes Eutric Leptosols and Rendzic Leptosols). Leptosols are very shallow soils over hard rocks or deeper soils that are extremely gravelly and/ or stony. These soils are particularly common in mountain regions. They are very shallow, less than 10 cm deep. Lithic Leptosols in mountain regions are the most extensive Leptosols on earth. Leptosols are unattractive soils for agriculture. They could have some potential for tree crops or extensive grazing. Leptosols are best protected under forests.

Vertisols are heavy clay soils in flat areas that have a pronounced dry season during which they shrink and have large deep cracks in a polygonal pattern. During the wet season the clay swells and causes pressure in the subsoil. Vertisols have a fairly good but limited agricultural potential because the land is rather difficult to prepare. Dry soils are hard and wet soils are sticky. There is only a short period when moisture conditions of the surface layer are favorable to prepare land. Another difficulty is that the drainability of the subsoil is very low because of the swelling clay. Very often the soils are flooded or have stagnant water during the wet season. The organic matter content in Vertisols is often not more than 1 %. The soil has high water retention, but a relatively small amount of water is available for plant growth. Rooting might be restricted because of the swelling and shrinking properties of the soil. This type of soil is exposed in the central part of the study area.

Luvisols have an argillic B horizon and a high base saturation (50 % or more). Those with vertic properties are Vertic Luvisols. Most Luvisols are good for agriculture: base saturation is good and they have minerals vulnerable to weathering. In soils with a heavy textured B-horizon or with vertic properties, permeability may be low and a good root distribution can be hindered, available P contents are low to moderate.

The next table shows soil types in the study area with their respective texture, hydrologic group and areal coverage in Upper Dhungeta and Ramis Sub-watersheds.

Table 3.2 Soils in the study area

SOIL TYPE	TEXTURE/LOCAL NAME	HYDROLOGIC SOIL GROUP	Area Coverage (%)
Eutric Vertisols	Clay	D	11%
Vertic Luvisols	clay loam	D	59%
Eutric Leptosols and Rendzic Leptosols	sandy loam	A	30%

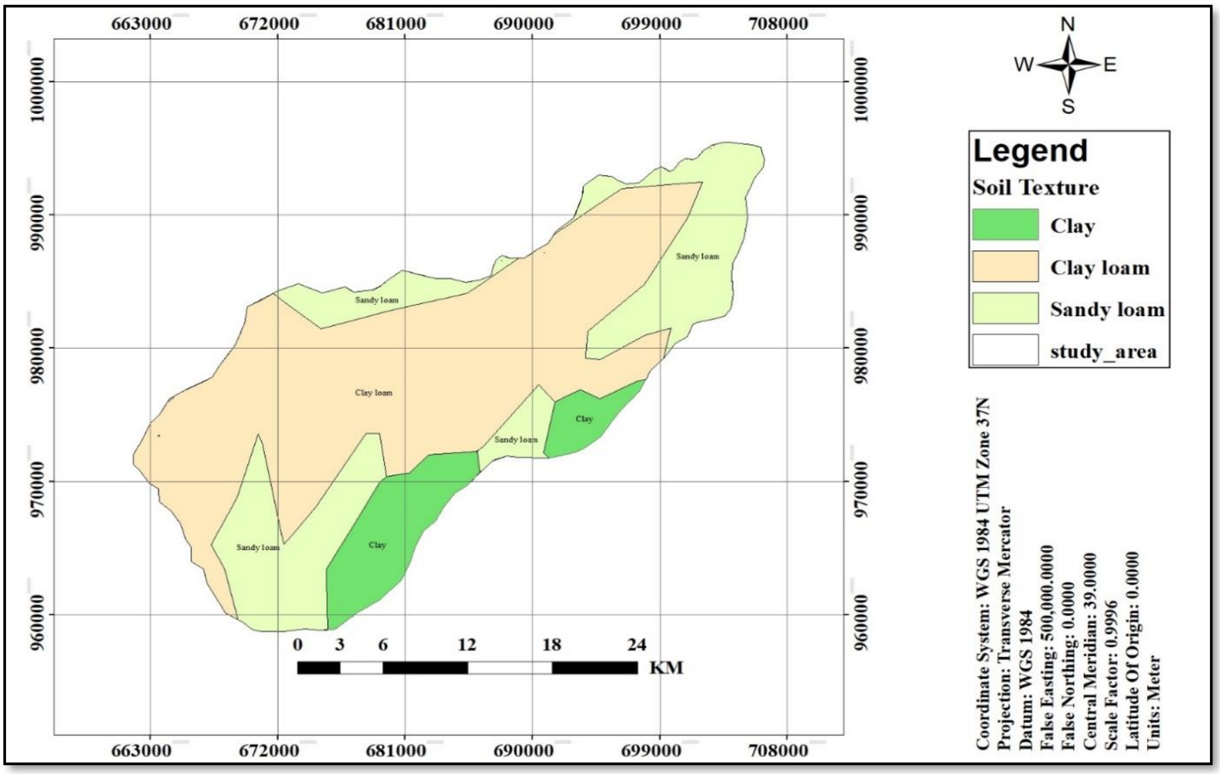


Figure 3. 5 Soil map of the area

3.5.2. Vegetation

The distribution of natural vegetation in the area is almost entirely controlled by the climate condition created by differences in altitude. The vegetation varies from small bushes to big trees. In the mountainous and plateaus areas with adequate rainfall and moderate or cool temperatures Eucalyptus trees and scarce bushes and mountain savannah are dominant. Coniferous forests including Producarps and Junipers are common on the highest (northern part of the study area) peaks. Some parts of the highland area are deforested for farm land, energy (fire wood) and construction of houses etc. The deep gorges are relatively densely vegetated by hard woods and coniferous forests. Varieties of large brood leaf trees were found following the stream channels and river valleys. The flatlands and relatively gently sloping areas are dominated by scattered small shrubs; low acacia trees sparsely distributed dry grass.

3.6. Land Use and Land Cover

Land degradation issues have been largely attributed to poor land use practices, inadequate management systems, and a lack of effective soil conservation measures throughout the country. Land use is a crucial component of the runoff process that influences infiltration, erosion, and evapotranspiration. The catchment area's land use, land cover, and soil type determine the amount of surface runoff and infiltration capability. Agriculture and rangeland are the main land uses in the study area. Commonly grown crops and vegetables include sorghum, maize, chat, onion, tomato, and others. Almost all vegetables are typically grown in the southern and central regions of the study area, whereas maize, sorghum, and chat (Catha Edulis) are extensively produced in the mountainous regions. Due to high demand of cultivable land, the marginal and grazing lands are brought under cultivation. In general, the major land use classes in the study area are crop lands, range lands and built areas and the rest classes are described in Table 3.3. With respect to cultivation the northern part of the study area is moderately cultivated whereas the southern part is intensively cultivated.

Classification process and analysis of the different LULC classes were done using one Landsat satellite images covering the Landsat 8 OLI/TIS acquired on 10 April, 2022. These images include; L8 OLI/TIRS (path 169, rows 54). The Landsat images were down-loaded from United States Geological (USGS) Earth Explorer (https://earthexplorer.usgs.gov/). The selection of the Landsat satellite images dates was influenced by the quality of the image especially for those with limited or low cloud cover. Each Landsat was Georeferenced to the WGS_1984 datum and Universal Transverse Mercator Zone (UTM) 37 Northern coordinate system. For this study, only supervised classification was performed. Using the Image Classification toolbar and Training Sample Manager of ArcGIS 10.8, it was determined the training samples were representative for the area and statistically separate. Then a maximum likelihood classification was performed from the toolbar. The classified image was then cleaned to create the final land use table and map as shown below.

Table 3. 3 Land use land cover of the study area

land use type	Area(km2)	Area coverage (%)
Flooded Vegetation	0.09	0.01
Trees	20.00	2.65
Open Water	5.93	0.79
Crop Lands	336.63	44.68
Built Areas	110.08	14.61
Bare Ground	0.07	0.01
Rangeland	280.72	37.25

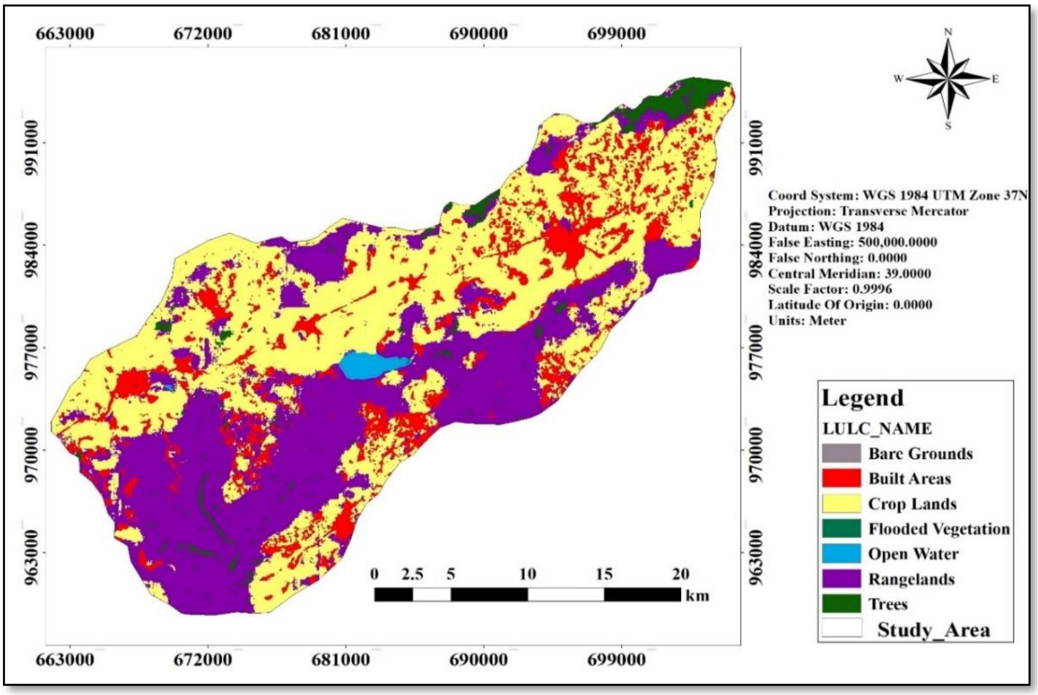


Figure 3. 6 Land use land cover map of the study area

3.4. Slope

The watershed slope explains the morphological inclination or position of land features. The highest slope gradient indicates the deep river gorges of the Upper Dhungeta and Ramis Sub-watersheds, while nearly horizontal slopes in the central plateau indicate lower slope in the sub-watersheds. For this purpose, a digital elevation model (DEM) was downloaded and analyzed from the United States Geological Survey's (USGS) Shuttle Radar Topography Mission (SRTM) data sets. The slope map of the watershed is derived from the digital elevation model using the spatial analyst tool of ArcGIS 10.8. The slope ranges from 0 to 24^0.

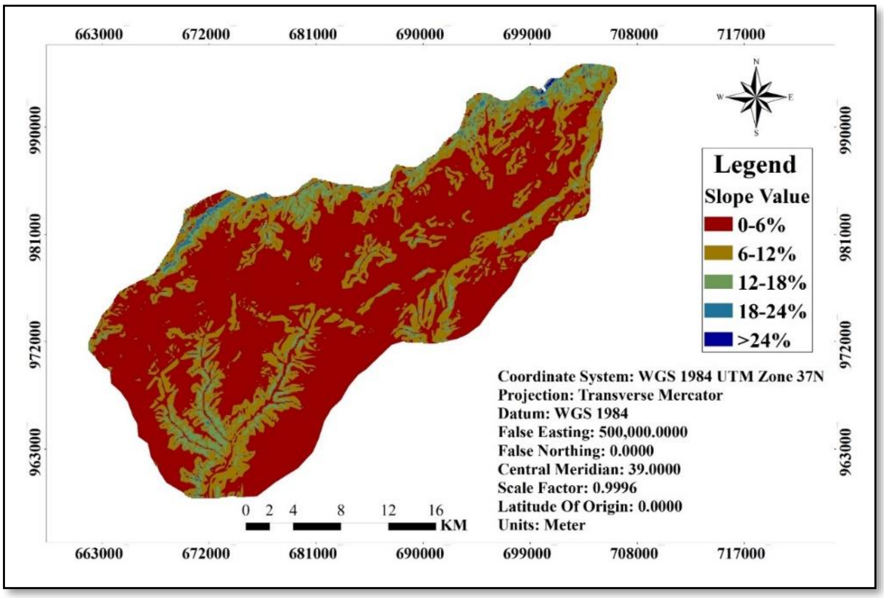


Figure 3. 7 Slope map of the study area

CHAPTER FOUR

Hydro-Meteorological Characteristics of the Study Area

4.1. General

Hydrometeorology is the branch of study which links both hydrology and meteorology (M.Shaw, 1994). Hydro meteorological data are required to determine the water balance of a basin for developing and managing its water resources. The most useful hydro meteorological elements are precipitation, evaporation, evapotranspiration, solar radiation (sunshine hours), air temperature, humidity, soil moisture, water levels (surface and underground), stream discharge, water quality (Akhter *et al.*, 2019). In this study, the main objective of analyzing hydro meteorological data is to calculate evaporation, Evapotranspiration, soil moisture and the results of the analysis further used in calculation of the water balance of the study area.

Meteorological parameters collected from the National Meteorological Agency of Ethiopia (NMA) include Precipitation, Temperature, wind speed, Relative humidity, and Sunshine hour. Out of these Gelemso station is first class with available data's including Relative Humidity, wind speed, SUNHUR, Temperature and Precipitation and Bedesa and Asebe Teferi stations are fourth-class stations in which the data available are precipitation and Temperature only. Meteorological data obtained from the National Meteorological Agency are incomplete.
For this study, data from 3 meteorological stations were taken for areal recharge estimation and climatic classification of the area and it is described in fig 3.4.

4.2. Areal Precipitation

4.2.1. Rainfall in Ethiopia

Rainfall in Ethiopia is the result of multi-weather systems that include Subtropical Jet (STJ), Intertropical Convergence Zone (ITCZ), Red Sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ), and Somali Jet (NMA. 1996). The intensity, position, and direction of these weather systems lead the variability of the amount and distribution of rainfall in the country. Thus, the rainfall in the country is characterized by seasonal and inter-annual variability (Berhanu, S. and Melesse, 2014). Moreover, the spatial distribution of rainfall in Ethiopia is significantly influenced by topographical variability of the country (NMA 1996; Camberlin 1997). This makes the rainfall system of the country more complex.

4.2.2. Spatial Variability of Rainfall

The regional and global change of the weather systems and the topographic variation along with the seasonal cycles are responsible for the spatial variability of rainfall in the country. The magnitude of the mean annual rainfall in the southeast, east, and northeast borders of the country is lower by as much as less than 200 mm. The central and western highlands of the country receive an annual mean rainfall of more than 1,200 mm. Looking into the rainfall variability of the country by river basins, the eastern flowing river basins (Wabishebele and Genale-Dawa) receive low to medium rainfall, whereas those that flow to the west (Abay, Baro-Akobo, Omo-Gibe, and Tekeze) receive a mean annual rainfall in the range of medium to high.

4.2.3. Rainfall pattern of the study area

The Ethiopian territory is divided into four zones marked as A, B, C, and D, each of them with different precipitation patterns. The seasonal classification and precipitation regimes of Ethiopia are characterized by (NMSA, 1996). The mapped area belongs to region A which is characterized by three distinct seasons, and by bimodal precipitation patterns with small peaks in April and the main rainy season during mid-June to mid-September with peaks in July. In general, the annual rainfall depends on the regional altitude variation of the area which receives the main annual rainfall from June through September as does most of the country. Highly elevated escarpment areas of the highlands receive more annual rainfall than the lower elevated parts of the lowland plain areas. Thus, rainfall increases with altitude (Kefale, 2010).

The rainfall patterns of the study area reflect Bi-Modal rainfall characteristics with double wet and dry seasons. The first wet season is between March and June and second wet season is between June and October. As we can see from the graph, the area receives higher mean monthly precipitation during the “Kiremt” season (July, August, and September) and the second moist season is the “Belg” season (March, April, and May) where a smaller amount of precipitation occurs relative to the “Kiremt” season. Other months between October and January, are regarded as “Bega” seasons. These months are considered as dry months in which most of the time there will not be precipitation but, rarely some showers of precipitation are recorded.

Table 4. 1 Areal coverage of precipitation conducted by Theison polygon method

No	Station	X	Y	Z	Annual RF in mm	Area of influence (km^2)	Weighted Percentage	Weighted Areal Rainfall(mm)	Total weighted average annual rainfall (mm)
1	Gelemso	40.525	8.80933	1739	962.7	337.26	45%	431.1	1011.1
2	Bedesa	40.7712	8.90833	1703	1056.8	402.74	53%	565.1	
3	Asebe Teferi	40.8715	9.0725	1792	848.7	13.2	2%	14.9	

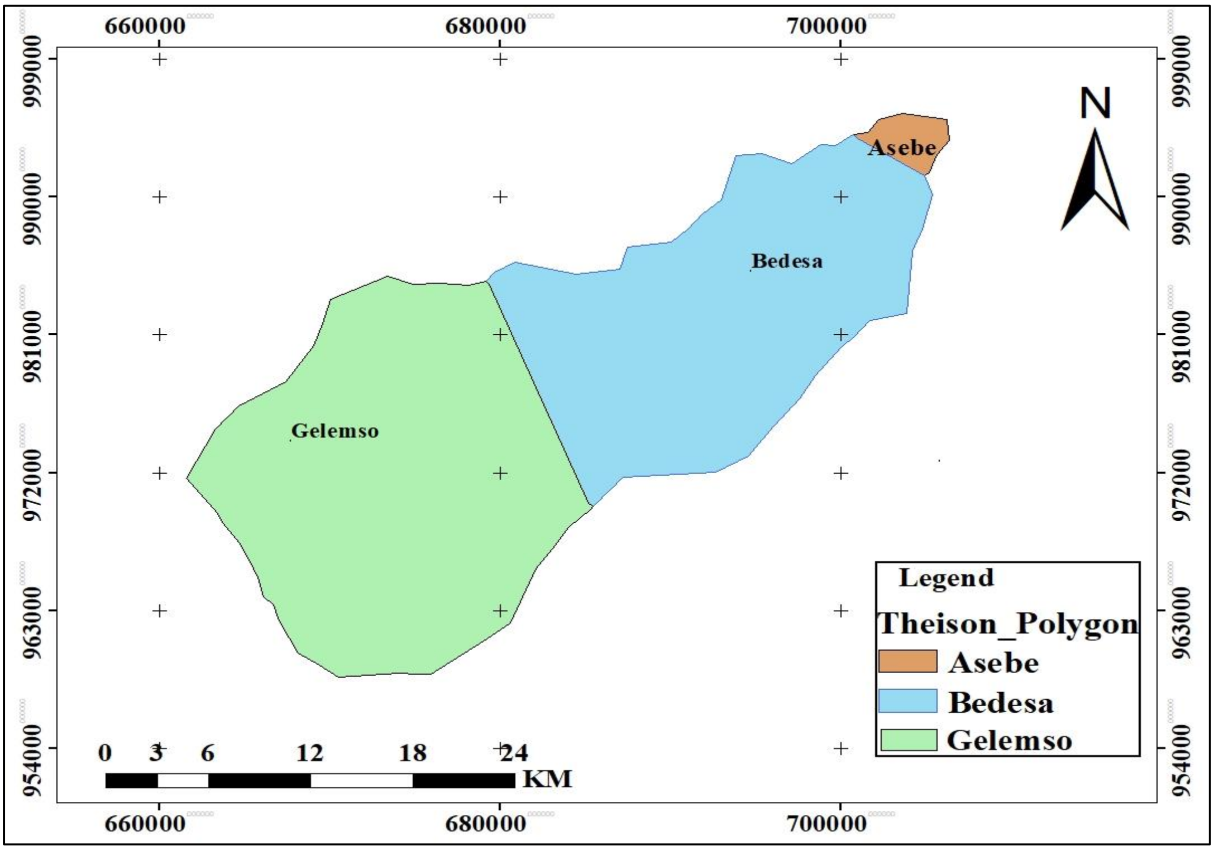
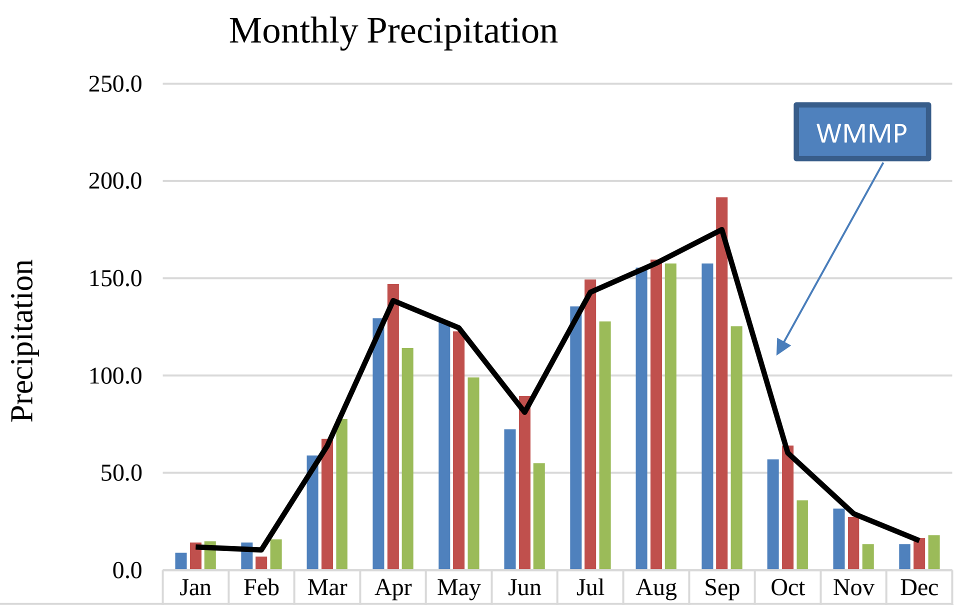


Figure 4. 1 Theison polygon map of the study area



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002-2017 Gelemso	8.9	14.2	58.9	129.6	127.9	72.5	135.6	155.5	157.7	57.0	31.6	13.4
2002-2017 Bedesa	14.3	7.0	67.5	147.1	122.8	89.5	149.5	159.6	191.7	64.1	27.3	16.5
2002-2017 Asebe Teferi	14.9	15.9	77.8	114.3	99.1	55.1	127.8	157.6	125.4	36.0	13.3	17.9
2002-2017 weghted MM precipitation	11.9	10.4	63.8	138.5	124.6	81.1	142.8	157.7	175.1	60.3	29.0	15.1

Figure 4.2 Weighted Mean monthly precipitation (mm/month)

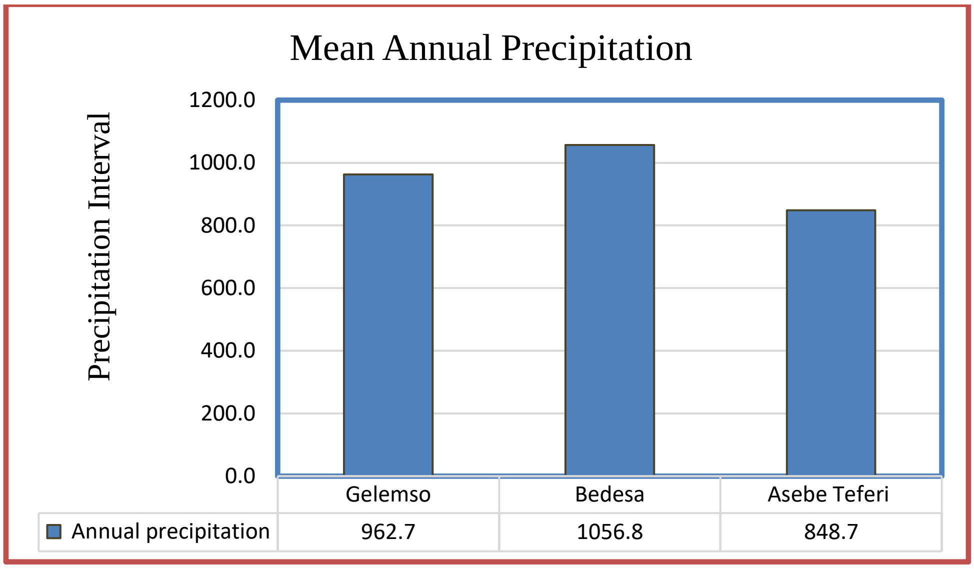


Figure 4.3 Mean Annual Precipitation (mm/year)

