

ADDIS ABABA UNIVERSITY

SCHOOL OF EARTH SCIENCE



AQUIFER CHARACTERIZATION AND WATER QUALITY ANALYSIS OF
SUNNUTA WELL FIELD, AFAR REGION, ETHIOPIA.

BY

KINFE ATSBHA

A Thesis Submitted to the School of Earth Sciences Addis Ababa University In
Partial Fulfillment for the Requirements of the Degree of Master of Science in Earth Science
(Hydrogeology)

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ABSTRACT

The Sunnuta well field is located within Uwa catchment in arid climate of Afar rift floor, Northern part of Ethiopia. It is one of the most water-stressed areas of the country, with only a short rainy period from mid-June to mid-September. Because rainfall in this region has been consistently erratic in the last decades, both in time and space, rain-fed agriculture has become problematic. Hence, in order to supplement rain-fed agriculture with small to large scale irrigation, a detailed understanding of local and regional groundwater resources is important. However, information on the availability and distribution of groundwater resources is scarce as there has never been a systematic and detailed investigation in this region. Hence, the main objective of this thesis is to study and characterize the aquifer system, estimation of recharge by considering Uwa catchment in which the Sunnuta wellfield is located and study the water quality of the well field. An intensive field campaign has been undertaken from February 10 to 30, 2015 to collect relevant information regarding geology, hydrology, and hydrogeology throughout the study area. Water samples were collected and analyzed in the hydrochemistry laboratory of water work design and supervision enterprise and Addis Ababa University Analytical laboratory, and results were compared with WHO drinking water standards. For most of the chemical constituents, water samples are within the safety standards, except surface water samples shows high Florid content ranging from 1.5-2.66 mg/l. From the geological survey, it follows that the uwa catchment is 55% covered with flvo lacustrin deposit and the other units are dalha basalt, ashenga basalt, recernt balst ,andustic tuff, granitic intrusion and sand stone, The sand stone unit covers a very small part of the well field. Most of which have been affected by different types of geological structures due to successive episodes of geological disturbances resulting from rifting activity. The average monthly temperature and the mean annual precipitation in the study area are 26.62⁰C and 400.9MCM, respectively. Potential evapotranspiration (PET) of the area was estimated using Penman Combination method which gives average annual PET value of stations 1298.88mm/y. Actual evapotranspiration value for the catchment estimated from Turc method gives value of 292.56MCM which is 72.9% of the total annual perception. The annual surface water out flow, estimated using runoff coefficient methods resulted 32.07MCM which is 8% the total annual precipitation. Water balance approaches were used to estimate recharge, while the annual recharge of the area is 76.27MCM/year which is 19% of the total precipitation. To characterize the aquifer system of the area pumping test data, well completion reports, well logs and geology of the area were analyzed. The study area is characterized by deep groundwater systems encountered at an average depth of 225m. The hydraulic characteristics are spatially variable, which the transmissivity of the study area ranges from 144.0 – 5533.56 m²/d and the mean is 2543.86 m²/d. the hydraulic conductivity ranges from 2 – 77 m/d and the mean is 39.9 m/d. The unconsolidated sediments and the fractured volcanic rocks are the main aquifer units in the area. These aquifers were found to be good groundwater potential zone. The general trend for groundwater flow observed from piezometric heads is from South east to North West of the study area. Piper plots used to know the water type. Groundwater type of the area was evolved from Ca-Mg-HCO₃ water type in the area closer to western escarpment in to Na-Ca- Cl-SO₄²⁻ – HCO₃ water type in the sunuta