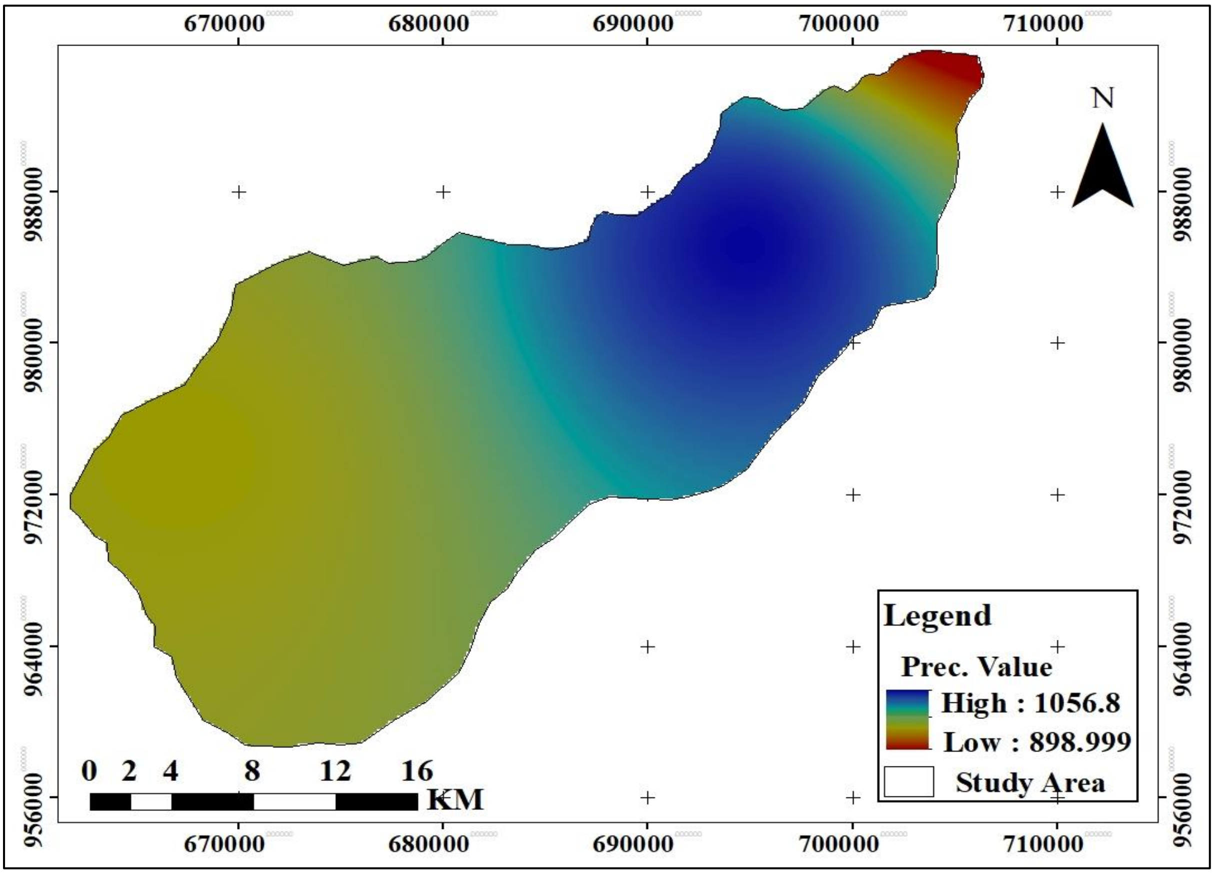


Figure 4.4 precipitation map of the area by IDW method

4.3. Temperature

The mean monthly temperature was calculated from 3 meteorological stations of 16 years (2002-2017 GC) daily maximum and daily minimum temperature. The mean monthly temperature of both maximum and minimum for all (three) stations with their respective average values is described in table 4.3 below. The annual average minimum and maximum temperatures are 13.9 ^{o}C and 27.6 ^{o}C respectively. The mean annual temperature of Upper

Dhungeta and Ramis Sub-Watersheds varies from 20.3°C to 21.4°C. As we can see from the table, the coldest month is December and June is the warmest month.

Table 4.2 Mean monthly temperature of Bedesa and Gelemso Sub-Watersheds

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MM T of the Area	19.7	20.8	21.8	21.6	21.8	22.1	21.3	20.9	20.8	20.0	19.3	18.8

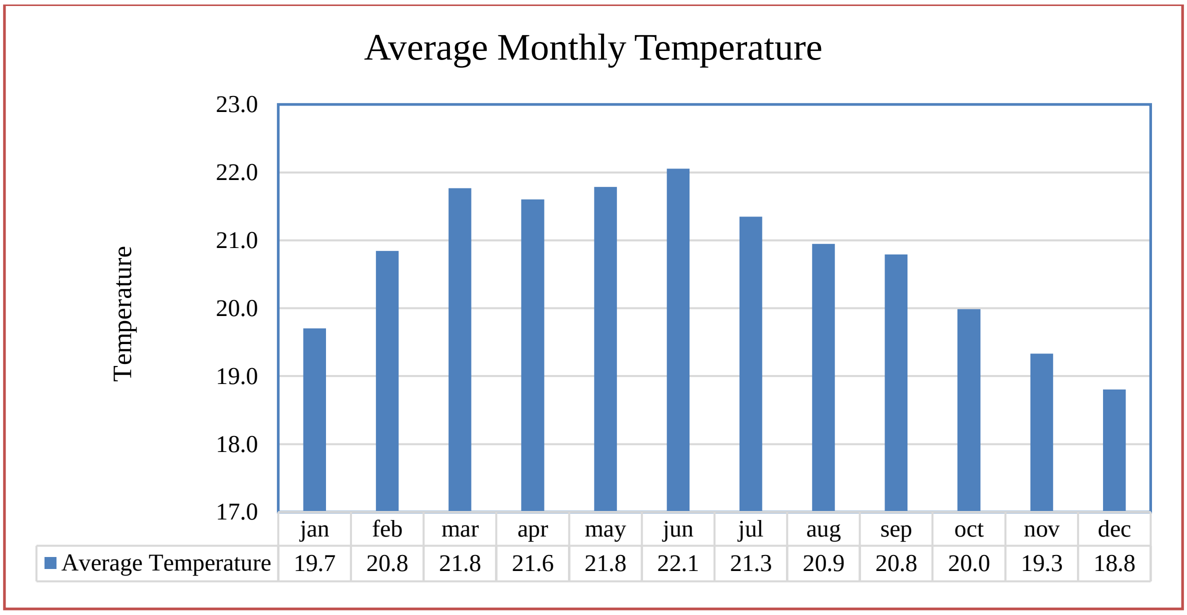


Figure 4.5 Graph that shows mean monthly temperature

Table 4.3 Mean Annual Temperature

Station	Bedesa			Gelemso			Asebe Teferi		
	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave
Mean Annual Temperature	28.1	13	20.5	26.9	13.7	20.3	27.8	15.1	21.4

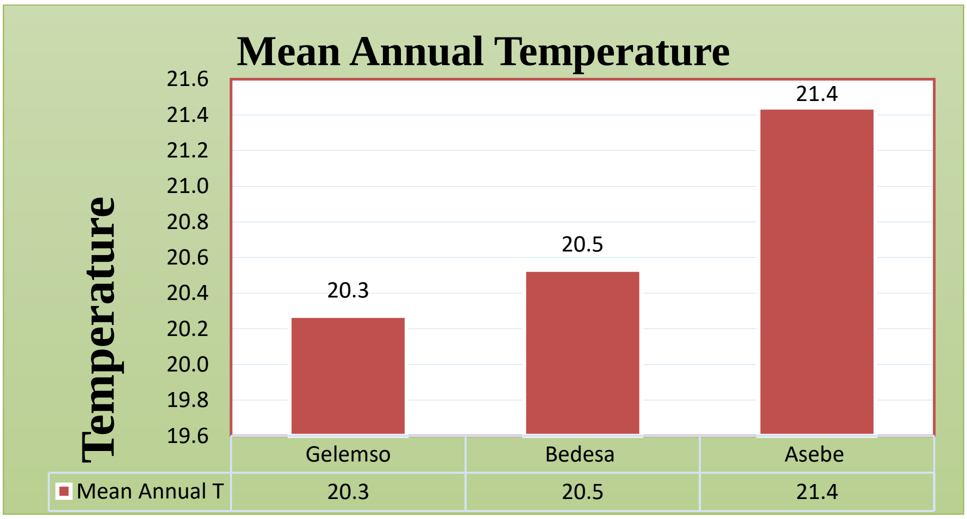


Figure 4.6 Mean Annual Temperature

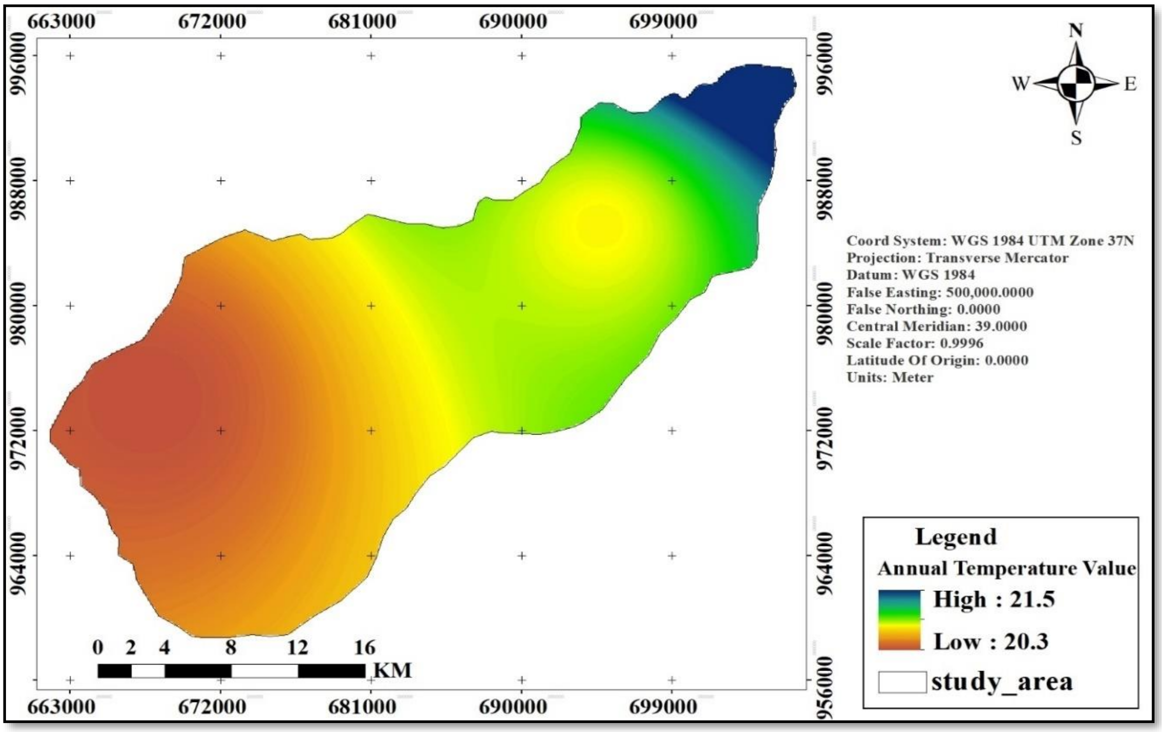


Figure 4.7 Temperature Map of the Study Area

4.4. Evapotranspiration

One of the output components used in water balance method is the evapotranspiration. The term evapotranspiration (ET) is commonly used to describe two processes of water loss from land surface to atmosphere, evaporation and transpiration. Evaporation is the process where liquid water is converted to water vapor (vaporization) and removed from sources such as the soil surface, wet vegetation, pavement, water bodies, etc. Transpiration consists of the vaporization of liquid water within a plant and subsequent loss of water as vapor through leaf stomata (Mannam, 2011). Evapotranspiration is a key hydro meteorological process and its estimation is important in many fields of hydrological and agricultural sciences. Accurate estimation of evapotranspiration has gained scientific interest due to high importance in hydrological modelling, irrigation planning and water resources management(Malamos *et al.*, 2015).

4.4.1. Potential Evapotranspiration (PET)

Potential evapotranspiration is "the water loss which will occur if at no time there is a deficiency of water in the soil for the use of vegetation (Thorenthwaite, 1944 in Fetter, 1994). It is evapotranspiration if adequate water supply is available to a vegetated surface. Potential evapotranspiration is dependent on the evaporative capacity of the atmosphere or it is theoretical calculation based on meteorological data (Freeze and cherry 1979).

In the water budget study of any catchment, determination of the amount of Potential evapotranspiration is essential in maintaining the water balance of the catchment. Potential Evapotranspiration is defined as the maximum amount of water that would be Evapo-transpired if there is enough water available from precipitation and soil moisture. It is an ideal quantity of water that can be evaporated per unit area, per unit time from an idealized unlimited free water surface under existing atmospheric conditions (Strzepe, 1994). The potential Evapotranspiration of the area was estimated using the Thorenthwaite method. The Thorenthwaite method mainly uses air temperature as an index of the energy available for evapotranspiration (Thorenthwaite, 1948).

The evaporation plus transpiration from a vegetated surface with unlimited water supply is known as potential evapotranspiration (PET) and it constitutes the maximum possible loss rate due to the prevailing meteorological conditions. The evapotranspiration that actually occur on the available moisture supply is actual evapotranspiration (AET).

PET ≥ AET

During dry seasons the value of PET greater than AET.

AET = PET in soggy soil or sufficient soil moisture available. Potential Evapotranspiration is calculated using the Thorenthwaite method. Based on this the monthly potential evapotranspiration is calculated using the mean monthly temperature calculated from 4 stations of 16-years daily maximum and minimum temperature using the following Thorenthwaite formula.

$$\boxed{Et = 1.6b\left[\frac{10T_a}{I}\right]^a}$$

Where: Et = Potential Evapotranspiration in cm/Month

Ta = Mean Monthly air temperature (°C)

I = Annual heat index

b = Latitude correction

The annual heat index (I) is calculated from the mean monthly temperature using the following formula and it is the sum of monthly heat indices.

$$I = \sum_{i=1}^{12}\left[\frac{Ta_i}{5}\right]^{1.514}$$

Where Tai is the mean monthly air temperature (°C) in this case the mean monthly temperature is shown in the table below. Based on this, I = Annual heat index is calculated as follows.

Table 4. 4 Step by step calculation of annual heat index

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MM T of the area	19.7	20.8	21.8	21.6	21.8	22.1	21.3	20.9	20.8	20	19.3	18.8
i(mean monthly heat)	8	8.7	9.3	9.2	9.3	9.5	9	8.7	8.7	8.1	7.7	7.4
I (annual heat index)												103.57

The exponent "a" is calculated from the annual heat index using the following formula. The value of "a" can determined by using annual heat index in the formula; $a = 0.49 + 0.0179I - 0.0000771I^2 + 0.000000675I^3$

$$= 0.49 + 0.0179(107.97) - 0.0000771(107.97)^2 + 0.000000675\,(107.97)^3$$

$$a = 2.27$$

From the table above by using air temperature as an index of the energy available for evapotranspiration, annual heat index (I) is **103.57**.

The latitude of the study area is approximated to be 10^0 N. Hence, the latitude correction (b) for the calculation of potential evapotranspiration is given in the following table.

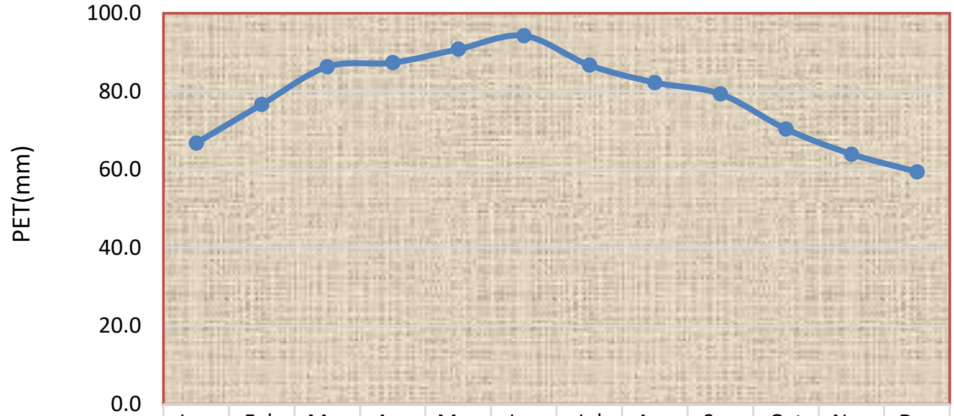
Table 4. 5 Latitude correction at 10°N Latitude

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B	0.97	0.98	1.00	1.03	1.05	1.06	1.05	1.04	1.02	0.99	0.97	0.96

Using the above parameters, potential evapotranspiration is calculated by substituting these values into the Thorenthwaite formula.

Table 4. 6 Average monthly potential evapotranspiration

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
T(mm)	19.70	20.85	21.77	21.60	21.79	22.05	21.35	20.95	20.79	19.99	19.33	18.80	
b	0.97	0.98	1	1.03	1.05	1.06	1.05	1.04	1.02	0.99	0.97	0.96	
i	8.0	8.7	9.3	9.2	9.3	9.5	9.0	8.7	8.7	8.1	7.7	7.4	
I	103.57												
a	2.27												
PET (cm)	6.7	7.7	8.6	8.7	9.1	9.4	8.7	8.2	7.9	7.0	6.4	5.9	
PET (mm)	66.8	76.7	86.3	87.3	90.8	94.2	86.7	82.3	79.3	70.4	64.0	59.4	**944.2**



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PET(mm)	66.8	76.7	86.3	87.3	90.8	94.2	86.7	82.3	79.3	70.4	64.0	59.4

Figure 4.8 Average monthly Potential evapotranspiration

As we can see from the above graph, the maximum potential evapotranspiration occurs at June month because in this month the temperature is very high whereas in other months, the potential evapotranspiration is lower since the temperature limits the value of PET.

The amount of annual potential Evapo-transpiration of the upper Dhungeta and Ramis Sub-Watersheds was estimated to be 944.2 mm/yr.

4.4.2. Actual Evapotranspiration

Actual evapotranspiration is actually evapo-transpired under the existing soil moisture supply. It is dependent on the unsaturated moisture storage properties of the soil. It is also affected by vegetated factors such as plant type and stage of growth (Freeze and Cherry, 1979).

Actual evapotranspiration is defined as the evaporation from the bare land, soil moisture, and water bodies combined with transpiration from plants under the available moisture, precipitation, and atmospheric condition.

The most difficult parameter to measure when calculating a site's water balance is actual evapotranspiration (AET), which is a function of precipitation, temperature, solar radiation, soil water storage, wind, canopy and understory interception, and growth rates. The most popular method of computing actual evapotranspiration is through the calculation of potential evapotranspiration. Actual evapotranspiration is calculated from potential evapotranspiration with the following procedures (Randall K. Kolka and Ann T. Wolf, 1998): (Randall K. Kolka, 1998)

Step 1: PET- potential evapotranspiration calculated with the Thorenthwaite equation.

Step 2: P-PET- precipitation less the potential evapotranspiration.

Step 3: Accumulated Potential Water Loss (ACPWL) - accumulated potential water loss, which is the amount of soil water lost when PET exceeds P; i.e., there is less precipitation than potential evapotranspiration. In the calculation of AET, ACPWL is not a factor until P-PET becomes negative. To determine the ACPWL for a particular month, the previous month's ACPWL and the current month's P-PET are summed. In the original program, ACPWL becomes 0 after a month in which PET < P.

Step 4: Soil moisture- soil storage is the maximum soil storage at field capacity (ACPWL = 0). When below field capacity (ACPWL < 0), soil moisture is a function of both maximum soil storage and ACPWL.

Step 5: Delta (change in soil moisture) - the difference between soil storage in successive months when it is less than maximum. When DELTA is negative, then AET < PET i.e., soil moisture is limiting evapotranspiration. When delta is positive, then AET = PET.

$$SM = 10^{\left[(\log MAWC) - \left(\left(0.525/(MAWC^{1.0371})\right) * \left|ACPWL\right|\right)\right]}$$

- Where SM is soil moisture and its Changing value is calculated by subtracting successive soil moisture value of months. When its value is negative one must sure that AET is < PET, if change in soil moisture is positive, there would be enough moisture content and PET =AET.
- MAWC, Maximum available water capacity
- ACPWL, accumulate potential water loss

Based on the above steps monthly AET is calculated for all types of soil and finally by adding the annual AET is calculated.

Table 4. 7 Monthly actual evapotranspiration of the study area for sandy loam soil

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year
p	11.9	10.4	63.8	138.5	124.6	81.1	142.8	157.7	175.1	60.3	29.0	15.1	1011
PET (mm)	67	77	86	87	91	94	87	82	79	70	64	59	944
P-PET	-55	-66	-22	51	34	-13	56	75	96	-10	-35	-44	66
ACPWL	-152.2	-218.5	-240.9	-189.7	-155.9	-169.0				-18	-53	-97	
AWC	150	150	150	150	150	150	150	150	150	150	150	150	
SM retained	54	35	30	42	53	49	150	150	150	133	105	78	
ΔSM	-24	-19	-5	12	11	-4	101	0	0	-17	-28	-27	
AET	36	30	69	87	91	86	87	82	79	77	57	42	822
	11	9	21	26	27	26	26	25	24	23	17	13	**247**

In the study area Monthly actual evapotranspiration for **sandy loam** soil covered with deep rooted crops (alfalfa, pasture grass, shrubs and 150 mm maximum available water capacity root zone) covers 30% of the study area so the calculated monthly AET value is multiplied by this fraction is 247.

Table 4. 8 Monthly actual evapotranspiration of the study area for clay loam soil

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year
p	11.9	10.4	63.8	138.5	124.6	81.1	142.8	157.7	175.1	60.3	29.0	15.1	1011
PET (mm)	67	77	86	87	91	94	87	82	79	70	64	59	944
P-PET	-55	-66	-22	51	34	-13	56	75	96	-10	-35	-44	66
ACPWL	-144	-210	-233	-182	-148	-161				-10	-45	-89	
AWC	250	250	250	250	250	250	250	250	250	250	250	250	
SM retained	140	108	98	121	138	131	250	250	250	240	209	175	
∆SM	-34	-33	-9	22	17	-7	119	0	0	-10	-31	-34	
AET	46	43	73	87	91	88	87	82	79	70	60	49	857
	27.3	25.4	43.1	51.5	53.6	52.0	51.2	48.5	46.8	41.4	35.6	28.9	**505.5**

In the study area Monthly actual evapotranspiration for clay loam soil covered with deep rooted crops (alfalfa, pasture grass, shrubs and 250 mm maximum available water capacity root zone) covers 59% of the study area so the calculated monthly AET value is multiplied by this fraction is 505.5.

Table 4. 9 Monthly actual evapotranspiration of the study area for clay soil

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year
p	11.9	10.4	63.8	138.5	124.6	81.1	142.8	157.7	175.1	60.3	29.0	15.1	1011
PET (mm)	67	77	86	87	91	94	87	82	79	70	64	59	944
P-PET	-55	-66	-22	51	34	-13	56	75	96	-10	-35	-44	66
ACPWL	-144	-210	-233	-182	-148	-161				-10	-45	-89	
AWC	200	200	200	200	200	200	200	200	200	200	200	200	
SM retained	97	70	62	81	95	89	200	200	200	190	160	128	
∆SM	-31	-27	-7	18	15	-6	111	0	0	-10	-31	-32	
AET	43	38	71	87	91	87	87	82	79	70	59	47	842
	4.7	4.2	7.8	9.6	10.0	9.6	9.5	9.0	8.7	7.7	6.5	5.2	**92.6**

In the study area Monthly actual evapotranspiration of Upper Dhungeta and Ramis sub-watersheds for **clay** soil covered with deep rooted crops (alfalfa, pasture grass, shrubs and 200 mm maximum available water capacity root zone) covers 11 % of the study area so the calculated monthly AET value is multiplied by this fraction is 92.6.

Finally, as it is computed from three soil type and the corresponding land use land cover units, annual actual evapotranspiration (AET) loss from the catchments is obtained by summing up the corresponding monthly AET about 845 mm, i.e., 83.6% of the Weighted Mean Annual Rainfall.

Table 4. 10 Calculated Monthly AET of the study area

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
AET	43	39	72	87	91	87	87	82	79	72	59	47	**845**

Table 4. 11 Calculated Monthly AET of the study area

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
AET	43	39	72	87	91	87	87	82	79	72	59	47	**845**

4.5. Surface Runoff

Runoff is the major component of the hydrologic cycle which is influenced by different factors such as rainfall intensity, climate, vegetation cover, topography, geology, soil type and characteristics, slope, and surface roughness (Rezaei *et al.*, 2019). Runoff is the water that moves in defined channels or all the water that moves over the land in undefined channels. The runoff process is strongly influenced by rainfall intensity and infiltration capacity. When precipitation occurs, rainwater infiltrates into the subsurface either joins the groundwater or it may follow the subsurface horizontal flow (interflow). When the soil layer reaches its maximum infiltration capacity, excess precipitation starts to flow on the surface of the Earth which is considered as surface runoff.

Southern and central parts of Ethiopia experience dual rainy seasons (Kiremt and Belg) with greater intensity of precipitation at a time. The higher the intensity of the precipitation and the wetter the environment, the higher the surface runoff.

The surface runoff of Upper Dhungeta and Ramis Sub-watersheds depends on potential maximum retention (S) after runoff begins and which also find by the curve number value (CN). The curve number value generated from the land use land cover and soil type of the target area. Therefore, surface runoff is determined by the precipitation value, land use land cover and soil type of the area. The Soil Conservation Service Curve Number (SCS-CN) provides an empirical relationship for estimating initial abstraction and runoff as a function of soil type and land-use (Ranjan, Mishra and Singh, 2020). Curve Number (CN) is an index developed by the Natural Resource Conservation Service (NRCS), to represent the potential for storm water runoff within a drainage area. The CN for a drainage basin is estimated using a combination of land use, soil, and Antecedent soil Moisture Condition (AMC).

Surface runoff is calculated using 16-year daily precipitation data which is the sum of the weighted precipitation from thee stations obtained from Meteorological Agency of Ethiopia using the following formula:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

$$S = \frac{1000}{CN} - 10$$

The amount of surface runoff is calculated by the Curve Number method developed by the Natural Resource Conservation Service (Mockus, 1972). The Curve Number (CN) method was developed to estimate the depth of surface runoff from the areal rainfall depth. The Curve Number is dependent upon the soil type and land use type of the area.

There are four hydrologic soil groups: A, B, C and D. each of them is described in the table 4.11. Below.

Table 4. 12 Hydrologic soil groups

Soil group	Description
A	(Low runoff potential) Soils that have a high infiltration rate even when wet. Deep, well-drained sands and gravels make up the majority of these. Water transmission is high in these soils (final infiltration rate more than 0.3 in. /h). Soil Texture: Sand, loamy sand, or sandy loam
B	When thoroughly wetted, soils with moderate infiltration rates. These primarily consist of soils with moderately fine to moderately coarse textures that are moderately deep to deep, moderately well-drained to well-drained. Water transmission is moderate in these soils (final infiltration rate 0.15–0.30 in. /h). Soil Texture: Silt loam or loam
C	When thoroughly wetted, soils exhibit slow penetration rates. Soils with a layer that prevents water from flowing downward or soils with a moderately fine to fine texture are the most common. Water transmission is slow in these soils (final infiltration rate 0.05–0.15 in. /h). Soil Texture: Sandy clay loam
D	When thoroughly wetted, soils with a high runoff potential have very sluggish penetration rates. Clay soils with a high swelling potential, soils with a constantly high-water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impermeable materials are the most common examples. Water transmission is exceedingly slow in these soils (final infiltration rate less than 0.05 in. /h). Soil Texture: Clay loam, silty clay loam, sandy clay, silty clay, or clay

The soil groups of Upper Dhungeta and Ramis Sub-watersheds are classified according to the FAO soil group. As a result, four soil classes are distinctly mapped: Eutric Vertisols (VRe), Vertic Luvisols (LVv), Eutric Leptosols (LPe) and Rendzic Leptisols (LPk). The main dominant soil textures are Clay, Clay loam and sandy loam with percentage proportion of 11%, 59% and 30% respectively. In this regard they are categorized into soil groups A and D (FAO, 2009).

Table 4. 13 Soil type and their major characteristics

Soil Type	Soil texture class	Hydrologic soil group	AWC	Sand (%)	Silt (%)	Clay (%)	Soil texture (%)
Eutric Vertisols	Clay	D	200	19	25	56	11
Vertic Luvisols	Clay loam	D	250	42	31	27	59
Eutric Leptosols and	Sandy loam	A	150	76	16	8	30
Rendzic Leptosols	Sandy loam	A	150	76	16	8	

The dominant land use land covers of the area are cultivated/crop land for agricultural purposes and range land and it is described in the table 3.3 above.

Table 4. 14 Curve Number Determination from Land Use and Soil Groups

Land use description	A	B	C	D
Commercial, town houses	80	85	90	95
Cultivated with conventional tillage	**72**	81	88	**91**
Woods or forest thin stand and poor cover	45	66	77	83
Pavement and roofs	100	100	100	100
Pasture or range poor condition	**68**	79	86	**89**
Farmsteads	59	74	82	86

By considering such conditions, the Curve Number (CN) for Upper Dhungeta and Ramis sub-watersheds is estimated by calculating for both dominant LULC conditions (i.e. crop land and range land) and then taking their average as follows

For crop land CN= (0.11*91) + (0.59*91) + (0.30*72) = **85.3**

For range land CN = (0.11*89) + (0.59*89) + (0.30*68) = **82.7**

CN = (85.3 +82.7)/2 = **84**

To calculate the runoff percentage of the area from the total precipitation, first calculate the potential maximum retention after runoff begins from the value of curve number.

$$Q = \sum \frac{(p-0.2S)2}{\mathrm{P+0.8S}} / n \qquad \text{For P > 0.2S}$$

Where: Q is a Surface runoff in inches

P is daily rainfall depth in inches

n is total number of days that p>0.2S is taken

CN is Curve Number Suggested by American Soil Conservation Service

S is potential Maximum retention after runoff begins. Potential Maximum Retention (S) is the infiltration that occurs after the rainfall has been started. For the calculation of Runoff, 16 years of daily precipitation from 4 meteorological stations were used. The potential maximum retention (S) is calculated from Curve Number (CN) using the following formula:

$$S = (1000 / CN) - 10$$

S = (1000/ 84) -10 = **1.9**

0.2 S = **0.38**

As described from the above formula, surface runoff for each daily runoff was calculated for P>0.2*S (P>0.38), and finally summed up and divided for number of years (16) to get the annual runoff for the given sub-watersheds. The amount of surface runoff of Upper Dhungeta and Ramis sub-watersheds using the above method is about **64.9**mm/yr. which is about **6.4**% of the total mean annual precipitation of the sub-watersheds.

4.6 Groundwater Recharge Estimation

Groundwater potential is directly dependent on recharge. Groundwater recharge is the process by which water percolates down the soil and reaches the water table either by natural or artificial methods to replenish the aquifer with water from the land surface (Teklebirhan, Dessie and Tesfamichael, 2012). Groundwater recharge takes place when water infiltrates at the earth's surface, percolates through the soil horizon passing the water table. It is the most important parameter for groundwater sustainability in arid and semiarid regions because the abstraction from a groundwater reservoir should, in the long term, not be larger than the long-term average recharge.

Quantifying groundwater recharge is thus a prerequisite for efficient and sustainable groundwater resource management. As aquifers are depleted, recharge estimates have become more essential in determining appropriate levels of groundwater withdrawal (de Vries and Simmers 2002). Estimation of groundwater recharge is regarded as a highly challenging parameter in hydrogeology. It is one of the most important components in hydrogeological characterization of aquifer systems and the major objectives in hydro-meteorological studies (Berehanu, Ayenew and Azagegn, 2017).

Groundwater recharge amount can be estimated by different methods; including Ground Water table fluctuation method, Catchment Soil-water balance method, Chloride mass balance method, and hydrograph separation.

In this study, the method applied for recharge estimation is the Soil water balance method. The water balance represents the hydrological gains and losses of a given system (reservoir, column of soil, aquifer, river basin, etc.) over a specific period. It requires evaluation of in and out flowing amount of water within the area under consideration (Ayenew, 2001).

$$P = AET + R + Q$$

Where P = precipitation (mm/yr)

AET = Actual Evapotranspiration (mm/yr)

Q = runoff expressed as millimeters over the catchment (mm/yr)

R = groundwater recharge (mm/yr)

$$R = P - AET - Q$$

$$R = 1011.1 - 845 - 64.9 = \mathbf{101.2}\text{ mm/yr}$$

Table 4. 15 Water Budget Components

Hydrologic components	Weighted Precipitation	Actual Evapotranspiration	Surface runoff	Recharge
Estimated amount (mm/yr)	1011	845	64.9	101.2mm/yr

The Mean Annual Recharge was estimated to be **101.2**mm/year, which is about 10% of the total annual precipitation.

4.7. Water Budget Analysis

The water budget is the analysis and consideration of the amount of water that enters and leaves the system (Stanton et al., 2011). It is the determination of all inflow and outflow components of a catchment, transfer between the components, and their relative contribution within the catchment which is very helpful to define how much water is available in a store, how much water is already consumed, to decide where the water is coming from and at what rate is the groundwater getting replenished. Water budget components include Precipitation, Evapotranspiration, Surface runoff, and Groundwater Recharge.

In this study, these components were determined using the soil-water balance method. The Weighted Mean Annual Precipitation of the catchment was 1011.1 mm/yr. From this annual precipitation, about 845 mm (83.6%) was evaporated back to the atmosphere, about 64.9mm (6.4%) of water flows over the Earth's surface as runoff and 101.2mm (10%) of the total precipitation has been infiltrated to replenish the groundwater. Generally, from the above estimated groundwater recharge, the total direct natural groundwater recharges for Upper Dhungeta and Ramis Sub-watersheds is (101.2mm/year) annually. The groundwater recharge of the Ethiopia has been classified in to four recharge regions, according to the estimated recharge of groundwater from rainfall, as follows: Region1: 250 to 400mm/year, Region 2: 150 to 250mm/year, Region 3: 50 to 150mm/year, and Region 4: less than 50mm/year. This general classification is taken from the hydrogeology of Ethiopia (Chernet, 1989) and it is a small-scale representation of the regional recharge conditions. According to this classification, Upper Dhungeta and Ramis Sub-watersheds falls under Region 3, which receives direct groundwater recharge from the rainfall. On monthly time scale groundwater recharge estimation, most of the study area will receive a good recharge in the rainy seasons. This region 3 is described by in areas of "much of Northern and North Western Highlands, Central Main Ethiopian Rift, Southern and Eastern regions between the Ogaden plain and the Arsi –Bale Highlands".

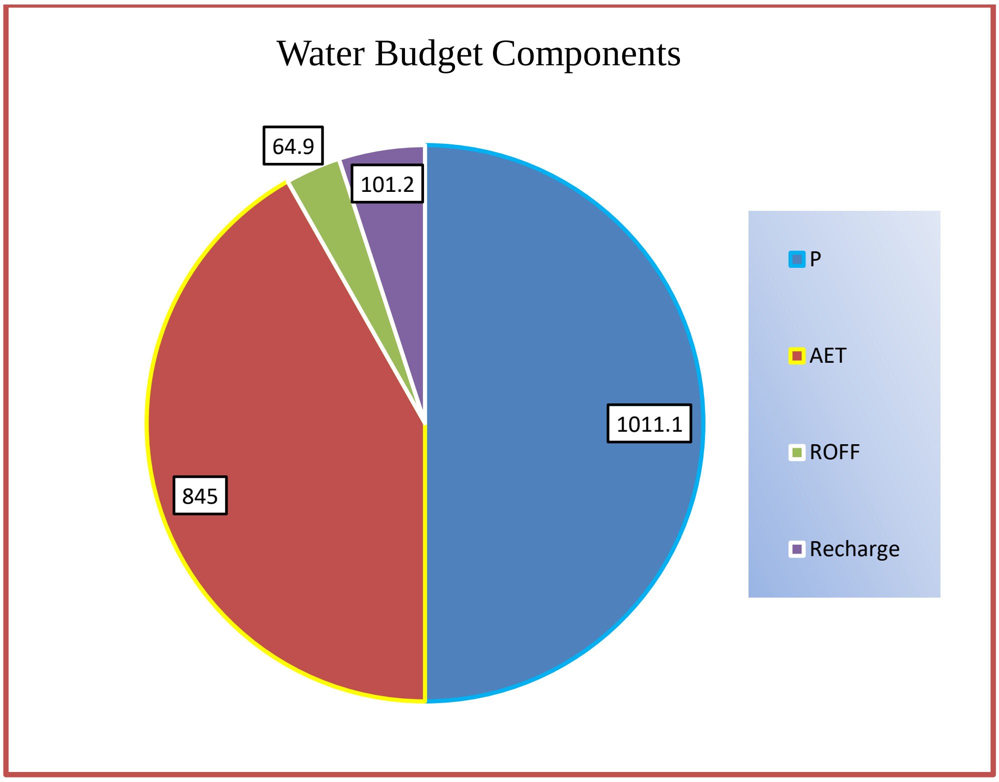


Figure 4.9 Water Budget Components

CHAPTER FIVE

Geology and Hydrogeology of the Study Area

5.1. Regional Geology and Tectonics

Mesozoic sediments occur in three regions of Ethiopia. The sediments are exposed in South Eastern Ethiopia (with three sub regions including Wabishebele, Genale Dawa and Ogaden), the Mekelle-Metema and Blue Nile basins.

In Ethiopian hydrogeological reports it is common to find estimation of hydrogeological features (such as permeability, storage properties and aquifer potential) of the Mesozoic sediments adapted from other sedimentary basins based on lithological similarity. For example, the Mesozoic Adigrat sandstone aquifers were anticipated to have similar hydrogeological properties as that of the Nubian sandstone underlying the vast region of north east Africa (Chernet 1993)(GSE, 1988).

5.1.1. Stratigraphy of the Sedimentary Sequences in Southeastern Ethiopia:

Grossly the Mesozoic sediments of Eastern Ethiopia is subdivided into three broad stratigraphic units namely the Adigrat sandstone, the Antalo super sequence and the Upper sandstone unit.

In the sedimentary basin of south eastern Ethiopia, the pre-Adigrat formation of the Blue Nile basin and Mekelle Outlier is represented by Karoo sedimentary sequence which is only encountered in drilled petroleum wells. The Karoo sediments are composed of Calub Sandstone, Bokh Shale and the Gumburo sandstone. Unlike the two other sedimentary basins, where sedimentation ended in upper cretaceous, in the South Eastern Ethiopia sedimentation continued until Eocene and thus the entire package of sedimentary rocks is much thicker and lithologically variable.

The Mesozoic sequence is composed from base to top the Adigrat Sandstone, the Hamainile-Urandab-Gabredarre Limestone formation, the Korahe formation, the Mustahil gypsum formation, The Ambaradom sandstone, Ferefer, Belete Uen, Jesoma sandstone, Auradu limestone and Taleh (anhydrite, gypsum, shale and dolostone) formations.

The Amba Aradom sandstones (Upper sandstones) are variegated quartzose sandstones of fluvial and/or littoral origin (60-150m). The Amba Aradom is a cliff forming formation and it is highly lateritized in some places in the north like in the area around Hagere Selam where it acts as an aquiclude below the Tertiary volcanics and causes a spring line in between. In other places where it is not lateritized it has high permeability and it produces a large number of springs at its contact with the underlying shales. In the southern and eastern parts of the country, the upper sandstone doesn't show lateritization and it is an aquifer of high productivity. Its high permeability and productivity (mostly producing springs) is a result of the moderate to coarse grain size, loose cementation and Limited shale intercalation.

Upper sandstone occurs in eastern, central and northern (Tigray region) parts of Ethiopia. The formation consists of sandstone, shale and marl. It lies conformably on the Jurassic Antalo Formation (Jt) in central part of the country, whereas in the Mekele (Tigray) and Garamulata (Hararghe) areas, it lies unconformably on the Jurassic sediments, namely, Jt and/or Ja and Ju and/or Jh (Mahadi, 1968; Greitzer, 1970; Kazmin, 1975).

The Hamainile formation is carbonate-clastic-evaporite unit. The Hamanlei series are organogenic and oolitic limestones with shale and sandstone. The Hamanlei and other formations of the Dawa series (Jh-Ju-Jo) are observable along the Genale - Dawa Rivers gently dipping downstream. Hamanlei, Warandab, and Kebri Dehar formations are all named after place names of the Ogaden region. The Hamanlei Iimestones outcrop in southeastern Ethiopia as described above in the Genale-Dawa river basins. Further to the east in the middle of the Wabi Shebelle basin, about 1400m of limestones occur instead of the 400m as in Harar; the limestones in the middle of Wabi Shebelle are not only Jurassic but also Cretaceous, up to the Turonian, Merla et al., 1979 (p 36). The Harar area to the northeast of the Wabi Shebelle was not the actual coast, but only a high during the Jurassic (Merla et al., 1979) and that is why, in addition to the subsequent erosion, that the sediments (sandstones and limestones) are rather thin there.

Urandab formation is dark grey black organogenic shales and subordinate limestone layers. The Gabredarre formation is a thinly bedded alternating oolitic and marly limestone, interbedded in the upper section with gypsum and shale.

The Korahe formation is composed of sequence of gypsum, anhydrities, iron carbonates, sandstones, shales, and marl and dolomitized limestones. The Mustahil formation is composed of yellowish, fine grained, highly fossiliferous limestone (Seifu Kebede, 2013).

5.1.2. Stratigraphy of the volcanic Sequences in Southeastern Ethiopia:

5.1.2.1.Tarmaber Formation

Tarmaber Formation represents Oligocene to Miocene basaltic shield volcanism on the northwestern and southeastern plateaus. The central type Tarmaber Formation basaltic volcanism was followed by fissural eruptions particularly along the escarpments of northwestern and southeastern plateaus. Basalts of the Tarmaber Formation in contrast to the tholeiitic and mildly alkaline nature of the earlier flood basalts typically have an alkaline affinity. On the northwestern plateau, the Tarmaber shield volcanoes become progressively younger from north to south.

The classification Tarmaber Guassa Formation (PNtb) for the shield volcanoes of the northern Ethiopian plateau with an absolute age range of 26 to 16 Ma and the name Tarmaber Megezez Formation (Ntb) for the younger shield volcanoes with an absolute age range from 16 to 13 Ma in the southern part of the northwestern plateau and the southeastern plateau has been widely used and the latter is believed to mark the initiation of rifting of the Main Ethiopian Rift (Kazmin, 1979 and references cited therein). The upper age limit of the Tarmaber-Megezez Formation (Ntb) is lowered to 7 to 8. Ma since the large basaltic center of Arba Gugu with similar alkaline affinity is considered to be the youngest episode of Tarmaber type volcanism. Other dominantly basaltic units erupted within the age intervals from (14 to 10 Ma (Anchar basalts(Rooney, 2020) mapped on the eastern escarpments of the MER and southern Afar and Miocene basaltic volcanism in western Ethiopia with an age range of 9 to 10 Ma (Upper aphyric basalt of Berhe et al., 1987) are also considered with the Tarmaber-Megezez Formation (Ntb) on chronological grounds.

5.1.2.2. Alajae - Formation

The Alajae Formation (PNa) mainly consists of aphyric flood basalts associated with rhyolite (ignimbrites) and subordinate trachytes. This formation (PNa) ranges in age between 36-13 Ma (Kazmin, 1979; Zanettin et al., 1980). A migration of Alajae type volcanism from north to south is indicated by the occurrence of the older volcanics of this formation on the northern part of the north Western plateau. Alajae Formation makes the bulk of the volcanic succession on both the northwestern and southeastern plateaus. On the northwestern plateau the Alajae Formation rests conformably on the Aiba Basalts (P3a) but in some places (e.g. Kassem Gorge, Mugher Canyon and in most outcrops on the southeastern plateau) it directly overlies on the Mesozoic sediments. The Alajae Formation contains basalts transitional to tholeiitic in nature and an increase in alkalinity is observed in the younger members of the formation. Thus, the Miocene members of the Alajae Formation are more alkaline and are associated with sub-alkaline acidic members.

5.2. Characteristic of the local geology in the sub-watersheds

Despite the small catchment size, the study area has different rock types. Mesozoic sedimentary rock, alluvial deposits and volcanic rocks are major Surface geological formations of the study area as shown in the following (Figure 5.1).

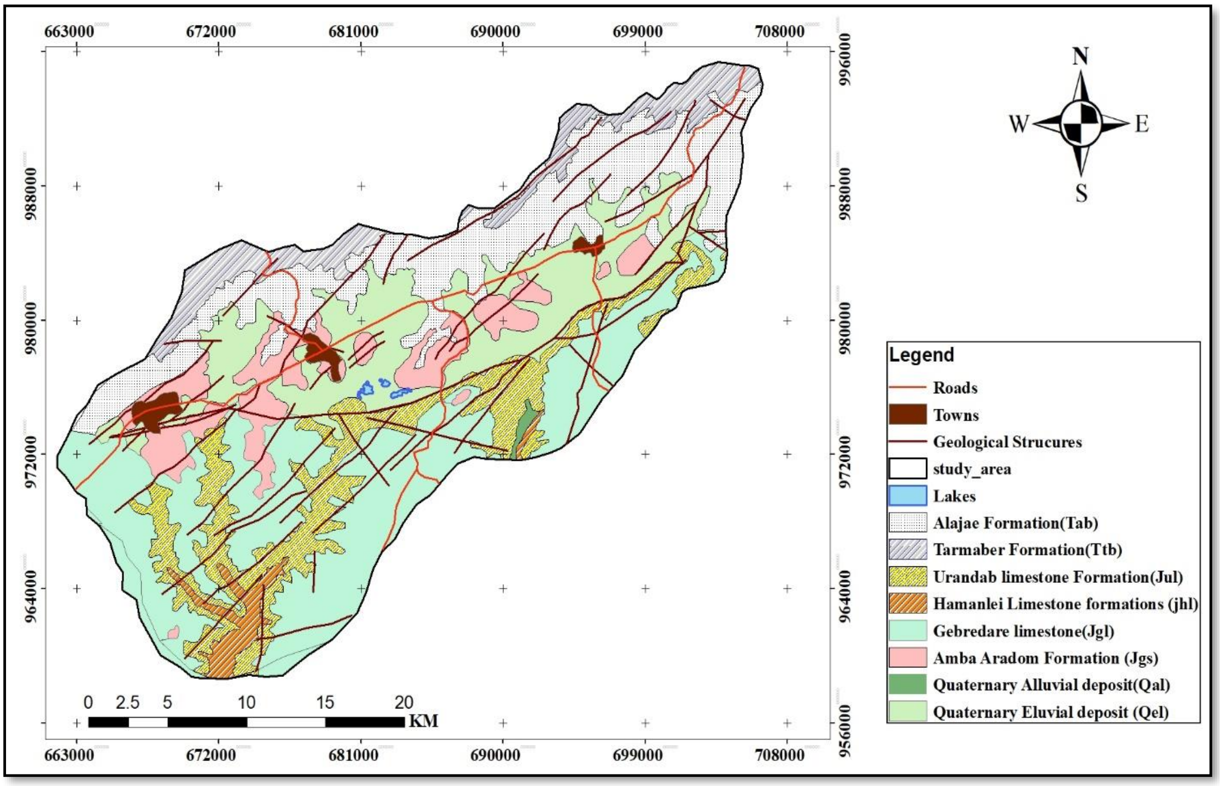


Figure 5.1 Geological map of Study area (digitized from the national geological map)

5.2.1. Sedimentary Rocks

Extensive outcrops of Mesozoic sedimentary rocks occur along the south west, central, south and southeastern part of the study area. The Mesozoic sedimentary rocks consist mainly the Amba Aradom sandstone (Upper sandstone formation), Marl (marly limestone), Shelly limestone and Hamanlie limestone formations.

5.2.1.1. Amba Aradom Formation (Jgs)

The Upper Sandstone is the clastic phase of the high stand system tracts (HST) consisting of deltaic deposits in the southern and strand of coastal sediment in the northern part of Bedesa sheet of geological map. It also known as Amba Aradom Formation (Ka), formerly known as the upper sandstone (Mehade, 1968; Beyth, 1971; Arkin et al. 1971; Kazmin, 1972 & 1975). It is also known as Garbahare sandstone and it is also one of the well exposed formation in the study area (Tesfaye, 1993). The formation shows very clear lateral variation both in thickness and in lithology. In the study area horizontally bedded extensive outcrops of the Upper Sandstone occur along the central part of the study area; mainly northwest part of the

Sub-water shades It is also exposed to the southwest of Bedssa town, surrounding the towns of Wachu and Gelemso and occupies 9.75% from the total mapped study area (73.5 km^2) (Figure.5.1). This rock shows well sorted, rounded grains, cross bedding and red color on the surface due to weathering and shows well developed horizontal bedding structures.

5.2.1.2. The Hamanlei Limestone formations (Jhl)

This formation presents marine sediments formed by the first flooding of the sea in the area. The Hamanilei Formation previously known as Hamanilei Series (Barberi, 1968; Kazmin, 1972 & 1975; Slobodian, 1984; BIECEP, 1985 and references cited therein) is wed for the fossiliferous limestone of Jurassic age of southeastern Ethiopia and the Ogaden region. The Hamanilei Formation (Jh), which consists of predominantly of limestone and dolomite is exposed in wide areas of Hararghe, Sidamo and Bale areas (Mohr, 1963, Greitzer, 1970) and is encountered in several drill holes in the eastern Ogaden. The rocks of this formation have gradational contacts with the underlying Adigrat Formation (Ja) and overlying Urandab Formation (Ju).

This formation is a transgressive system tract consisting mixed carbonate-clastic unit in the lower part and grainy limestones with storm layers (coquina) in the upper part (middle to upper Jurassic). In the study area it is exposed along stream valleys and is typically non-fossil bearing formation. Dominantly the outcrops of this unit are present in the east and southeastern part of the study area as observed in (Fiure.5.1). It covers about 15km^2 (1.99%) from the total mapped study area. This unit has high fractured and horizontal deep bedding along the road cross which are important for occurrence of groundwater. In the elevated topography of area shows intercalations of thin beds of light brownish color marl stone.

5.2.1.3. Gebredare limestone (Jgl)

The Gabredare formation and the overlying Garbahare sandstone, constitutes Highstand Systems Tracts. They announced the termination of the landward advancement of the sea accumulation by a thin stack of carbonates (Gabredare) first, followed by a progradational clastic wedge (Garbrehare). The formation comprises fossiliferous limestone that containing mainly large and thick shelled bivalves, and gastropods with a variety of brachik. Fossiliferous limestones are typical of the formation commonly composed of thin to medium bedded grain stones and mudstone-wackstone successions. The sediments of the Gabredare formation appear to represent open sea sediments. This formation is exposed in the western and southern part of the study area and covers about 222.4km^2 area which is around 29.53% of the total study area.

5.2.1.4. Urandab limestone Formation (Jul)

This Urandab limestone formation in the study area is a drowned shelf succession which is characterized by corals and sponges with slope deposits in the south and southeast part of the study area and this formation is overlaid by Jgl (Gebredare Limestone) and underlaid by Jhl (Hamanlei Formation). This formation is the most widely exposed in plains, ridges, local hills and stream beds. In the uplifted northern part, it occupies the bed of small streams, where as in the south its base is exposed on the banks of larger streams. It is a widely exposed unit and mainly occupies gentle slope forming areas of Dhungeta, Saketa and Omocho where it has a total thickness of approximately 150 m. In the plain area, its upper part is commonly affected by erosion; the formation generally presents a bulk of light grey to grey colored mudstone-wakstone succession with small grain stone beds developing.

The Urandab formation in the mapped area contains a fairly abundant number of fossils with a remarkably diverse range of corals and sponges to different forms of brachiopods, gastropods and ammonites. All types of fossils in the formation are typically small in size and thin-shelled. The outcrop of this formation covered south and southeast part of the study area and covers 101.7 km^2 (13.5%) from the total mapped study area.

Figure 5.2 out crop of layered and jointed Urandab limestone Formation around Surri area

5.2.2.Tertiary Volcanic Rocks

This geological formation is exposed in the north and northeastern part of the study area near the boundary of Awash and Wabe Shebele river basin (figure.5.1). In the northern part the rocks are exposed sporadically from the northwest to outside of the study area towards northeastern corners. Most of the rocks are basaltic flows and are believed to relate to the rift processes. Based on age data from Kazmin and Seifemichael (1978), Merla et al. (1979) and Mengesha et al. (1996) the rocks are classified as Tertiary basalts and Quaternary basalts. Tertiary Alajae basalts (Tab) and Tarmaber basalts (Ttb) occurring in the northern part of the area mark the margin of the Main Ethiopian Rift and Afar. It includes mainly basaltic rock and they are fine texture. The basalts are columnar jointed and conchoidally fractured as observed along the road cut, local fault line and quarry sites.

5.2.2.1. Alajae Formation (Tab)

In the study area the outcrop of this formation is exposed in the northern part of the whole study area. This basaltic flow, formation is characterized by thin columns of joints and conchoidal fracturing as observed along the road cut, local fault line and quarry sites in the study area. This formation occupies 20.46 % from the total mapped study area (154.1km^2) (Fig.5.1).

Figure 5.3 Outcrop of fractured Columns of joints on Alajae Basalts in the study area

5.2.2.2. Tarmaber Formation (Ntb)

This Tertiary Termaber basalt formation (Ttb) out crop in the study area is exposed in in the north tip part of the study area and it is characterized by porphiric texture and also it is a part of jebel sadulei. This Tertiary Termaber basalt formation (Ttb) out crop in the study area is exposed in in the north tip part of the study area and it is characterized by porphiric texture and also it is a part of jebel sadulei. In the study area this formation covers $53km^2$ or 7.04% of the total area. It is characterized by porphiric texture.

5.2.3.Alluvial Deposits

As noted on (Hydrogeological and hydro geochemical maps of Bedesa NC 37-16, compiled by Kefale Tilahun and edited by Jiri Sima in 2010. Recent deposits are widely developed above any lithological unit. Commonly they are soil horizons named either as Elluvial deposits (Qel) or Alluvial deposits (Qal). Accumulation of fine grade colluvium (soil) is high in the Bedesa graben. Mixed structures of colluvium increase their ability to absorb water and the spongy effect leads to the creation of marshes which are typical for the graben. Marshy areas east of Gelemso and the vicinity of Oromo ethnic spiritual worship and culture "Oda – Bultum" can be described as examples. From well logging information and practical field observations in the Bedesa graben it is estimated to be 15–27 m thick while the alluvium of the stream valleys is estimated to have a thickness of 50–65 m in places.

The alluvial deposits are mainly found in the central part of the watersheds Fig 5.1 and it includes fine material such as clay, silt clay and fine sandy clay. Due to weathering of the country rocks, and subsequent erosion and deposition, thick residual clay and silty clay soil covered most part of the flat land of the study area.

Under these two types are categorized (Qel and Qal) and totally constitutes about 133.51k m 2 (17.72%) from the total mapped study area. They stretch from the east to west along the main regional fault line (Qel) and north south direction of drainage part of the watershed or local fault line parts from the bottom of the mountain areas as shown in (figure.5.1). The relative abundance and stratigraphic relation of the sediments, however, are generally not uniform throughout the Sub-watersheds. The alluvial sediments in general dominated by fine-grained fragments with variable content of fine-grained sand. Alluvial deposit is fine-grained sand with variable content of silt and clay. These two categories are: -

5.2.3.1. Quaternary Eluvial deposit (Qel)

It is a residual soil developed on top of the carbonates covering plain topography. Exposed in the central part of the study area. Most drilled boreholes in the study area are located in this formation/part and it covers about $131.69km^2$ and 17.48% of the total study area.

5.2.3.2. Quaternary Alluvial deposit (Qal)

A transported soil, accumulated at the valley floors and Bedesa graben. Covers $1.82km^2$(0.24%) of total area and exposed in lower part of the area especially along the floor of the rivers.

5.3. Geological Structures

The study area, Upper Dhungeta and Ramis Sub-watersheds are affected by the effect of regional faults of the eastern escarpment of the main Ethiopian rift valley since they are near (adjacent) the rift. Local faults also exist in the Sub-watersheds and generally four types of fault systems were recognized in the Sub-watersheds trending in NE-SW, NW-SE, rarely NEE-SWW and N-S directions. These faults are the main structures along which ground water recharge and movement takes place. Structurally the flat land of the study area is formed by east-west regional fault. Northern part of the Sub-watersheds is demarcated by the tallest mountain formed of volcanic rocks. This mountain is the eastern extreme boundary of the main Ethiopian rift valley. The southern part area demarcated relatively by mountain is formed entirely by sedimentary rocks typically sandstone, limestone which are part of Wabishebele river basin as shown in (Fig.5.1).

5.4. Hydrogeology

The term hydrogeology encompasses the interrelationships between geologic material and the processes within water (fetter, 1994). It deals with the occurrence, distribution, and movement of groundwater in addition to physical and as well as chemical relationship with the surrounding environment (sen, 1995).

The data obtained from hydrogeological investigations is used to determine the aquifer characteristics and distinguish major water bearing rocks for groundwater utilization (Tamru, 1992).

The hydrogeological classification of local rock units is based on quantitative data like permeability, yield, aquifer thickness, and transmissivity, while the qualitative investigation includes field observations of the geological, hydrogeological, geomorphological, physical, and geographical setup (Bereket and Mihret, 2019).

The surface water divides between the Awash and Wabeshebelle basins roughly corresponds with the boundary between the Eastern Plateau and the Escarpment. Runoff and base flow on this plateau drain relatively slowly southwards in contrast to the ones of the Escarpment which flow vigorously northwards until it reaches the plain of Afar, where it quickly loses its water into the alluvium (Habteab and Jiri, 1986; Andarge and Jiri, 2010).

As described by in (Addisu, D. 2012), The hydrogeological study of (WWDSE, 2003) and (OWWDSE, 2011) in the study area distinguished that the Mesozoic sedimentary formations (particularly upper sandstone and limestone) and the alluvial deposits are the major water bearing formations with a yield of more than 20 L/S and 5 L/S respectively from a well depth ranging from 150- 250m at the foot of the Escarpment.

In the Escarpment zone and in the southern edge of the plains area where rocks of relatively higher infiltration capacities occur, infiltrated water rapidly joins the regional groundwater body which is at minimum depth of 25m (Tesfamikael, 1974). According to this author the main mechanism of infiltration suggested was selective infiltration through cracks (fractures) in limestone while concentrated infiltration occurs along the river beds through gravels and exposed limestone and sandstones. (Habteab and Jiri, 1986) also considered sedimentary and volcanic rocks in the escarpment area with karastic and fissured permeability to have good groundwater resource.

The limestone outcrops occupy the central and southern parts of the Bedesa sheet (NC-37_16) hydrogeology which is conducted by Ethiopian Geological survey Regional department (GSE. 2006). The limestone units of the area are from bottom to top: Hamanlei, Urandab and Gabredare and represent the major water bearing formation of the area and of Ethiopia as a whole. The limestone represents a large and highly productive fissured and karstic aquifer in the area. Particularly Hamanlei limestone is well jointed and fractured with karastified features. In some places it is intercalated with beds of calcareous sandstones, siltstone and gypsum. Based on their qualitative and quantitative characteristics, rock units in the upper Dhungeta and Ramis Sub-watersheds are classified into the following aquifer types:

5.4.1. Extensive and Moderately Productive Porous Aquifers

This aquifer is the quaternary alluvial deposits and, in some parts, the Hamanlei limestone formation. These aquifers are shown in fig 5.2 in light blue. Flowing rivers and intensive run-off deposit sediments along channels, valleys and in flood plains that form porous media, when the sedimentary layer is thick enough, they are a good source of groundwater. The Quaternary sediment of the study area is classified as a moderately productive aquifer considering their position at the bottom of valleys along stream channels, flat lands and narrow valleys which are convenient for water storage and water well sitting. Alluvial sediments overlay the limestone formation and have a limited lateral extent and vertical thickness in the area. The grain size of these alluvium deposits varies greatly, ranging from clay and silt to sand and gravel, and occasionally boulder size. These deposits have relatively good permeability and productivity with sand to gravel grain size as well as with some fine-grained undifferentiated sediments. A residual soil developed on top of the carbonates covering plain topography and a transported soil, accumulated along the valley floors and Bedesa graben areas with variable permeability that relies on the grain size, sorting and recharge conditions. The permeability and productivity of these deposits with silt and sand grain sizes are better, whereas those with very fine deposits have low permeability and productivity. But the Hamnlei limestones are well jointed and fractured with karastified and they have also a moderate to high permeability.

This aquifer extends more than 100km^2 with Transitivity value of = 1.1- 10m^2/d, specific discharge (q) of 0.011 – 0.1 l/s.m, with spring and well yield Q = 0.51 – 5 l/s) or local or discontinuous but highly productive aquifers in which flow is mainly through inter granular. This aquifer covers 150.7km^2 (20%) from the total study area.

5.4.2. Extensive and Highly Productive Fissured Aquifers

The fissured and karst aquifers altogether consist of various limestones of the Mesozoic age. The limestone outcrops occupy the southern parts of the study area. In the Mesozoic sedimentary units, the water is accumulated in its weathered, fractured horizons and holes of solution cavities, caverns, fissures and sometimes in caves – like wide holes in which water flows very long distances with very high discharge. These aquifers are shown on the map in dark green. The extent and location of these fissured aquifers are shown in Fig. 5.2. The marly limestone and shelly limestone (Urandab Formation) are typical examples of this aquifer system. Marly limestone aquifer is characterized by corals and sponges with slope deposits whereas shelly limestone is characterized by a shallow marine fossiliferous limestone, containing mainly large and thick shelled bivalves, and gastropods with a variety of brachik. The degree and intensity of fracturing, the enhancement of jointing, and the interconnection of primary porosity all have a role in the permeability of this aquifer. The Marly limestone have good fracturing, hence it has good hydraulic properties. Groundwater is under water table conditions in all of these aquifers.

In the study area only, few water points/wells are drilled from this aquifer. This aquifer extends larger than 100km^2 and it is a highly productive fissured and karstic aquifer. This aquifer covers 353.3 km^2 (46.9%) from the total study area. This aquifer has a transitivity of (T= 10.1- 100 m^2/d, q= 0.11 – 1 l/s.m with spring and well yield Q = 5.1- 25 l/s in which flow is mainly through regular developed systems of fissures of sedimentary rocks and karst openings).

5.4.3. Extensive and Moderately Productive Fissured Aquifer

The fissured aquifers altogether consist of various volcanic rocks of Quaternary and Tertiary age (Tarmaber basalt formation and Alaji basalts) and sandstone of Mesozoic age (Upper Sandstone). The rocks represent large and moderately productive fissured aquifers in the area. The degree and intensity of fracturing, the enhancement of jointing, and the interconnection of primary porosity all have a role in the permeability of this aquifer. These aquifers are shown on the map in light color. Secondary cracks and weathering strengthen the columnar joints, resulting in the development of springs in this aquifer. Faulting and jointing increases permeability and leads to the formation of a groundwater conduit in some areas, particularly along northern part of the watersheds, and greatly improves the water-bearing capacity of the aquifer.

The groundwater in the Termaber basalt is manifested by springs discharged from it. The concentrated joints created during lava cooling, lava tubes, interconnecting vesicles, and voids left between lava flows are responsible for this high-water storage, transmissivity, and permeability. The presence of a major numerous localized fractures and faults affect the hydraulic properties of this unit. The principal water-bearing structures are formed where secondary cracks alter and enhance the primary porosity as a result of tectonic and weathering processes (Bereket and Mihret, 2019). Groundwater in these volcanic aquifers is mostly under water table conditions, however semi-confined conditions can be found. These semi-confined conditions are a result of vertical as well as lateral inhomogeneity of volcanic rocks partly intercalated by various impermeable (clay and clayey paleosol) and permeable (gravel and sand) sediments.

The upper sandstone doesn't show lateralization and it is an aquifer of high productivity. Its high permeability and productivity (mostly producing springs) is a result of the moderate to coarse grain size, loose cementation and Limited shale intercalation. This aquifer is recharged from ridges formed by fresh limestone in the highlands. The water circulates in the sandstone through joint sets vertically to the bedding which enhanced the vertical permeability. These secondary fissures play a vital role in groundwater circulation in the sandstone. This aquifer has a transmissivity values of (T=1.1-10m^2/d, q= 0.011- 0.1l/s.m, with spring and well yield Q= 0.51-5 l/s) or local or discontinuous but highly productive aquifers in which flow is mainly through regularly developed systems of fissures and joints of sedimentary and volcanic rocks. Rainfall recharges this aquifer directly. This aquifer covers 249.5 km^2 (33.1%) from the total study area.

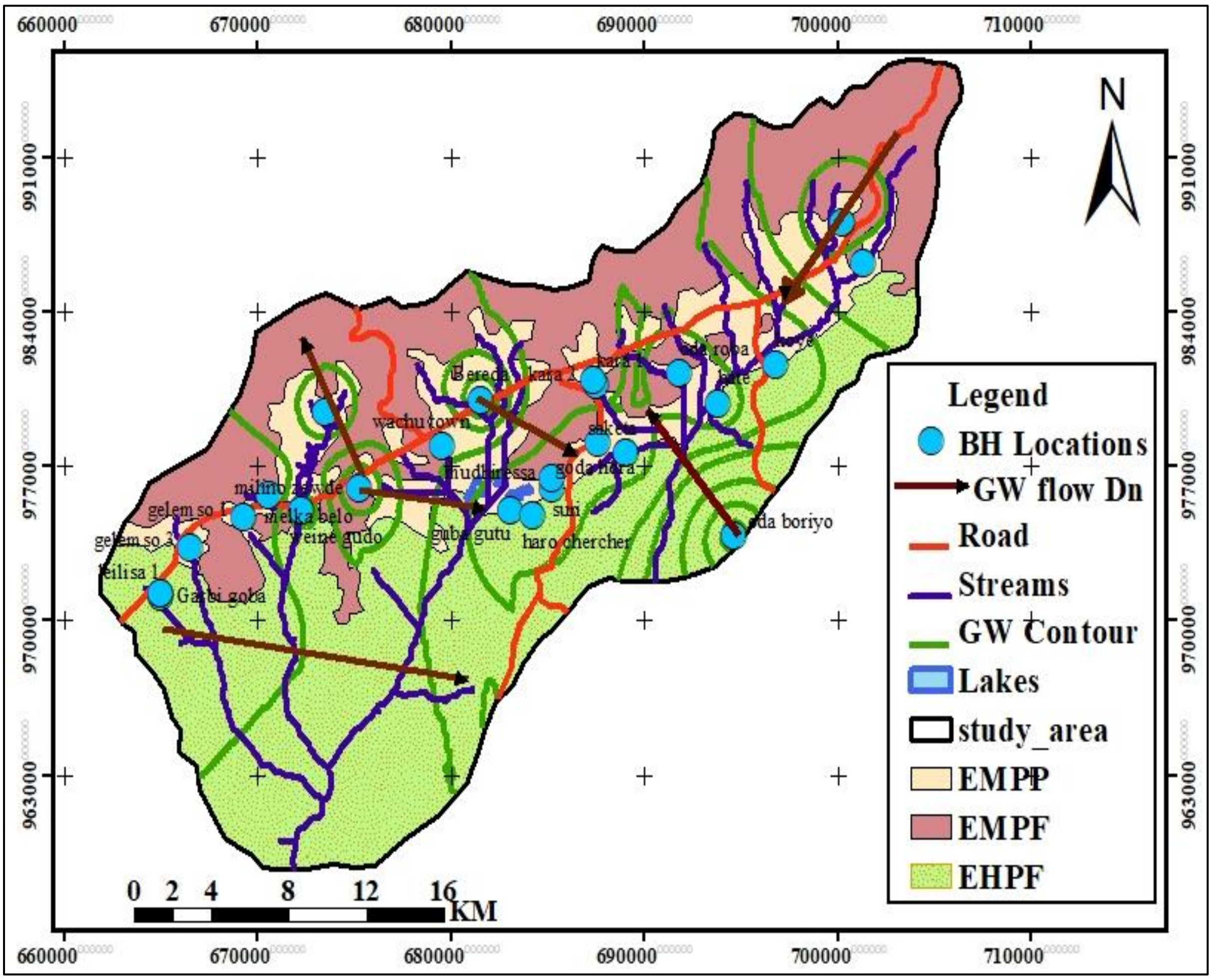


Figure 5. 4 Hydrogeological Map of the study area

5.5. Surface water resource

As illustrated in Fig 3.1, the area is located in the drainage basin of Wabe Shebele River that eventually flows to Somalia. Rivers from the five streams mentioned above (Homecho, Jawis, Midhegdu, Tiro, Hewena and Awsaid) are the major sources of surface water in the study area fig 3.3. The rivers are semi perennial. Out of these Tiro, Hewena and Awsaid drains to Dhungeta River whereas Homecho, Jawis and Midhegdu drains to Saketa then to Ramis River. Then both Ramis and Dhungeta Drains to Wabishebelle River. In addition, Haro Carcar Lake is one of the major surface water resource in the area, which is used for local irrigation purpose and water supply for local community in the study area. The volume of this lake increases during the summer season and decrease during dry season.

Figure 5. 5 Lake Haroo Carcar

5.6. Spring

Natural springs may be defined as points, lines or limited area of earth 's surface through which groundwater rise up according to the hydrological characteristics of the various water bearing formations occurring at shallow or great depth. Springs occur in many forms and have been classified by means of their origin, rock structure, discharge, temperature and variability (Tenalem and Tamiru, 2001). Within the study area springs are common available water resources. Their discharge varies according to the recharge area coverage, fracturing effect and seasonal variation. They display some seasonal discharge variation typically lower discharge at December, January, February and June. The availability of springs and their discharge rate increase from higher to lower topography and in areas where there is dense fracturing effect and fault. The discharge rate varies from 0.1-15 l/sec and with 2.5l/sec average values and most of them are unprotected. Details and Distribution of these springs within the sub-watersheds are described in (Annex 3).

Figure 5. 6 A) and C) developed spring around Sebale kebele and B) Unprotected spring around Kolu kebele

5.7. Hand dug wells.

Hand dug wells are very shallow groundwater. Due to low Transmissivity (T) and hydraulic-conductivity (K) of some upper layer soil and rock type, infiltrated rain water accumulated at shallow depth. Where the local or regional groundwater table is very shallow, it is possible to get hand dug wells (kebede, 2005). In the study area, local people’s use hand dug wells from alluvial, sandstone, residual silt clay soil and from volcanic rocks. There are few properly constructed and hand pump installed hand dug wells within the study area. Almost all hand dug wells in the sub-watersheds are extracted from the central part (mostly from Bedesa graven). These water schemes with their distribution is described in (Annex 4).

5.8. Boreholes and their hydraulic characteristics

Boreholes are drilled wells with drilling machine (rig) for different purposes. Boreholes are used for water supply, industries, irrigation, explorations, groundwater monitoring, and injection wells for industrial waste disposal purposes (kebede, 2003). But the available boreholes in the study area mainly used for domestic water supply purposes. Most boreholes in the study area were drilled in central part of the study area.

Pumping tests are the most accurate way to determine aquifer parameters. This test entails drawing water from a well at a certain temperature and watching the water level change. The period between the start of pumping and the start of an appreciable flow of water from the aquifer to the well is largely determined by the aquifer's transmissivity (Khadri & Moharir, 2016). The rate at which water of a given density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient is called transmissivity (m^2/day). It can also be described as the amount of water that can be transported horizontally through a unit width by the aquifer's full saturated thickness under a hydraulic gradient. It is determined by the liquid's properties, the porous media's thickness, and the thickness of the porous media.

The ease with which water can pass through a unit thickness of an aquifer is measured quantitatively as permeability. The expression connects hydraulic conductivity (K) and Transmissivity (T).

As a result, $K = T/b$

Where b = saturated thickness of the aquifer, which is equivalent to total screen length (Tse & Amadi, 2010).

Based on the obtained pump test result data aquifers thickness and borehole yield in the study area varies from 30m to 134m and 3.4 L/s to 28.3 l/s respectively but this yield does not determine the aquifer potentials capacity but, it determine the capacity of pump installed in the borehole due to this the potential of the aquifers were determined by their Transmissivity value. In general, the study area is characterized by an average saturated thickness of (from drilled borehole data) about 85m and static water level ranges from 0.7m to 86.9m with average value of 29m. The boreholes drilled on Extensive and Moderately Productive Porous Aquifers have relatively good yield (3.4-28.3 l/sec) with a transmissivity value of 0.6 - 411 m^2/d and hydraulic-conductivity value of 0.05-4.17 m/d and where as those bore holes drilled on Extensive and Highly Productive Fissured Aquifers have relatively good yield (6.7-17 l/sec) with transmissivity value of Guba Gutu well 84.7 m^2/d and hydraulic-conductivity of 0.8m/d). While the boreholes drilled on Extensive and Moderately Productive Fissured Aquifer have good yield (4-18.7 l/sec) and the transmissivity (T) and hydraulic-conductivity (K) values obtained from pump test result data of Minilo Zewde well are 28m^2/d and 0.4m/d respectively. Generally, the result shows variation these hydrostratigraphic unit's characteristic such as degree of weathering, fracturing, faulting, topographic of features, etc. accordingly.

The other main aquifer characteristics is a well's Specific Capacity which is calculated by dividing the pumping rate (Q) by the drawdown in feet (s). Specific capacity can also be used to calculate the well's design pumping rate or overall yield, as well as the transmissivity of the formations penetrated by the well screens.

$$Sc = Q/\Delta S$$

Where Sc is specific capacity, Q well discharge and ΔS is change in draw dawn. The initial Specific Capacity can be used to estimate a well's maximum pumping rate. The maximum pumping rate is determined by multiplying the Specific Capacity by the maximum drawdown available. Accordingly, from the computed pump test result data the minimum specific capacity in the study area which is recorded in Gelemso 1 borehole is 0.007 and the maximum value which is recorded at Guba Gutu, Melka Belo, Haro chercer and Minilo zewde's boreholes is 0.5 and 0.272 is average value.

Table 5.1 Summary of aquifer properties

No	properties	Maximum	Minimum	Average
1	well depth(m)	325	74	173.47
2	SWL(m)	79.4	1.2	22.38
3	Q(l/s)	28.3	3.4	12.61
4	Sc(l/s/m)	0.5	0.007	0.272
5	DD(m)	59	0	16.717
6	T(m2/s)	411	0.6	123.84
7	K(m/s)	4.17	0.047	1.405

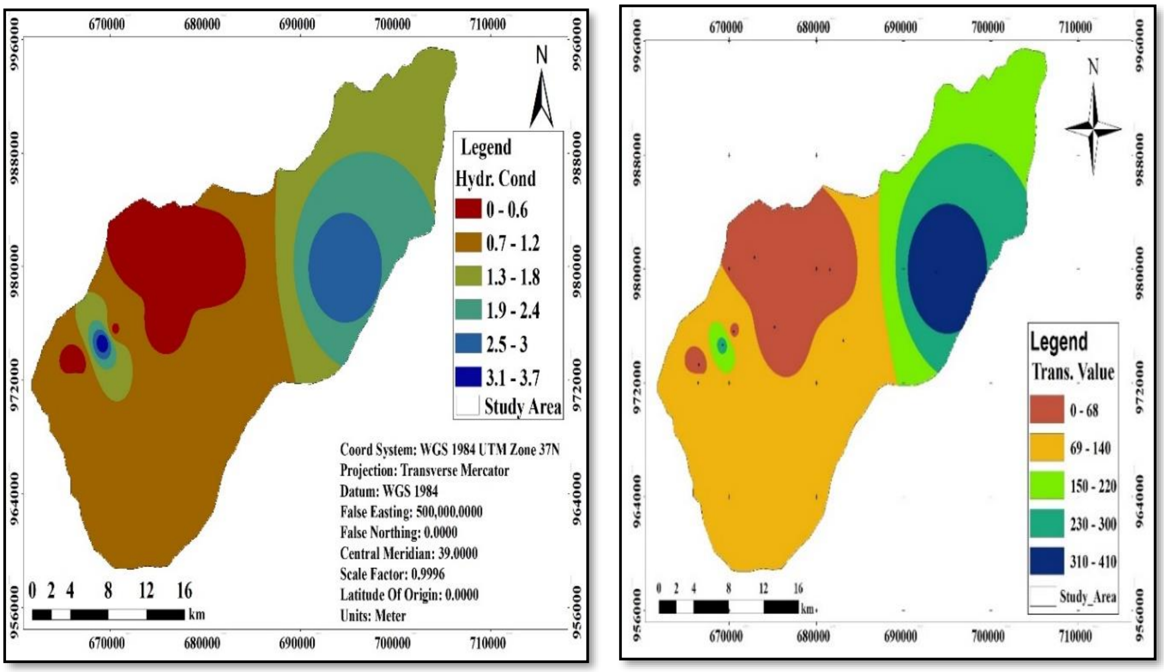


Figure 5. 7 The spatial distribution of Transmissivity (a) and Hydraulic conductivity (b) in the sub watersheds

As it is shown on the map both the Transmissivity and hydraulic conductivity in the study area faces high at the southeast part due to the geology and the specific capacity map below (fig.5.9) shows low value at north and north east part of the study area.

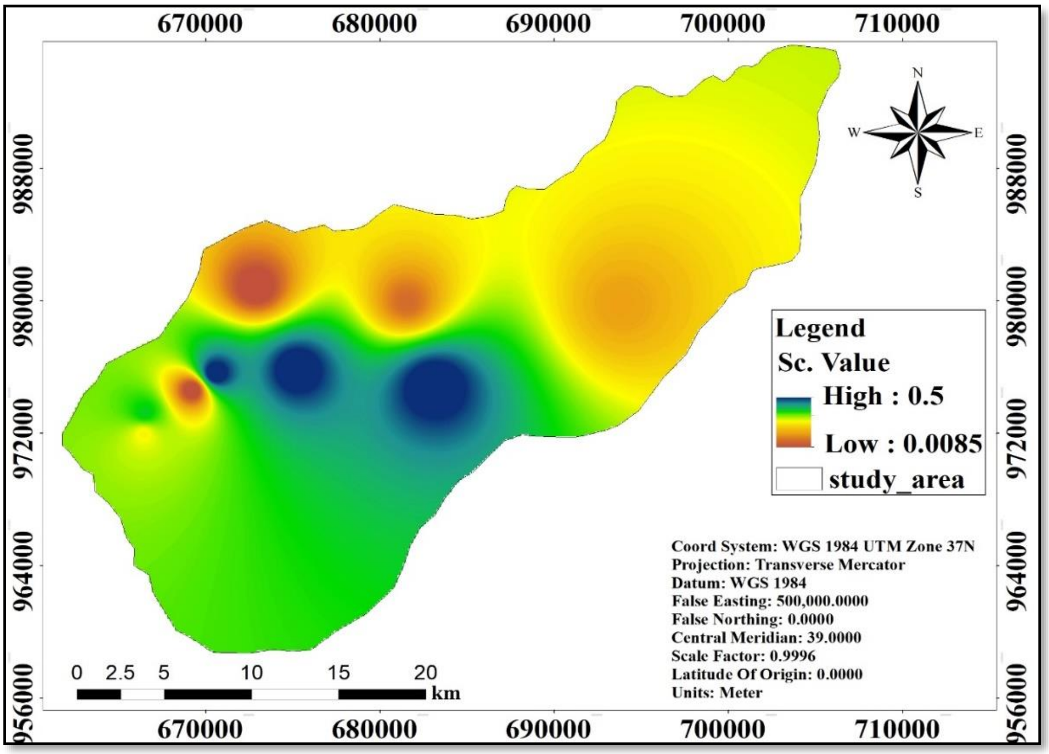


Figure 5. 8 Specific capacity map of the sub watershed

5.9. Determination of groundwater flow direction of the area

Groundwater does not usually remain stationary, but moves or flows underground according to forces acting on the groundwater. The most direct method of determining the direction of groundwater movement is by measuring the elevation of groundwater at multiple locations over the aerial extent of an aquifer. Measurements are plotted on a map of the area and lines are drawn to connect points of equal elevation. These lines represent equal pressure between connected points and are called equipotential lines. Groundwater moves along a flow path perpendicular to equipotential lines and the direction of movement is from lines of higher value to lines of lower value (i.e., higher to lower elevation or pressure). Groundwater flow paths are usually shown by arrows on equipotential surface plots pointing in the direction of groundwater flow. Groundwater usually flows towards and eventually drains into streams, lakes, rivers, seas, ponds and boreholes. The flow of groundwater in aquifer does not always reflect the flow of water on the surface. It is necessary to know the direction of groundwater flow to determine the recharge zones and make sure that human activities in the area do not pose threat to the quality of the groundwater to enable a sustainable use of the resources. Given that water always flows from a region of higher head to a region of lower head, it is found that groundwater use within an area at a higher water level directly affects the quality of water available to people living in regions of lower water levels (Oborie E. & Nwankwoala; 2017).

Groundwater flow directions of the study area was determined from groundwater contour map that was prepared from the groundwater level data of the wells in the sub watershed using GIS software 10.8 by assuming groundwater flow from higher hydraulic head to lower hydraulic heads. Important data for determining ground water flow direction are location data of water points. By subtracting static water level data from their surface elevation data, groundwater level elevation data were developed using excel. From this the groundwater contour map was developed using kriging interpolation method and flow direction is prepared by considering the hydraulic head difference from prepared ground water contour map. Based on this as it is shown in hydrogeologic map above (fig 5.5) Locally the groundwater is flow towards the low land areas which is considered as discharge area where most boreholes were drilled and regionally it flows towards the central part of the study area (Bedesa graben) and towards south east direction of the study area.

CHAPTER SIX

Hydro-Geochemistry and Groundwater Quality

6.1. Hydro-Geochemistry

The study of chemical composition of natural waters is known as hydro-geochemistry (Canora et al., 2019; Rajesh et al., 2019). Hydro geochemical investigations are crucial in determining the potential of groundwater resources. Natural waters' chemical composition is influenced by both geogenic (natural) and anthropogenic sources. As precipitation hits the earth, it interacts with dirt, rock, and organic debris, naturally dissolving additional chemicals in addition to any contamination caused by human activities (Rahmanian et al., 2015). The amount of solute in the initial rain, the degree of reaction with rock and soil, the loss of constituents due to precipitation or absorption, and the loss of water due to evaporation, transpiration, or reaction with minerals are all factors that influence the level of trace and major elements. According to (Rahmanian et al., 2015), one of the most significant natural changes in groundwater chemistry occurs in the soil. Carbon dioxide is abundant in soils, and as it dissolves in groundwater, it forms a weak acid capable of dissolving several silicate minerals. Groundwater can dissolve substances as it encounters or deposit some of its constituents along the way as it travels from recharge to discharge area (Nur et al., 2012). Temperature and pressure levels, as well as the types of rock and soil formations through which the groundwater flows, and probably the residence time, all influence the final consistency of the groundwater.

The chemical composition of natural water is derived from many different sources of solutes, including gases and aerosols from the atmospheres, weathering and erosion of rocks and soils, solution and precipitation reactions occurring below the land surface, and cultural effects resulting from human activities. The ways in which solutes are taken up or precipitated and the amounts present in solution are influenced by many environmental factors, especially climate, structure and position of rock strata, and biochemical effects associated with life cycle of plants and animals, both microscopic and macroscopic (Hem,1992). As a result of chemical and biochemical interaction between groundwater and the geological materials through which it flows, and to a lesser extent because of contribution from atmosphere and surface water bodies, ground water contains a wide variety of dissolved inorganic chemical constituents in various concentrations (Freeze and Cherry, 1979). The concentrations, relative proportions and rates of transport of dissolved materials in water sample reflect their sources path and interactions with different substances (Tenalem Ayenew, 1998). Therefore, hydrochemical data are important tools to study different water samples and safely limit of their utilization

The current research examined the hydrochemistry of groundwater in Upper Dhungeta and Ramis Sub-watersheds to determine the consistency of groundwater and its suitability for drinking, agricultural and industrial purposes by analyzing laboratory results. The sub-watersheds being studied contains information on: The interaction of water with geological materials or the atmosphere, different geochemical processes that regulate the chemical evolution of ground water, the source of both surface and subsurface water, Conditions of groundwater flow and anthropogenesis. This hydrogeochemical investigations primarily aims is to differentiating between the origins of various water bodies and to better understand groundwater dynamics.

6.1.1. Water sample collected and analyzed

During this study three water samples were collected in the field from three boreholes. Water samples were collected from around Bedesa area of the study area, including Oda Roba, Ganda Bultum and Mudhiiresa kebeles. All parameters including TDS, PH, Eh, turbidity, etc. are measured in the laboratory. Representative water samples were collected carefully by prescribed standard methods. The sample are collected in one-liter polyethylene plastic bottle and conserved before analysis for two days in 4 pocks without any disruption. The analysis was made in the laboratory of 'Addis Environmental Services' (Addis Ababa) between December 10, 2020 up to January 1,2022(Oda Roba Well), 2021, February 3, 2022 up to February 4, 2022(Ganda Bultum well) and March 08, 2022 to March 09, 2022(Mudhiiressa well). Accuracy of the analysis was assessed and reaction error for each sample was checked to be less than 5 %. The chemical analysis result is summarized in table below

Table 6. 1 Analyzed laboratory result of collected water sample

Site Name	Northing	Easting	Elevation	pH	Turbidity,	E.C(μSm/c)	TDS (mg/l)	Bicarbonate $HCO3^-$	Chloride,	CO_3, mg/l	S, (mg/l	K, (mg/l K^+)	Na, (mg/l	Ca, (mg/l Ca^{2+})	Mg, (mg/l	T. hardness, (mg/l)	Fe, mg/l	Nitrite, (mg/l NO_2)	NO_3^- (mg/l)	Mn(mg/l))	F- (mg/l)	PO_4^{3-},mg/l)	T. Al, mg/l)	NH_4
Oda roba	9811	6918	1643	6.9	2.11	727	363	427	17	Nil	84	5.5	11	380	40	310	0.05	0.01	0.4	0.2	0.96	0.12	350	0.07
Ganda bultu	97803	68762	1640	6.75	5.32	1106	553	561.2	48	Nil	160	3.2	57	364	40	330	0.3	Nil	0.1	2.08	1.18	0.22	460	0.48
Mudh iiressa	97636	68518	1672	7.02	2.52	1007	503	564.2 5	120	Nil	96	8.8	45	331	70	300	0.35	Nil	0.32	0.95	0.97	0.05	462.5	1.23

6.1.2. Laboratory result data Collected and interpreted

To analyse and understand hydrogeochemical properties of water within Upper Dhungeta and Ramis Sub-watersheds, a total of **24** boreholes chemically analysed data were used. These Chemical groundwater result data were collected from west hararghe zone water development and energy office, Oda Bultum Woreda Water Resource Development and Energy Office and ODA (Oromia Development Association Office at Bedesa Town). These samples are plotted on hydrogeological map and analyzed using piper diagram (Figure 6.5) and their detail is displayed by chart in appendices part (Annex 10).

The collected Data contains physical parameters such as pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), salinity, and ions including Ca^{2+}, Na^{+}, K^{+}, Mg^{2+}, Cl^{-}, SO_4^{2-} , NO_3^{-}, Fe(iron), Fluoride(F^{-}), and HCO_3^{-}. The chemical analysis result is summarized in table below and each sample detail is listed at annex 8.

Table 6.2 Summary of Collected Laboratory Result Data in the Study Area

Parameter	pH	Color	Turbidity,	Temperatur	EC µSm/cm	TDS mg/l	Total solids	HCO3-	Cl^{-} mg/l	CO_3^{-} mg/l	SO_4^{2-} mg/l	K^{+} mg/l	Na^{+}) (mg/l	Ca^{2+}) mg/l	(Mg^{2+}) mg/l	Hardness, (mg/l $CaCO_3$	Fe, mg/l	NO_2) (mg/l	NO_3^{-}) (mg/l	(NH_3) mg/l	(Mn mg/l)	F- mg/l	PO_4^{3-}) (mg/l	T. Alk mg/l	NH_4
Analyzed result	6.05 - 8.88	22 - 50	0.34 - 27.4	20 – 23.4	236 - 1371	160 – 750	20 – 800	34.2 - 600	0 - 120	0 – 58	0.29 – 160	0.4 - 11	7 - 152.1	3.36 - 380	0.51 – 70	10.5 – 446	0 – 0.78	0 – 0.28	0 – 8.8	0 - 1.23	0– 2.08	0 – 1.2	0.002 - 18	120 - 600	0 – 1.23

6.1.3. Physical parameters in Groundwater chemistry

Solids form the most obvious extraneous matter to be carried along by a flowing river. The quantity and type of solids depend on the discharge and flow velocity. They range from tree trunks, boulders and other trash dislodged and carried away by floods to minute particles suspended in a tranquilly flowing stream. The solid pollutants of a river derive from organic and inorganic sources. When evaluating quality for the potential use of water, suspended solids (SS) are measured in mg/l.

6.1.3.1. Hydrogen-ion Activity (PH)

PH is a measure of the concentration of hydrogen ions (H^{+}) and indicates the degree of acidity or alkalinity of the water. PH=log101/ (H^{+}) and the range is 0 to 14, with 7 being the neutral value 7, Acidity is indicated by a pH less than 7, whereas a pH greater than 7 indicates a base. The pH of water is an extremely significant indicator of water quality.

6.1.4. Water type classification

The presentation, classification and interpretation of chemically analysed water results depend on the specific objective of the analysis. For instance, water intended to use for drinking is quite different water for industries or agriculture. In order to identify groundwater interaction with subsurface geology and utilization of water for various purposes, it is essential to categorize and classify water on the basis of

-Total hardness

- Electrical conductivity (EC) and Total Dissolved Solids (TDS)

- Major cat-ions and anion

6.1.4.1. Classification based on Total Hardness

Hardness is a measure of the concentration of alkaline salts in water, mostly calcium and magnesium. The amount of calcium and magnesium concentrations, both expressed as $CaCO_3$ in mg/l, determines total hardness. Hardness might be considered to be the soap consuming property of water and usually expressed in terms of calcium carbonate. Hardness of water may be divided into two types: carbonate and non-carbonate. Carbonate hardness includes that portion of calcium (Ca) and magnesium (Mg) ions that combines with bicarbonate and the small amounts of carbonate present. This is called temporary hardness because it can be removed by boiling. Non- carbonate hardness is the difference between total hardness and carbonate hardness. The amounts calcium and magnesium that combines normally with Sulphate, chloride and nitrate ions (Tenalem Ayenew and Tamiru Alemayehu, 2001)

Hardness (HT) $=Ca*CaCO_3/Ca + Mg*CaCO_3/Mg$

Where HT, Ca and Mg are expressed in mg/l.

Each concentration is multiplied by the ratio of the formula weight of CaCO3 to the atomic weight of the ion (Freeze and Cherry, 1979).

The ratio in equivalent weight is given by: Hardness (HT) = $2.5(Ca^{2+}) + 4.1(Mg^{2+})$

Table 6.3 Hardness classification of water (Durfer and Beeker, 1964)

Hardness in mg/l as $CaCO_3$	Water Classes
0 – 60	Soft
61 – 120	Moderately hard
121 -180	Hard
>180	Very hard

Table 6.4 Water Classification of the study area based on Total Hardness

Water source	No. of samples considered	Minimum value(mg/l)	maximum value(mg/l)	Average value	Water class
Bore holes	24	10.5	446	239.64	Very hard

Hardness in water primarily affects consumer preferences and the condition of water pipes. The Ethiopian national standard for hardness in drinking water is 300 mg/L (as CaCO3). There is no relevant WHO Guideline Value, and the WHO Guidelines note that public acceptability of hardness in drinking water may vary considerably. Though hardness varied a bit by the source of water collected, the share of the population whose water is hard or very hard did not vary much by source type or location. Based on the average value described in Table 6.3, the water type in the study area grouped as very hard. From the analysed laboratory results Saketa well have higher total hardness value whereas Chefa 12 have lowest value.

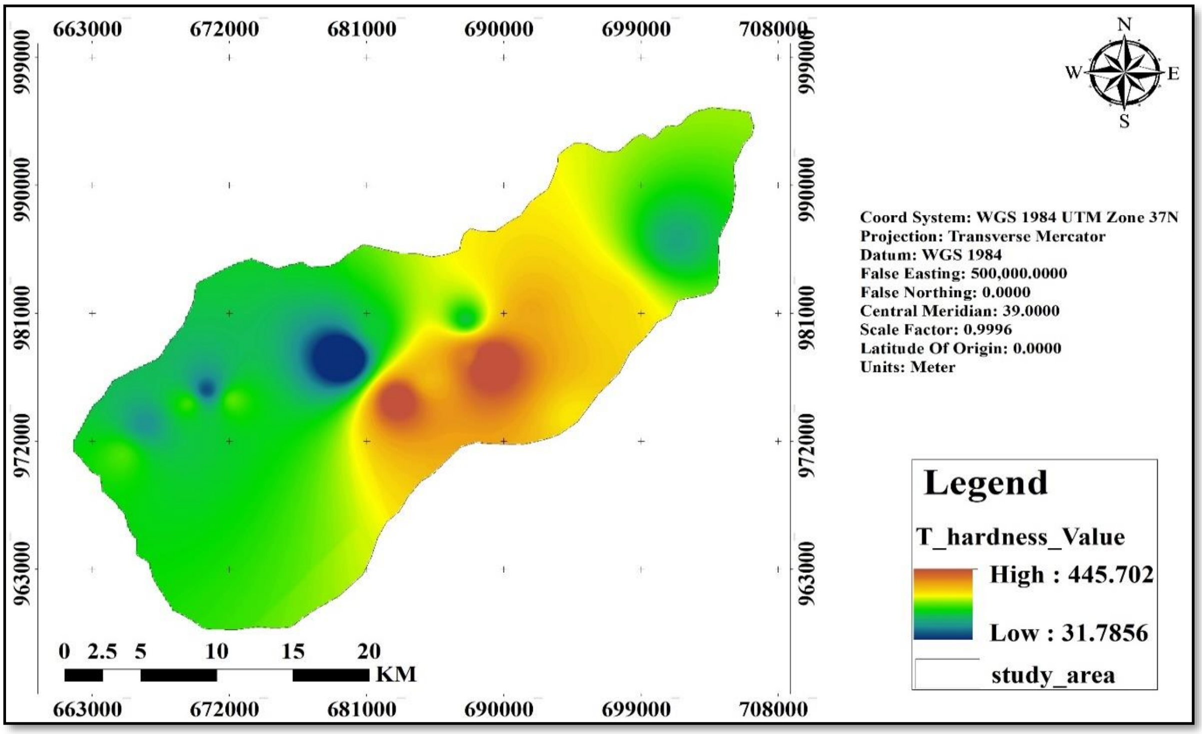


Figure 6.1 Total hardness map of the study area

6.1.4.2. Classification based on Electrical Conductivity, and Total Dissolved Solids

6.1.4.2.1. Electrical Conductivity (EC)

Electrical conductivity (EC) is a physical property of water that is dependent on the dissolved salts. Water's ability to conduct electric current is known as conductivity. Electric current is carried through water by the presence of dissolved solids such as calcium, chloride, and magnesium. According to (Rahmanian et al., 2015), mineral water is expected to have high mineral content, resulting in a higher conductivity value. Conductivity has no direct effect on human health. It's used for a variety of things, including determining the mineralization rate (the presence of minerals like potassium, calcium, and sodium) and estimating the number of chemical reagents used to treat the water. Its measurement in micro Siemens per centimeter (μS cm−1) which gives a good estimate of the dissolved solids content of a water. Electro-conductivity is closely linked to total dissolved solids, salinity, and hardness, but conversion factors can vary depending on both the composition and the temperature of the water. There is neither an Ethiopian national standard nor a WHO Guideline Value for electro conductivity in drinking water. However, the Australian standard considers electrical conductivity of <800 μS/cm to indicate good quality. High conductivity can reduce the visual value of water by imparting a mineral taste to it. The conductivity of water is crucial to monitor in both industrial and agricultural activities.

Table 6.5 description of EC value in the Sub-Watersheds

Water source	No. of samples considered	Minimum value(mg/l)	maximum value(mg/l)	Average value
Bore holes	23	236	1371	668.70

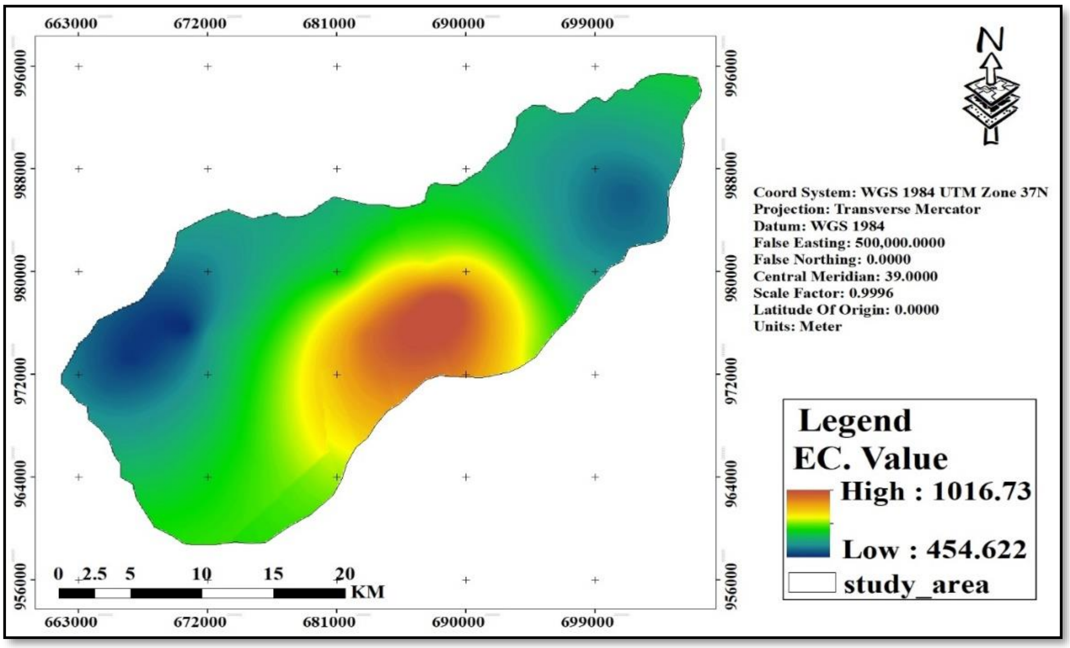


Figure 6.2 EC map of the study area

The spatial distribution map of EC (μS/cm) in the Upper Dhungeta and Ramis Sub-watersheds shows that the central part around Bedesa graven which is relatively low land has relatively high EC and also indicates it is a discharge area since most of drilled boreholes are concentrated there.

6.1.4.2.2. Total dissolved solids (TDS)

Total dissolved solid includes all solid materials in solution, whether ionized or not. TDS stands for total dissolved solids, which refers to the inorganic salts and small quantities of organic matter that are found in solution in water. Calcium, magnesium, sodium, and potassium cations, as well as carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions, are the most common constituents. More than 90% of the dissolved solids in ground water can be attributed to eight ions, Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, CO_3^{2-}, HCO_3^{-}, and SO_4^{2}. These ions are usually present at concentration greater than 1 mg/l (Fetter, 1994). As it is related to the sum of the concentration of all ions, it is directly related to the electrical conductivity. TDS of natural water range from less than 10ppm of dissolved solids for rain and snow, to more than 300,000ppm for some brine (Tenalem and Tamiru, 2001). Water type classification based on their total concentrations of dissolved solids is the simplest classification (Devis and DeWiest, 1991).

Table 6.6 Water classification based on TDS values (Source: Freeze and Cherry, 1979)

Water type	Total dissolved solids (TDS)
Fresh water	0-1000
Brackish water	1000-10,000
Saline water	10,000-100,000
Brine water	>100,000

Table 6. 7 Water classifications of the study area based on TDS value

Water source	No. of samples considered	Minimum value(mg/l)	maximum value(mg/l)	Average value	Group
Bore holes	23	160	750	357.35	Fresh water

TDS levels were less than 1000 mg/l (WHO) in all of the water samples collected from the study area, and ranges from 160 to 750. Based on the result the water in the study area is Fresh water and is suitable for drinking and agricultural use in terms of total dissolved solids (TDS). Figure 6.3 below indicates TDS distribution in the study area. Since TDS is related with EC, the central part of the study area shows relatively higher TDS concentration, while the peripheral part shows low TDS concentration and this indicates recharge area.

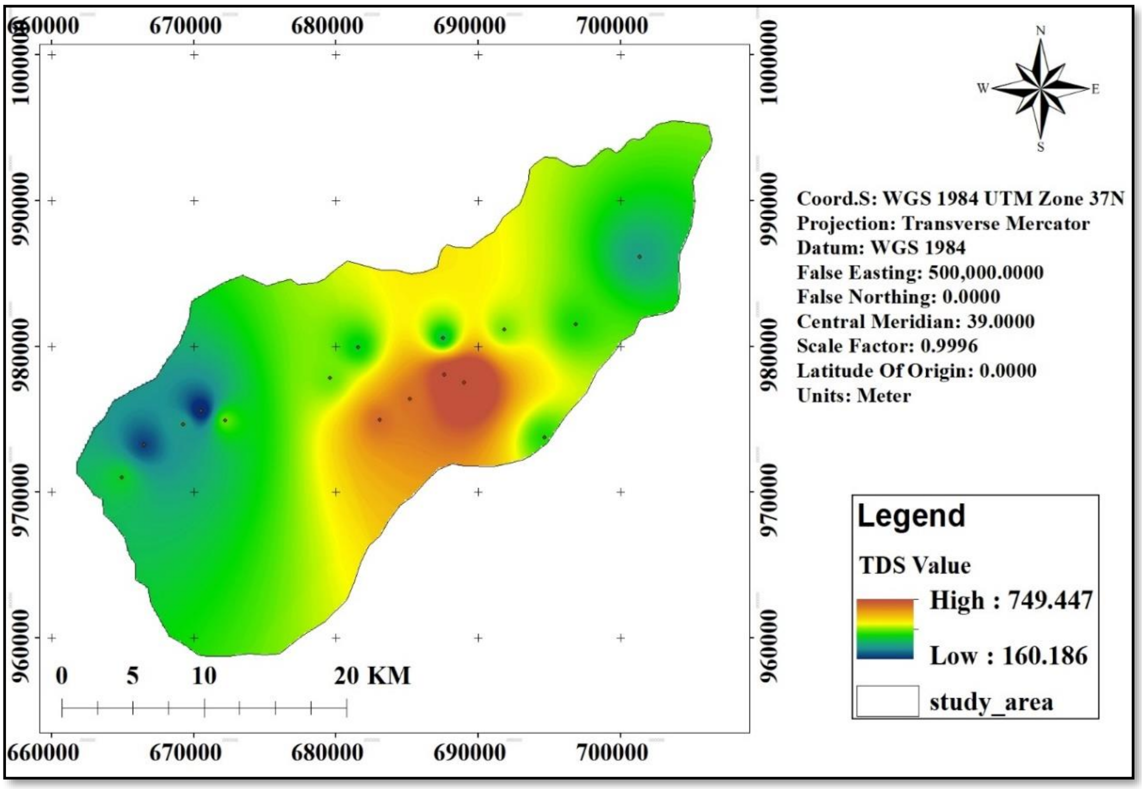


Figure 6.3 TDS map of the area

6.1.4.3. Classification based on major Cations and Anions

In order to categorize and classify water on the basis of their respective percentage composition of cations and anions, different graphical presentation is essential. Among these graphical presentation, Piper tri-linear diagram is the most useful methods. The geochemical evolution of groundwater can be understood by plotting the concentrations of major cations and anions in in the piper tri-linear diagram (piper, 1944). The major ionic species in most natural waters are Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, CO_3^{2-}, HCO_3^{-}, and SO_4^{2-}. In piper diagram, major ions are plotted in the two base triangles as major cations (Ca^{2+}, Mg^{2+}, and Na^{+} + k^{+}) and major anions (Cl^{-}, $SO4^{2-}$ and CO_3^{-} plus HCO_3^{-}) in milli equivalent percentages. A Piper tri-linear diagram can show the percentage composition of these ions. By grouping Na^{+} and K^{+} together, the major cations can be displayed on one tri-linear diagram. Likewise, CO_3^{2-} and HCO_3^{-} should be grouped in to one. Piper tri-linear diagram plotting points were done based on computer software package called Aquachem. Piper diagram has been widely used to study the similarities and differences in the composition of waters and to classify them in to certain chemical types (piper, 1944). In this work, classification and grouping was done for boreholes water sample laboratory results and both major cations and major anions statistical description is displayed in Table 6.8 below.

Table 6. 8 Summary of Analysed Major Cations and Anions Concentration in the study area.

Type of Cations and Anions in mg/l	No of samples	Water source	Minimum	maximum	Average value
Sodium (Na^+)	24	borehole	7	205.3	40.887
Magnesium (Mg^{2+})	24	borehole	0.51	70	22.0733
Calcium (Ca^{2+})	24	borehole	3.36	380	115.235
potassium(K^+)	24	borehole	0.4	11	4.04
Chloride (Cl^-)	24	borehole	0	120	22.52
Sulphate (SO_4^{2-})	24	borehole	0.19	160	55.51
Bicarbonate (HCO_3^-)	24	Borehole	34.2	600	333.15
Carbonate (CO_3^-)	24	borehole	0	58	17.36

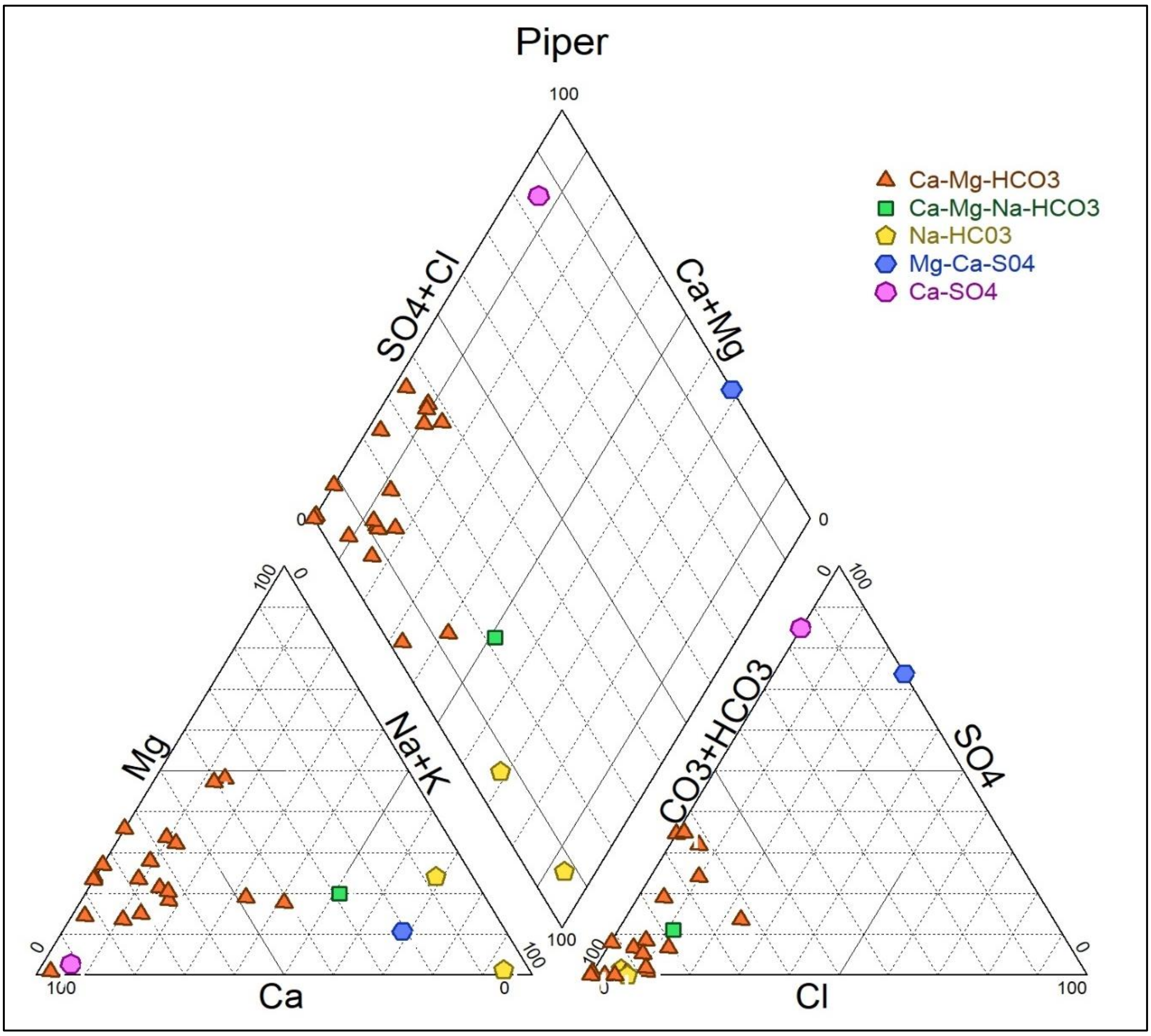


Figure 6.4 Piper plots of water samples in the study area.

6.1.5. Groundwater Type Classification and presentation of analytical results

Water can be classified based on the dominant major ions present in it. The ionic dominancy changes as water flow from the recharge area to the discharge area encountering various rock units. The dissolved ion concentration of water samples is mainly dependent on the lithology, regional tectonic structures as well as minor localized geological features, altitude, climatic conditions, and human activity. The chemistry of groundwater does not dramatically alter along its flow path unless it comes into contact with rocks that have a completely different character. The total chemistry of groundwater at any given time and place is the consequence of dissolution, ion exchange, and precipitation processes continuing to operate. Increases in total dissolved solids and most of the major ions are common along the groundwater flow path in the saturated zone (Freeze & Cherry, 1979). Consequently, as it is shown in figure 6.3 above, the ion concentrations show significant variation throughout the area from the western and eastern part to the central part of the area in increasing manner.

Piper diagrams outline such basic concepts in a graphic technique that appears to be an efficient method in separating analytical data for crucial analysis of dissolved constituents in water sources (Tank & Chandel, 2010; Rajesh et al., 2019). The Piper diagram is divided into three sections: two trilinear diagrams at the bottom and one diamond-shaped diagram in the center. The relative concentrations of cat-ions (left diagram) and anions (right diagram) in each sample are depicted in the trilinear diagram. The concentrations of eight major ions (Na^{+}, K^{+}, Mg^{2+}, Ca^{2+}, Cl, CO_3^{2-}, HCO_3 and $SO4^{2-}$) are represented on a tri-linear diagram by grouping the K^{+} with Na^{+} and the CO_3^{2-} with HCO_3^{-}, resulting in a reduction of the number of plotting parameters to six (Amadi et al., 2014).

The relative concentrations of cations and anions are plotted in the lower triangles on the Piper diagram, and the two points that result are extended into the central field to reflect total ion concentrations. The Piper diagram may also demonstrate the degree of mixing between freshwater and saltwater. Based on their dominant ions, Piper diagram can also be used to sort groundwater samples into different hydro-chemical facies (regions where water chemistry characterized by similar mixtures of constituents and it reflects water with similar history, origin, interactions, etc.).

By the order of dominance, almost all water sample chemical result shows the water falls under Ca-Mg-HCO_3 Type, other one sample under Ca-Mg-Na-HCO_3 Type, two samples categorized under Na-HCO_3 Type, one sample under Na-HCO_3 Type and one sample under Ca-SO_4 Type.

6.2. Quality of Groundwater

Water quality refers to the chemical, physical, and biological characteristics of water, usually in terms of its suitability for a specific reason. As a result, quality requirements are dependent on the use of water for a specific reason, and quality levels must be maintained in water supply for various uses in order to prevent negative consequences. To put it another way, whether a given quality of groundwater is appropriate for a given use is determined by the parameters or requirements of reasonable quality for that use (Patil et al., 2012).

The usefulness of water for the desired purpose is determined by its chemical and biological characteristics. The physical, chemical, and biological qualities of water are necessary for every given application. Water quality monitoring provides empirical evidence for health and environmental decision-making. Water-quality requirements for various water uses, such as drinking water, irrigation, livestock watering, fisheries, leisure activities, amenities, and the preservation of river system flora and fauna, should be clearly defined. The occurrence of some ionic species in water above a certain limit may deteriorate human health and the environment. Water quality standard depends on the use of water body. Water designed for drinking, irrigation, industrial and aquatic life have different quality standards and these criteria are usually numerical (e.g., a precise measurement of an allowable chemical concentration, not be exceeded). Different countries have water quality standards for the desired purpose. However, there is one general standard formulated by World Health Organization (WHO). Ethiopia has its water quality standard formulated by the Ethiopian Standards Agency in 2013.

6.2.1. Water Quality for Domestic Use

Drinking water standards are based on two criteria; 1) the presence of objectionable test, odours or colours, and 2) the presence of substances with adverse physiological effects (Davis and Dewiest, 1991). For example, nitrate, arsenic, fluoride, are some of hydrochemical elements which adversely affect the health of human being. The exact optimum limits of all the ions are actually controlled by the health, size and age of the individual as well as by his eating and drinking habits. Climate also has an effect on the liquid intake and methodology of waste eliminations (Niguse kebede, 2005).

To assess the suitability of water for drinking purposes, the results of the chemical analyses were compared with the Ethiopian standards for drinking water prepared by the Ethiopian Standards Agency, and the Guidelines formulated by World Health Organization.

For successful water quality activities; legal frame work or water quality standards should be established. Accordingly, in this work, more emphasis is given to chemical water quality in relation to the WHO and Ethiopian (Ministry of Water Resource) drinking water standards or guidelines.

Table 6. 9 Comparison of water quality with WHO and Ethiopia water quality standards or guideline. (Source: WHO water quality standard, 1993 and Ethiopia quality guideline, 2002)

Water quality parameter in mg/l	WHO (mg/l) standard	No of sample <WHO standard	No of samples >WHO standard	Ethiopian(mg/l) standard	No of samples < Ethiopian standard	No of samples >Ethiopian standard	Analyzed result from the data
PH	6.5-8.5	2	1	6.5-8.5	2	1	6.05 - 8.88

Color	15	All	0	15	All	0	22 - 50
Turbidity (NTU)	5	10	8	5	10	8	0.34 - 27.38
TDS	1000	All	0	1000	All	0	160 - 750
Hardness	500	All	0	300	16	7	10.5 - 446
Ammonia	1.5	All	0	1.5	All	0	0 - 1.23
Sodium	200	19	1	200	19	1	7 - 152.1
Potassium				1.5	5	15	0.4 - 11
Calcium	75	13	9	75	13	9	3.36 - 380
Magnesium	50	22	1	50	22	1	0.51 - 70
Aluminum	0.2			0.2			
chloride	250	All	0	250	All	0	0 - 120
Copper	1			2			
Fluoride	1.5	all	0	3	All	0	0 - 1.2
Sulphate	250	All	0	250	All	0	0.29 - 160
Nitrate	50	All	0	50	All	0	0 – 8.8
Nitrite	3	All	0	3	All	0	0 – 0.28
Iron	0.3	15		0.3	15	3	0 – 0.78
Manganese	0.4	20	2	0.5	20	2	0 – 2.08
Cd	0.003			0.003			
Cr	0.05			0.05			
Pb	0.01			0.01			
Zn	4			5			

As we can see from the table most of the water samples in the study area fulfill the requirements for drinking purposes. However, in some wells calcium and potassium concentrations are above the required limit set by World Health Organization. The presence of limestone in the study area cause water to have a high concentration of calcium and that is the case for dental and skeletal problems in the society living in the area even though it is not that much significant. Besides fluoride ion which has low solubility and occurs in igneous which includes Apatite, Amphiboles such as hornblende and some of the micas and sedimentary rock contains fluoride.

Rocks in alkali metals, and also obsidian, are as a class higher in fluoride content than most other igneous rocks. Fluoride is commonly associated with volcanic or fumarolic gases (Hem, 1992). Fluoride in drinking water can have toxic effects in both excess and deficiency. WHO guide line value set 1.5 mg/l for excess fluoride as susceptibility in deficiency is highly dependent on nutritional status. Excess fluoride may lead to dental or skeletal fluorosis. A lack of fluoride may cause dental caries, a weakening of the teeth.

Based on the result obtained from the collected laboratory analysis result, all samples fluoride concentration is below the maximum permissible limits set by both WHO standard (1.5mg/l) and Ethiopian guidelines (3mg/l) and it is described in table 6.9 below.

6.2.2. Water Quality for Irrigation

The quality of water is an important component with regard to sustainable use of water for irrigated agriculture, especially when salinity development is expected to be a problem in an irrigated agricultural area. It is also a crucial factor in irrigated agricultural long-term sustainability, especially where salinity development is predicted to be an issue. Since salts can impair both soil structure and crop output, salinity levels are the principal water quality concern in most irrigation systems. The high salinity water is poisonous to plants and creates a salinity danger. Saline soils are those that have a high amount of total salinity. A “physiological” drought can be caused by high salt concentrations in the soil (Fipps, 2003). Because of sodium's impact on the soil, irrigation water containing significant quantities of sodium is of particular concern and poses a sodium threat (Tank & Chandel, 2010). SAR, or sodium adsorption ratio, is a common way to express sodium hazard.

The Sodium Adsorption Ratio (SAR) is an irrigation water quality parameter used in the management of sodium-affected soils. It is an indicator of the suitability of water for use in agricultural irrigation, as determined from the concentrations of the main alkaline and earth alkaline cations present in the water. It is also a standard diagnostic parameter for the sodicity hazard of a soil, as determined from analysis of pore water extracted from the soil (Reeve, et.al., 1954).

Due to the impact of sodium on the soil, irrigation water having high levels of salt is of particular concern and constitutes a sodium hazard. Sodium hazard is usually expressed in terms of the Sodium Adsorption Ratio (SAR) which is calculated from the ratio of sodium to calcium and magnesium. The latter two ions are important since they tend to counter the effects of sodium. Using water that has a high SAR value for irrigation results in a breakdown in the physical structure of the soil. Due to its nature, sodium can be adsorbed and becomes attached to soil particles that make the soil hard and compact when it is dried and increasingly impervious to water penetration. Soils having fine texture, especially with high clay content are vulnerable to such effects.

The United States soil laboratory proposed the following relation to calculate the effect of sodium on soil fertility (McGeorge, 1954). This formula is used to classify the waters found in the area for irrigation.

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^{2+}]+[Mg^{2+}]}{2}}}$$

SAR allows assessment of the state of flocculation or of dispersion of clay aggregates in a soil. Sodium and potassium ions facilitate the dispersion of clay particles while calcium and magnesium promote their flocculation. The behavior of clay aggregates influences the soil structure and affects the permeability of the soil which directly depends the water infiltration rate. It is important to accurately know the nature and the concentrations of cations at which the flocculation occurs: critical flocculation concentration (CFC). The SAR parameter is also used to determine the stability of colloids in suspension in water.

Although SAR is only one factor in determining the suitability of water for irrigation, in general, the higher the sodium adsorption ratio, the less suitable the water is for irrigation. Irrigation using water with high sodium adsorption ratio may require soil amendments to prevent long-term damage to the soil (DWAF, 1996).

According to (Rollins, L. 2007), if irrigation water with a high SAR is applied to a soil for years, the sodium in the water can displace the calcium and magnesium in the soil. This will cause a decrease in the ability of the soil to form stable aggregates and a loss of soil structure and tilth. This will also lead to a decrease in infiltration and permeability of the soil to water, leading to problems with crop production. Sandy soils will have less problems, but fine-textured soils will have severe problems if SAR is greater than 9. When SAR is less than 3, there will not be a problem.

The concept of SAR addresses only the effects of sodium on the stability of soil aggregates. However, high K and Mg concentrations have also negative effects on soil permeability. The effect of potassium can be similarly treated by means of the potassium adsorption ratio (PAR), (Garrison, 2008) To consider simultaneously all major cations present in water, a new irrigation water quality parameter was defined: the cation ratio of structural stability (CROSS), a generalization of SAR (Rengasamy et al., 2011).

The other important classification of irrigation water is based on electrical conductivity (EC) and soluble sodium percentage (also known as sodium percentage), which is calculated using the formula (Wilcox, 1955)

$$\%Na = (Na^{+}+K^{+}) *100/ (Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})$$

Table 6.10 Classification of water based on Sodium Adsorption Ratio and Percent Sodium

Equation	Equation	Range	Water class
1	$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$	<10	Excellent
		10–18	Good
		18–26	Doubtful
		>26	Unsuitable (S4)
2	$\%Na = \frac{Na^+ + K^+}{Ca^{2+}+Mg^{2+}+Na^+ + K^+} \times 100$	<20	Excellent
		20–40	Good
		40–60	Permissible
		60–80	Doubtful
		>80	Unsuitable

The United States Department of Agriculture has established a classification of water for agriculture based on the Sodium Adsorption Ratio (SAR) or percentage as a sodium hazard index and specific electrical conductivity (EC) as a salinity hazard index.

Table 6.11 Classification of water based on EC and Na%

water class	EC(µSm/cm)	Na%
Excellent	<250	<20
Good	250-750	20-40
Permissible	750-2250	40-60
Doubtful	2210-4000	60-80
Unsuitable	>4000	>80

Table 6.12 categorization of water samples in the study area based on their %Na

%Na Range	<20	20 - 40	40 - 60	60 - 80	>80
No. of samples considered	18	1	2	2	1
water class	Excellent	Good	Permissible	Doubtful	Unsuitable

Table 6.13 Classification of water based on EC and (SAR)

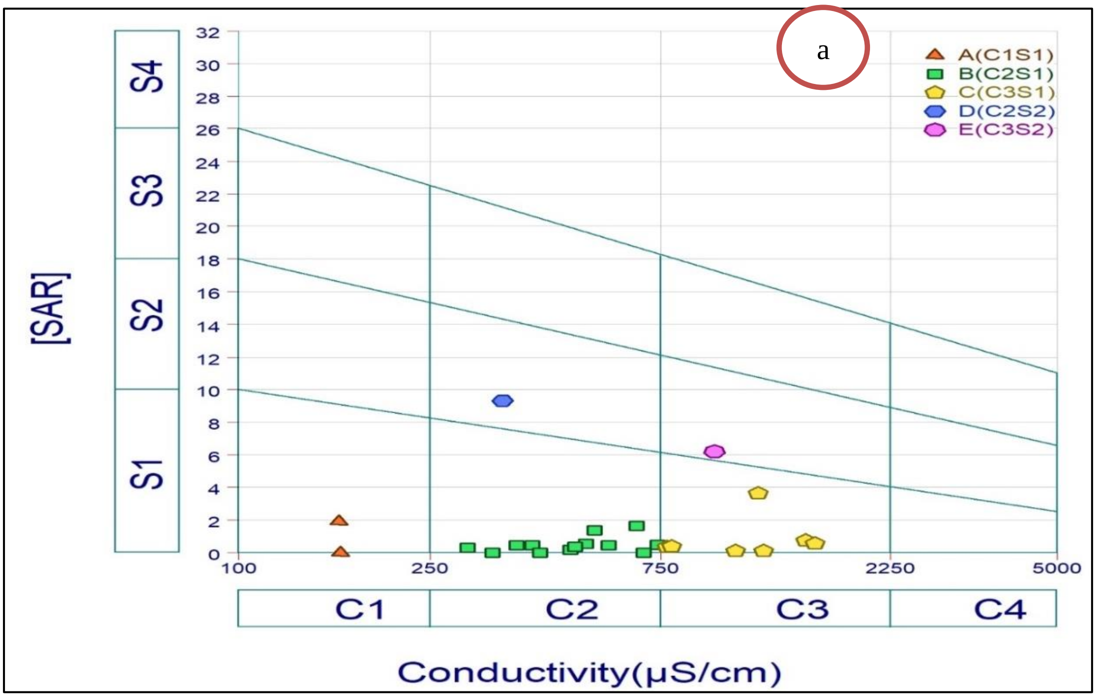
water class	EC(µSm/cm)	SAR	Effects	Class	Classification	Uses
Excellent	<250	<10	Excellent	Low	Low sodium water	For all crops in all soils
Good	250-750	10-18	Good	Moderate	Medium sodium water	Can be used in coarse grain soils
Medium	750-2250	18-26	Fair	Medium-high	High sodium water	Can be used, Leaching is done and requires good drainage system
Bad	2210-4000	>26	Poor	High	Very high sodium water	Not usable
Very bad	>4000					

Table 6.14 water classification using SAR values (Sabrina et al., 2005).

SAR	Ground water quality	Irrigation type	Water class
<10(Low)	Excellent	All soil types can be irrigated	C1- low salinity
10-18(Medium)	Good	Low cat ion exchange soils can be irrigated	C2-medium salinity
18-26(High)	Fair(tolerable)	For irrigation, soils need a good drainage and organic compounds addition	C3- high salinity
>26(Very High)	Poor(unsuitable)	Irrigation is possible only with low salinity waters	C4- very high salinity

Table 6.15 Water Classification of in the sub watersheds based on SAR value

Water source	No. of samples considered	Minimum value(mg/l)	maximum value(mg/l)	Average value	Groundwater quality
Bore holes	24	0.00	9.34	1.30	Excellent



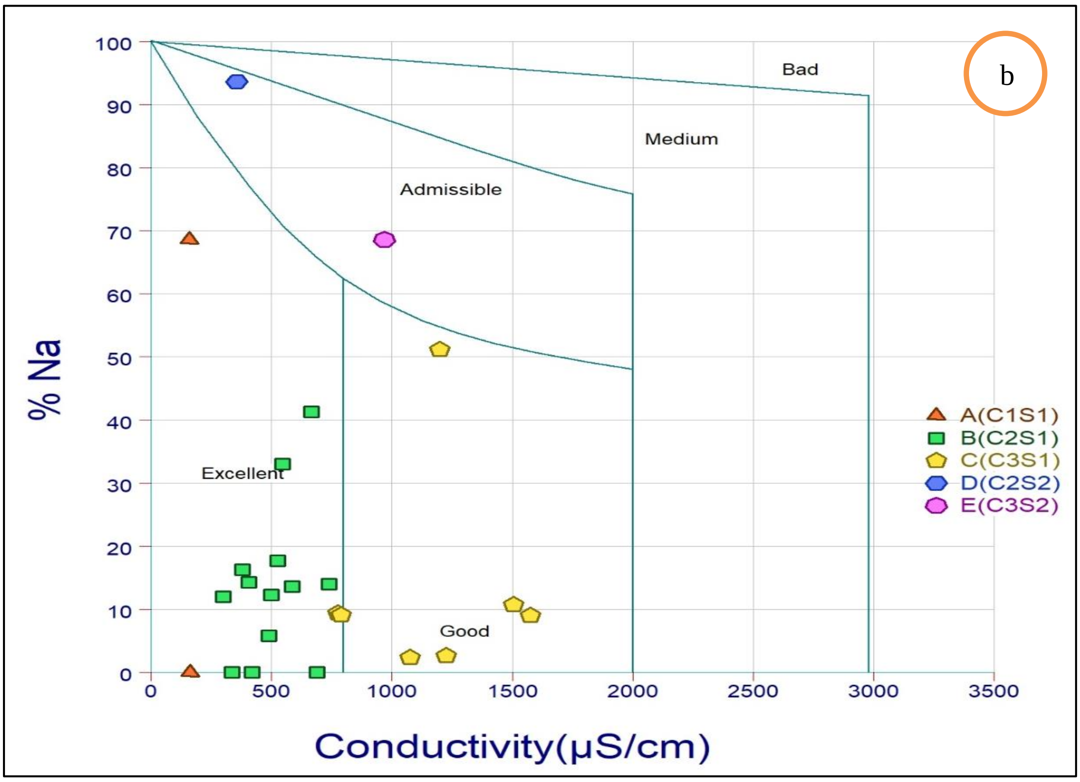


Figure 6. 5 a) SAR and b) sodium percent distribution map of the study area

Based on %Na analysis two samples (wachu town and Kara Kurkura 1 wells) fall under admissible water class, and all other samples fall under Excellent and good Water Class. The sodium adsorption ratio of all well water samples is very low (<10) indicating that there is no sodium ion-related hazard and these waters can be used for irrigation.

In general, except few samples from groundwater wells, almost all groundwater wells in the Upper Dhungeta and Ramis sub-watersheds have low sodium hazards and are suitable for irrigation purposes.

6.2.3. Industrial Use

The majority of the upper limits for companies whose goods are used by humans do not surpass the human-set limits for drinking water. The quality requirements for industrial water supplies range widely, and almost every industrial application has its own standards. For some uses such as single-pass condensing of steam or for cooling or for concentrating ores, chemical quality is not particularly critical and almost any water may be used. At the opposite extreme, water approaching or equaling the quality of distilled water is required for processes such as the manufacture of high-grade paper or pharmaceuticals, where impurities in the water would seriously affect the quality of the product. Modern maximum-pressure steam boilers may require makeup water less concentrated than the average distilled water of commerce, and very pure water is desirable in nuclear reactors to minimize radioactivity induced by neutron activation of the dissolved species. The American Water Works Association has set some additional concentration limits for certain industries, which are described in the table below.

Table 6.16 Limits on fluoride concentrations in industries (after Todd, 1980, and Hem, 1992)

S/No	Type of industry	Ranges in recommended limits concentrations of F^- (mg/l)	The analyzed fluoride ion concentration range
1	Brewing	1.0	0 – 1.2
2	Carbonate beverage	0.2-1.0	0 – 1.2
3	Drinking	1.4-2.4	0 – 1.2
4	Food canning and freezing	1.0	0 – 1.2
5	Food equipment, washing	1.0	0 – 1.2
6	Food processing, general	1.0	0 – 1.2
7	Canned, dried, frozen fruits and vegetable	1.0	0 – 1.2
8	8 Soft-drinks bottling	It is forbidden to consume more than the human body needs.	0 – 1.2

Based on the required recommended limit concentration of F^-, almost all samples fall under American Water Works Association recommended concentration limits for certain industries.

CHAPTER SEVEN

Conclusion and Recommendation

7.1. Conclusion

The study area is located in the upper part of Wabishebele river basin which covers 753.2km^2 and having average elevation ranges from 1374m and 2948m above mean sea level. The area has 20.3 to 21.4°C average annual temperature and temperate (weyna dega) climate.

Three meteorological stations within and around study area had recorded 848.7mm to 1056.8 mm annual rain fall. Asebe Teferi and Bedesa stations record minimum (848.7mm) and maximum (1056.8mm) annual rainfall values respectively. The area has two rain fall regime (Bimodal rainfall characteristics) that is small rain (bulg season) in the month of April and May, and big rain (Kiremt season) in the month of July, August, and September. Weighted Areal depth of precipitation in the three stations (Gelemso, Bedesa and Asebe Teferi) in the study area are 431.1, 565.1 and 14.9mm respectively. And Weighted Areal depth of precipitation in the study area is 1011.1mm (761.6 Mm^3).

From the available meteorological data potential evapotranspiration is calculated using Thorenthwaite method and the result is 944.2mm. Lower monthly potential evapotranspiration is occurred in the months of December and January because of high humidity in the atmosphere while higher potential evapotranspiration occurs in the month of June. Based on soil, land use /land cove categories and meteorological data, the actual evapotranspiration of the basin is calculated using Thorenthwaite and Mather soil water balance model and the annual AET is 845 mm (83.6%) of the rainfall leaves the sub-watersheds by evapotranspiration.

From the computed water balance of the study area, the amount of water infiltrated to subsurface is 101.2mm (10%) of total precipitation. This water is 76.2million cubic meter (76.2 Mm^3) for the total 753.2 km^2 of the study area. This infiltrated water could recharge the groundwater.

The local geology of the area is mainly Amba Aradom Formation (Jgs), Hamanlei Limestone formations (Jhl), Gebredare limestone formation (Jgl), Urandab limestone Formation (Jul), Alajae Formation (Tab), Tarmaber Formation (Ntb), Quaternary Eluvial deposit (Qel), and Quaternary Alluvial deposit (Qal).

The upper part is relatively undulated with rugged ridges topography and it is the southern part of the main Ethiopian rift escarpment. In the study area the groundwater is mainly controlled by its topography and geology. Most of the precipitation goes back as evapotranspiration and the infiltrated water immediately drained to relatively lower and flat to gentle slope topography (central part of the study area of the sub watersheds (discharge area). Because of high to medium permeability of the recharge area, the rain water percolate at higher elevation (recharge area) of the sub-watersheds and flows to central part of the study area (Bedesa graben). The wells drilled on this central part (Extensive and Moderately Productive Porous Aquifers) have relatively good yield (3.4-28.3 l/sec) with a transmissivity value of 0.6 - 411 m^2/d and hydraulic-conductivity value of 0.05-4.17 m/d.

The groundwater flow direction is towards the depressed flat topography from the surrounding hilly landscapes and general trend of the groundwater flow is from west to east and southeast direction.

From 24 water samples physical parameters and chemical laboratory analysis result, all water samples are fresh water (TDS = 160-750mg/l), the other two (chefa 12 and wachu town borehole water samples) are soft, 3(Melka Belo, Oda Tuta and Gelemso 3 borehole water samples) are hard water and the rest 19 samples are very hard water.

Based on chemical laboratory analysis result, almost all water samples are categorized under Ca-Mg-HCO_3 water type. This indicates the water immediately gets to discharge area and less water to rock/soil interaction and less residence time to the discharge area. It also shows highland areas water behavior.

7.2. Recommendation

Based on available data, analysis and the outcome of this study, the following recommendations are given

- Since the recharge condition is studied by soil water balance method the future researchers are recommended to carry out their investigations by another recharge method at larger scale than the present in order to get more detailed and refined findings and results.
- Meteorological stations are so limited and that of Bedesa and Asebe Teferi are 4th classes only precipitation and temperature data are available, so it is better to be updated.
- The present work used only deep wells laboratory result data due to lack of shallow dug wells and springs laboratory data (almost all hand dug well and springs water samples hydrochemical test is not conducted).
- In order to understand well and evaluate the aquifer behavior and groundwater potential zone precisely, additional test wells could be drilled which can be used as productive well for required purposes keeping fair distribution within the catchment with appropriate drilling and pumping test is recommended.

- The present water resource development activities like water harvesting, spring development, hand dug well constructions or shallow wells machine drilling particularly in rural areas are very low. In order to solve drinking water supply and food deficiencies problems, water resource development activities should be practiced in most of the rural areas within the sub-watersheds.
- The main difficulty encountered in the estimation of the groundwater recharge of study area was the absence of long time meteorological data and within the study area there are only two stations, and the recently installed 3rd stations even though not included in the analysis and also the absence of exact discharge data of shallow and deep wells to confirm the estimated recharge; therefore further water balance investigations are necessary to validate the estimated annual groundwater of the Upper Dhungeta and Ramis Sub-watersheds.
- Well distributed of deep wells data with full pumping test data and shallow wells data with exact water level data should be investigated to determine the exact local and regional aquifer system of the Upper Dhungeta and Ramis Sub-watersheds
- Water quality requires regular review and control, as well as an assessment of the impact of development on water quality in comparison to a set of standards.
- Even though due to budget limitation small number of chemical laboratory analysis is conducted in this study work, different organizations that drilled different water resource in all form of schemes (as spring on spot development, Hand dug well, shallow wells and deep well) for different purpose in the area have to conduct both physical and chemical analysis and result data have to be organized in water sectors both at woreda and zone water sector offices.

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Appendices

Annex 1: - Monthly Mean Precipitation of the study area

month	Year			
	2002-2017	2002-2017	2002-2017	2002-2017
	Gelemso	Bedesa	Asebe Teferi	Weighted MM precipitation
Jan	8.9	14.3	14.9	12.7
Feb	14.2	7.0	15.9	12.4
Mar	58.9	67.5	77.8	68.1
Apr	129.6	147.1	114.3	130.3
May	127.9	122.8	99.1	116.6
Jun	72.5	89.5	55.1	72.3
Jul	135.6	149.5	127.8	137.6
Aug	155.5	159.6	157.6	157.6
Sep	157.7	191.7	125.4	158.2
Oct	57.0	64.1	36.0	52.3
Nov	31.6	27.3	13.3	24.1
Dec	13.4	16.5	17.9	15.9

Annex 2: - Mean monthly minimum, maximum and average temperature of the study area

Station		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Mean
Gelemso	Max	26.4	27.9	28.6	27.5	27.7	27.8	26.8	26.2	26.3	26.3	26.0	25.2	26.9
	Min	12.1	13.5	14.5	14.8	15.0	15.1	15.1	15.1	14.5	11.5	10.7	12.0	13.7
	Ave	19.2	20.7	21.6	21.2	21.4	21.5	21.0	20.6	20.4	18.9	18.3	18.6	20.3
Bedesa	Max	28.4	29.7	29.9	28.4	28.4	28.1	27.2	26.9	27.1	27.7	28.1	27.4	28.1
	Min	11.5	11.6	13.3	14.4	14.4	14.5	14.8	14.6	13.9	12.0	10.3	10.1	13.0
	Ave	19.9	20.7	21.6	21.4	21.4	21.3	21.0	20.8	20.5	19.9	19.2	18.7	20.5
Asebe	Max	26.5	27.8	28.9	28.5	28.8	29.2	28.4	27.1	27.3	27.4	27.2	25.9	27.8
	Min	13.4	14.6	15.3	16.0	16.3	17.6	15.7	15.7	15.7	14.9	13.8	12.4	15.1
	Ave	19.9	21.2	22.1	22.2	22.6	23.4	22.1	21.4	21.5	21.2	20.5	19.1	21.4

Annex 3:- Spring distribution in Upper Dhungeta and Ramis Sub-Watersheds

NO	Site Name	X	Y	Z	Yield	Formation
1	Burqa	691089	985203	1785	12	Limestone
2	Kolu	695201	987139	1742	0.9	volcanic
3	Kereyu	697214	991008	2223	0.8	volcanic
4	Sebale	700210	988118	1800	0.3	volcanic
5	Sebale	699251	990527	1996	0.5	volcanic
6	Idoo Bariso	700720	987008	1800	0.3	volcanic
7	Obi17	688673	986596	2097	3	volcanic
8	Burqa-Bakanisa	701830	979507	1767	5	limestone
9	Mekenisa	682507	982553	1967	0.7	volcanic
10	Mekenisa	689756	982714	1700	0.5	volcanic
11	Oda Baso	691089	985203	1785	0.8	alluvial
12	Goda Hora	687785	975226	1648	0.6	sandstone
13	Midhegdu	694020	980321	1650	1	limestone
14	Midhegdu	696603	981433	1661	0.9	limestone
15	Saqariga	694859	989958	1956	1.2	volcanic
16	Saqariga	695449	990066	1911	1.1	volcanic
17	Saqariga	695186	989724	1904	0.6	volcanic

18	Saqariga	695037	990766	1978	0.9	volcanic
19	Midhegdu	697755	982281	1682	0.5	limestone
20	Hajidin (Bedesa)	696578	981401	1670	15	limestone
21	Sororo	703507	992966	2223	10	volcanic
22	Midhegdu	684753	981348	1776	0.4	limestone
23	Goda Hora	689454	982886	1718	0.4	limestone
24	Bekenisa	679021	980416	1794	0.5	limestone(contact)
25	Damise	697317	989064	1973		
26	Hormaata	697214	991008	2223		
27	Darbaalee	700210	988118	1800		volcanic
28	Siyum	699251	990527	1996		volcanic
29	Idoo Bariso Gadii	700720	987008	1800		volcanic
30	Waqali	696928	986992	1736		volcanic
31	Alli	699139	986873	1760		volcanic
32	Saqela	694859	989958	1956		volcanic
33	Laga Adam	695449	990066	1911		volcanic
34	Mangudoota	695186	989724	1904		volcanic
35	Dhukaamsa	695037	990766	1978		
36	Kalaala	694020	980321	1650		alluvial
37	Deefoo	693927	980112	1642		alluvial
38	Haamadoo	697755	982281	1682	0.1	alluvial
39	Bultum	687785	975226	1648		sandstone
40	Burqaa	691089	985203	1785		volcanic
41	Ifa Baas	689756	982714	1700	1	volcanic
42	Tiin	689756	982714	1700	0.3	sandstone
43	Simonii	687785	978226	1648	0.4	alluvial
44	Abbaa Shaawul	685421	977097	1743		volcanic
45	Ushe	696093	987190	1682		volcanic
46	Wallembo	685753	981348	1776		sandstone

Annex 4:- HDW distribution in Upper Dhungeta and Ramis Sub-Watersheds

No	Site name	x	y	z	Swl	Gwl	Q (yield)	total depth	source Type	geological formation
1	Kaarraa/Coontee	687291	982421	1744	4	1740	1	9	HDW	sandstone
2	Kaarraa	687279	982421	1752	3	1749	1.5	10	HDW	sandstone
3	Bekenisa	689479	982847	1716	5	1711	0.9	16	HDW	Alluvial
4	Bekenisa	688507	985553	1967	3	1964	1	15	HDW	Alluvial
5	Bereda	681341	979435	1712	4	1708	1	13	HDW	alluvial
6	Oda Roba	689756	982714	1700	1	1699	1	15	HDW	alluvial
7	Oda Roba	690682	982502	1689	4	1685	1	16	HDW	alluvial
8	Jarra	696138	985172	1750	5	1750	1.2	15	HDW	alluvial
9	Gola	691970	980591	2058	3	2058	0.6	11	HDW	alluvial
10	Faaroo Olii	698715	986025	1732	4	1732	1	9	HDW	alluvial
11	Faaroo Gadii	698799	986228	1742	4	1742	1.3	8	HDW	alluvial
12	Goda Hora	694020	980321	1650	1	1649	1.1	8	HDW	alluvial
13	Goda Hora	692160	978369	1636	2	1634	1.2	9	HDW	alluvial
14	Midhagidu	689752	979293	1636	1	1635	0.8	10	HDW	alluvial
15	Mendera	666517	973731	1733	4	1729	1	17	HDW	alluvial
16	Awsaid	666877	973646	1726	3	1723	1.3		HDW	alluvial
17	Mendera	666227	972451	1724	2	1722	1.4		HDW	alluvial
18	Kara	692699	981928	1642	3	1639	1		HDW	alluvial
19	Oda Roba	690682	982502	1689	4	1685	0.9		HDW	alluvial

20	Oda Roba	689756	982714	1700	1	1699	0.8		HDW	alluvial
21	Bekenisa	689479	982847	1716	5	1711	0.5		HDW	alluvial
22	Bekenisa	688507	985553	1967	3	1964			HDW	alluvial
25	Bereda	681341	979435	1712	4	1708			HDW	alluvial
27	Bereda	682605	980379	1725	9	1716	1.1		HDW	alluvial
30	Haro Charcher	683110	976271	1673	2	1671	1		HDW	alluvial
31	Haro Carcer	678486	974959	1671	1.5	1669.5	1		HDW	alluvial
32	Haro Carcer	678242	975537	1675	3	1672			HDW	alluvial
33	Gerbi Teka	677679	975537	1686	7	1679	1.1		HDW	alluvial
34	Gerbi Teka	678000	975434	1675	8	1667	1.2		HDW	alluvial
35	Gerbi Teka	677397	976344	1690	6	1684			HDW	alluvial
36	Gerbi Teka	676579	976014	1706	8	1698			HDW	alluvial
37	Bedhadha	673531	976084	1700	6	1694			HDW	alluvial
38	Melka Belo	670393	975419	1733	2	1731			HDW	alluvial
39	Laga Bera	664123	971383	1748	5	1743			HDW	alluvial
40	Laga Bera	664152	918191	1819	4	1815		7	HDW	alluvial
41	Laga Bera	664177	971395	1745	3	1742	0.2	6	HDW	alluvial
42	Barkalee	699012	989277	1886	4	1882	1.3	8	HDW	alluvial
43	Gabiboo	700430	985421	1736	2	1734	1.2	16	HDW	alluvial
44	Odaa Bultee	699633	983734	1704	2	1702		14	HDW	sandstone
45	Lukanda	699455	986527	1752	3	1749	1.8	13	HDW	sandstone
46	Madabanya	699176	986307	1742	4	1738		14	HDW	sandstone
47	Kaartoo	696838	985072	1710	5	1705		10	HDW	alluvial
48	Kurfa	700591	984374	1725	3	1722		9	HDW	alluvial
49	Gohii	693890	981356	1647	5	1642	1	13	HDW	sandstone
50	Saqaa	694032	980359	1649	6	1643	0.9	16	HDW	alluvial
52	Baaboo	692723	979132	1641		1641	0.7	17	HDW	
53	Kurfa	692068	978360	1630		1630	0.9	12	HDW	
54	Sheeka	696603	981433	1661		1661		15	HDW	
55	M/Barumsa O/Roba	693793	983000	1664		1664		16	HDW	
56	Warjii	693376	983821	1866		1866		15	HDW	volcanic
57	Madara	691684	981256	1647		1647	0.9	13	HDW	
58	Waraqata	692699	981928	1642	7	1635		16	HDW	sandstone
59	Hadra	691685	981258	1649	7	1642	1.1	12	HDW	
60	Gondare	692030	981173	1649	6	1643	1	12	HDW	alluvial
61	Buchoo	690367	981277	1653	3	1650	1.7		HDW	sandstone
62	Nolee	692013	980082	1635	3	1632	1.6		HDW	sandstone
63	Horaa	692436	979515	1635	2	1633	1.4		HDW	sandstone
64	Meeta	691352	978578	1624	3	1621	0.8		HDW	sandstone
65	Abadir	692079	984256	1709	2	1707	1		HDW	
66	Udee/ Adasho	687966	987903	1993	3	1990	0.6		HDW	volcanic
67	Coontee	687291	982421	1744	5	1739	0.5		HDW	volcanic
68	Halchawa	686985	982282	1738	4	1734	0.6		HDW	volcanic
69	Halchawa	687082	982067	1729	6	1723	0.7		HDW	volcanic

Annex 5:- Borehole distribution in Upper Dhungeta and Ramis Sub-Watersheds

NO	Site Name	x	Y	z	SWL	dd	Dwl	Pp	Gwl	Aquifer thickness (B)	well yield	total depth	source	geological formation/ aquifer type
1	Suri	685214	975933	1672	29.25	29.25	1643		1642.8			103	BH	alluvial
2	Guba Gutu	683068	974953	1679	66.7	23.5	90.2	155	1612.3	90	11.9	173	BH	limestone

3	Koye	696836	981513	1664	10	0	52	60	1654.0	36	13	82	BH	limestone
4	Oda Tuta	698790	970808	1769	37	32.2	69.7	170	1732.0	66	9	200	BH	limestone
5	Saketa	689016	977524	1635	0.46	0.5	0.98	98	1634.5	60	15	200	BH	limestone
6	Oda Boriyo	694630	973755	2034					2034.0		8		BH	limestone
7	Haro Carcar	702293	944156	1660	205.73	1.67	207.4	226	1454.3		3.4	325	BH	limestone
8	Mudhiiressa	685189	976368	1672	27	5	32.6	164	1645.0		20.89	174	BH	limestone
9	Kara 1	687524	980575	1662	11.9	7	19	114	1650.1	84	27	190	BH	sandstone
10	Kara 2	687350	980841	1675	15.6	5.39	21	100	1659.4	76	28.3	199	BH	sandstone
11	Iddo Bariso	700229	987976	1790	20	59	79	108	1770.0	30	4	143	BH	basalt
12	Goda Hora	687627	978037	1640	0	55	55	116	1640.0		19.78	174	BH	upper sandstone
13	Oda Roba	691816	981156	1643	10	21	31	100	1633.0		19.28	180	BH	upper sandstone
14	Bereda	681544	979950	1772	7.2				1764.8	58	11.7	119.48	BH	alluvial
15	Wachu Town	679569	977814	1712	32.3	0.66	32.96		1679.7		6.8	150	BH	upper sandstone
16	Milino Zewde	675212	975895	1772	8	8.61	16.61		1764.0	64	18.7	74	BH	alluvial
17	Melka Belo	670519	975602	1749	6	17	23	80	1737.0	108	10	154	BH	upper sandstone
18	Leilisa 1	664943	971002	1737	34	7.36	41.36	111	1703.0		6.7	173	BH	upper sandstone
19	Leilisa 2	664971	971185	1746	0	16.61	6	75.4	0.0		6	154	BH	upper sandstone
20	Gelemso 1	669272	974650	1727	1.5				1725.5	80	7.5		BH	upper sandstone
21	Gelemso 3	666522	973252	1737	1.2				1735.8	90	7.5		BH	upper sandstone
22		664971	971185	1746	7.5				1738.5	130	7		BH	sandstone
23	Weine Gudo	672224	974896	1680	21.9	24.64	25.09	54	1665.1	127	17	200	BH	upper sandstone
24	Haro Chercher	684181	974670	1718	79.4	2.05	81.45	129.4	1638.6	134	6.3	155.23	BH	limestone
25	Bate	693780	979780	1646	12.8				1633.2	120	25	190	BH	limestone
26	Waltane	986138	701353	1763	39.4	17.9	57.3	148	1723.6		5.5	152	BH	limestone
27	Chefa No12	673500	979376	1687	27				1660				BH	Volcanic
28	Garbi Goba	664971	971185	1746	14				1732				BH	Limestone

Annex 6: Groundwater Depth and Groundwater Level in the Study Area

NO	Site Name	X	Y	Z	depth (SWL)	GWL
1	Suri	685214	975933	1672	29.25	1643
2	Guba Gutu	683068	974953	1679	66.7	1612
3	Koye	696836	981513	1664	10	1654
4	Saketa	689016	977524	1635	0.46	1635
5	Oda Boriyo	694630	973755	2034		2034
6	Mudhiiressa	685189	976368	1672	27	1645
7	Kara 1	687524	980575	1662	11.9	1650
8	Kara 2	687350	980841	1675	15.6	1659
9	Iddo Bariso	700229	987976	1790	20	1770
10	Goda Hora	687627	978037	1640	0	1640
11	Oda Roba	691816	981156	1643	10	1633
12	Bereda	681544	979950	1772	7.2	1765
13	Wachu Town	679569	977814	1712	32.3	1680
14	Milino Zewde	675212	975895	1772	8	1764
15	Melka Belo	670519	975602	1749	6	1743
16	Leilisa 1	664943	971002	1737	34	1703
18	Gelemso 1	669272	974650	1727	1.5	1726
19	Gelemso 3	666522	973252	1737	1.2	1736

20	Leilisa 2	664971	971185	1746	7.5	1739
21	Weine Gudo	672224	974896	1680	21.9	1658
22	Haro Chercher	684181	974670	1718	79.4	1639
23	Bate	693780	979780	1646	12.8	1633
24	Waltane	701353	986138	1763	39.4	1724
25	Cheffa No12	673500	979376	1687	27	1660
26	Garbi Goba	664971	971185	1746	14	1732
27	Coontee	687291	982421	1744	4	1740
28	Coontee 2	687279	982421	1752	3	1749
29	Bekenisa	689479	982847	1716	5	1711
30	Bekenisa	688507	985553	1967	3	1964
31	Bereda	681341	979435	1712	4	1708
32	Oda Roba	689756	982714	1700	1	1699
33	Oda Roba	690682	982502	1689	4	1685
34	Jarra	696138	985172	1750	5	1745
35	Gola	691970	980591	2058	3	2055
36	Faaroo Olii	698715	986025	1732	4	1728
37	Faaroo Gadii	698799	986228	1742	4	1738
38	Goda Hora	694020	980321	1650	1	1649
39	Goda Hora	692160	978369	1636	2	1634
40	Midhagidu	689752	979293	1636	1	1635
41	Mendera	666517	973731	1733	4	1729
42	Awsaid	666877	973646	1726	3	1723
43	Mendera	666227	972451	1724	2	1722
44	Kara	692699	981928	1642	3	1639
45	Oda Roba	690682	982502	1689	4	1685
46	Oda Roba	689756	982714	1700	1	1699
47	Bekenisa	689479	982847	1716	5	1711
48	Bekenisa	688507	985553	1967	3	1964
49	Bereda	681341	979435	1712	4	1708
50	Bereda	682605	980379	1725	9	1716
51	Haro Charcher	683110	976271	1673	2	1671
52	Haro Charcher	678486	974959	1671	1.5	1670
53	Haro Charcher	678242	975537	1675	3	1672
54	Gerbi Teka	677679	975537	1686	7	1679
55	Gerbi Teka	678000	975434	1675	8	1667
56	Gerbi Teka	677397	976344	1690	6	1684
57	Gerbi Teka	676579	976014	1706	8	1698
58	Bedhadha	673531	976084	1700	6	1694
59	Melka Belo	670393	975419	1733	2	1731
60	Lega Bera	664123	971383	1748	5	1743
61	Lega Bera	664177	971395	1745	3	1742
62	Barkalee	699012	989277	1886	4	1882
63	Gabiboo	700430	985421	1736	2	1734
64	Odaa Bultee	699633	983734	1704	2	1702
65	Lukanda	699455	986527	1752	3	1749
66	Madabanya	699176	986307	1742	4	1738
67	Kaartoo	696838	985072	1710	5	1705
68	Kurfa	700591	984374	1725	3	1722
69	Gohii	693890	981356	1647	5	1642
70	Saqaa	694032	980359	1649	6	1643
71	Baaboo	692723	979132	1641	6	1635
72	Kurfa	692068	978360	1630	3	1627
73	Sheeka	696603	981433	1661	4	1657

74	M/Barumsa O/Roba	693793	983000	1664	6	1658
75	Warjii	693376	983821	1866	7	1859
76	Madara	691684	981256	1647	6	1641
77	Waraqata	692699	981928	1642	7	1635
78	Hadra	691685	981258	1649	7	1642
79	Gondare	692030	981173	1649	6	1643
80	Buchoo	690367	981277	1653	3	1650
81	Nolee	692013	980082	1635	3	1632
82	Horaa	692436	979515	1635	2	1633
83	Meeta	691352	978578	1624	3	1621
84	Abadir	692079	984256	1709	2	1707
85	Coontee	687291	982421	1744	5	1739
86	Halchawa	686985	982282	1738	4	1734
87	Halchawa	687082	982067	1729	6	1723
88	Melka Belo	670532	979350	1868	12	1856
89	Melka Belo	672087	979256	1788	13	1775
90	Chefa	672120	978630	1763	12	1751
91	Chefa	671199	979371	1836	15	1821
92	Chefa	671179	980041	1843	16	1827
93	Chefa	673082	976400	1708	12	1696
94	Chefa	673500	976093	1696	10	1686
95	Chefa	673531	976084	1700	9	1691
96	Busetu	672692	975750	1696	4	1692
97	Busetu	671419	976063	1700	11	1689
98	Melka Belo	672057	975101	1687	11	1676
99	Melka Belo	672253	975445	1684	7	1677
100	Melka Belo	670574	975175	1718	15	1703
101	Melka Belo	670599	974863	1718	15	1703
102	Gerbi Teka	676953	977616	1729	15	1714
103	Gerbi Teka	677857	977891	1714	17	1697
104	Bedhadha	677943	977856	1711	18	1693
105	Bedhadha	676573	976010	1714	20	1694
106	Bekenisa	679485	980399	1788	9	1779
107	Bereda	680657	980377	1753	20	1733
108	Bereda	681459	978049	1684	2	1682
109	Bereda	682662	980413	1732	18	1714
110	Haro Charcher	683090	976293	1676	9	1667
111	Warjii	693376	983821	1866	9	1857
112	Dhahi Baaboo	690613	983207	1706	6	1700
113	Funyaandara	689479	982847	1716	7	1709
114	Haro Carcar	685253	973925	1866	23	1843
115	Bekenisa	679485	980399	1788	9	1779
116	Bereda	680657	980377	1753	20	1733
117	Bereda	681459	978049	1684	2	1682
118	Bereda	682662	980413	1732	18	1714
119	Haro Carcer	683090	976293	1676	9	1667
120	Midhagidu	686782	980891	1695	1	1694
121	Burqa	691089	985203	1785	0	1785
122	Kolu	695201	987139	1742	0	1742
123	Kereyu	697214	991008	2223	0	2223
124	Sebale	700210	988118	1800	0	1800
125	Sebale	699251	990527	1996	0	1996
126	Idoo Bariso	700720	987008	1800	0	1800
127	Obi17	688673	986596	2097	0	2097

128	Burqa-Bakanisa	701830	979507	1767	0	1767
129	Mekenisa	682507	982553	1967	0	1967
130	Mekenisa	689756	982714	1700	0	1700
131	Oda Baso	691089	985203	1785	0	1785
132	Goda Hora	687785	975226	1648	0	1648
133	Midhegdu	694020	980321	1650	0	1650
134	Midhegdu	696603	981433	1661	0	1661
135	Saqariga	694859	989958	1956	0	1956
136	Saqariga	695449	990066	1911	0	1911
137	Saqariga	695186	989724	1904	0	1904
138	Saqariga	695037	990766	1978	0	1978
139	Midhegdu	697755	982281	1682	0	1682
140	Hajidin (Bedesa)	696578	981401	1670	0	1670
141	Sororo	703507	992966	2223	0	2223
142	Midhegdu	684753	981348	1776	0	1776
143	Goda Hora	689454	982886	1718	0	1718
144	Bekenisa	679021	980416	1794	0	1794
145	Damise	697317	989064	1973	0	1973
146	Hormaata	697214	991008	2223	0	2223
147	Darbaalee	700210	988118	1800	0	1800
148	Siyum	699251	990527	1996	0	1996
149	Idoo Bariso Gadii	700720	987008	1800	0	1800
150	Waqali	696928	986992	1736	0	1736
151	Alli	699139	986873	1760	0	1760
152	Saqela	694859	989958	1956	0	1956
153	Laga Adam	695449	990066	1911	0	1911
154	Mangudoota	695186	989724	1904	0	1904
155	Dhukaamsa	695037	990766	1978	0	1978
156	Kalaala	694020	980321	1650	0	1650
157	Deefoo	693927	980112	1642	0	1642
158	Haamadoo	697755	982281	1682	0	1682
159	Bultum	687785	975226	1648	0	1648
160	Burqaa	691089	985203	1785	0	1785
161	Ifa baas	689756	982714	1700	0	1700
162	Tiin	689756	982714	1700	0	1700
163	Simonii	687785	978226	1648	0	1648
164	Abbaa Shaawul	685421	977097	1743	0	1743
165	Ushe	696093	987190	1682	0	1682
166	Wallembo	685753	981348	1776	0	1776

Annex 8: - chemical analysis result of groundwater samples in the study area

site name	Northing	Easting	Elevation	pH	temperature	Turbidity, (NTU)	E. C, µSm/cm	TDS mg/l	T. Solids at 105°C	Bicarbonate	Chloride mg/l	Carbonate, mg/l CO_3)	Sulphate, (mg/l SO_4^{2-})	K^+ mg/l	Sodium, (mg/l Na^+)	Calcium, (mg/l Ca^{2+})	Mg (mg/l Mg^{2+})	T. hardness, (mg/l	Total Iron, Fe, mg/l	NO_2mg/l	NO_3^- mg/l	Ammonia, (mg/l NH_3)	Manganese, (mg/l Mn)	Fluoride F-	Phosphate, (mg/l PO_4^{3-})	Total Alkalinity, mg/l as $CaCO_3$	Ammonium, NH_4
Oda Roba BH	981156	691816	1643	6.9		2.11	727	363		427	17	Nil	84	5.5	11	380	40	310	0.05	0.01	0.4	-	0.2	0.96	0.12	350	0.07
Ganda Bultum BH	978037	687627	1640	6.75		5.32	1106	553		561.2	48	Nil	160	3.2	57	364	40	330	0.3	Nil	0.1	-	2.08	1.18	0.22	460	0.48
Mudhiir essa BH	976368	685189	1672	7.02		2.52	1007	503		564.25	120	Nil	96	8.8	45	331	70	300	0.35	Nil	0.32	-	0.95	0.97	0.05	462.5	1.23
Koye BH	981513	696836	1664	7.34	-	31	498	334	368	336.23	11.33	Nil	20.16	6.1	17	94.4	12	286	0.21	0.019	3.5	0.7	0.03	0.18	0.86	275.6	-
Waltane BH	986138	701353	1763	7	-	2.23	444	266	20	235	16.5	Nil	2.1	0.4	13.9	55.3	11.1	184	0.08	0.02	1.58	0	0.06	0.4		235	0
Kara Kurkura 1	980575	687524	1662	6.6		1.2	605	303	300	450	15	Nil	5.1	1	205.3	19.4	38.3	206	0.78	0	0.26	0	0.05	0.56		450	0
Boke Tiko 1	944156	702293	1660	7.06	23.3	6	666	333		384	Nil	Nil	160	2.5	8	324	2	332	0.03	0.026	7.04	0.085	0.02		0.46	384	0.09
Boke Tiko 2	962079	686397	1740	7.11	23.4	7	668	333		34.2	Nil	Nil	150	2.2	7	113	2	288	0.07	0.036	3.98	0.045	0.04	0.4	0.62	394	0.052
Leilisa 1	971002	664943	1737	6.88		12	479	314	342	286.94	13.39	Nil	22.66	5.3	20	73.08	12.75	235.2	0.09		0.59	0.23	0.05	0.75	0.26	235.5	
Leilisa 2				6.62		1	372	236	240	212.28	8.94	trace	0.29	2.8	14.5	54.6	10.71	180.6	0.009	0.28	8.16	0.18	0.02	0.5	0.18	174	
Chefa 12				8.88			297	196	198	141.5	8.94	28.8	trace	0.5	69.5	3.36	0.51	10.5	0.05	0.01	0.35	trace		0.5	0.05	164	
Chefa 13				7.33	20	3	410	205		195.2	0	Nil	1			64	12	210	0.17	0.029	8.8	0.07	0.001		0.1	195.2	0.08
Mudhiir esa				6.95		3.72	1371	686	800	600	48.5	0	67.31	10.1	152.1	77.9	32.7	329.2	0	0.01	0	1.13	0.15	0		600	1.2
Oda Boriyo	973755	694630	2034	6.4		1	673	337	720	350	19	0	140.7	1.3	20	48.7	37.6	276.6	0	0.01	0.32	0	0	0.69		350	
Oda Tuta	970808	698790	1769	6.95		7.4	678	339	390	445.3	23.3	Nil	21.3	8.7	48.6	46.4	12.1	165.7	0	0	0	0	0	0.26		365	
Weine Gudo	974896	672224	1680	7.25		0.34	715	357	710	290	19.3	0	4.5	4	13	44.1	31.2	238.5	0	0.01	0.3	0	0	0		290	

Guba Gutu	974953	683068	1679	7.03		14	1016	508		202	3.4	58	138	2.9	17.54	100	36	400	0.08	0.003	0	0.052	0.016	1.2	18	360	
Melka Belo	975602	670519	1749	6.05		27.38	236	160	200	146.4	12.74	Nil	9.57	0.7	8.2	35.2	12.45	140	0.03	0.02	6.52	0.3	0.01	0.48	0.002	120	
Bareda	979950	681544	1772	7.13			534	320	340	336.72	5.5	Nil	0.19	2.1	46	60	14.4	210	0.03	0.01	3.35	0.22	0.04			276	
Wachu Town	977814	679569	1712	7.5			717	358	460	_	6.8	_	25.3	11	24.6	8.3	2.6	31.4	0.2	0	0.62	0	0			350	
Gelemso 1	974650	669272	1727	6.89	20.6		513	264		290.36		Nil	2			67.6	15.12	232	0.04		2.2		0.01	0.12	1.6	238	
Gelemso 3	973252	666522	1737	6.67	20.9		401	201				Nil				52	9.6	170	0.2		1.76		0.006	0.17	3.8	198	
Saketa	977524	689016	1635	7.2		trace	1247	750	752	507.52	14.56	Nil			19.5	123.2	3.12	446	0.18	0.008		0.11	trace	0.5		416	

Annex 9- Cations and Anions chemical analysis result of groundwater samples in the study area

Site Name	Ca	Mg	K	Na	Na+K	%Na	SAR in meq	Cl	So4	Hoo3	co3	HCO_3 $+CO_3$	EC, μSm/ cm
Oda Roba BH	18.96	3.29	0.14	0.48	0.62	2.71	0.14	0.49	1.75	7.00	0.00	7.00	727
Ganda Bultum	18.16	3.29	0.08	2.48	2.56	10.66	0.76	1.37	3.33	9.20	0.00	9.20	1106
Mudhiiressa	16.52	5.76	0.23	1.96	2.18	8.92	0.59	3.43	2.00	9.25	0.00	9.25	1007
Koye	4.71	0.99	0.16	0.74	0.90	13.58	0.44	0.32	0.42	5.51	0.00	5.51	498
Waltane	2.76	0.91	0.01	0.60	0.61	14.34	0.45	0.47	0.04	3.85	0.00	3.85	444
Kara Kurkura 1	0.97	3.15	0.03	8.93	8.96	68.49	6.22	0.43	0.11	7.38	0.00	7.38	605
Boke Tiko 1	16.17	0.16	0.06	0.35	0.41	2.46	0.12	0.00	3.33	6.30	0.00	6.30	666
Boke Tiko 2	5.64	0.16	0.06	0.30	0.36	5.85	0.18	0.00	3.13	0.56	0.00	0.56	668
Leilisa 1	3.65	1.05	0.14	0.87	1.01	17.64	0.57	0.38	0.47	4.70	0.00	4.70	479
Leilisa 2	2.72	0.88	0.07	0.63	0.70	16.3	0.47	0.26	0.01	3.48	0.00	3.48	372
Chefa 12	0.17	0.04	0.01	3.02	3.04	93.54	9.34	0.26	0.00	2.32	0.96	3.28	297
Chefa 13	3.19	0.99	0.00	0.00	0.00	0	0	0.00	0.02	3.20	0.00	3.20	410
Mudhi Iresa 2	3.89	2.69	0.26	6.62	6.87	51.1	3.65	1.39	1.40	9.84	0.00	9.84	1371
Oda Boriyo	2.43	3.09	0.03	0.87	0.90	14.05	0.52	0.54	2.93	5.74	0.00	5.74	673
Oda Tuta	2.32	1.00	0.22	2.11	2.34	41.37	1.64	0.67	0.44	7.30	0.00	7.30	678
Weine Gudo	2.20	2.57	0.10	0.57	0.67	12.28	0.37	0.55	0.09	4.75	0.00	4.75	715
Guba Gutu	4.99	2.96	0.07	0.76	0.84	9.52	0.38	0.10	2.88	3.31	1.93	5.24	1016
Melka Belo	1.76	1.02	0.02	0.36	0.37	11.87	0.3	0.36	0.20	2.40	0.00	2.40	236
Bareda	2.99	1.18	0.05	2.00	2.05	32.96	1.38	0.16	0.00	5.52	0.00	5.52	534
Wachu Town	0.41	0.21	0.28	1.07	1.35	68.27	1.91	0.19	0.53	0.00	0.00	0.00	717
Gelemso 1	3.37	1.24	0.00	0.00	0.00	0	0	0.00	0.04	4.76	0.00	4.76	513
Gelemso 3	2.59	0.79	0.00	0.00	0.00	0	0	0.00	0.00	0.00	0.00	0.00	
Saketa	6.15	2.73	0.04	0.85	0.89	9.13	0.4	0.42	0.00	8.32	0.00	8.32	
Merkech	6.4	3.6	0.0	0.0	0.0	0.0	0.5	5.9	0.0	5.9	0.0	0.0	6.4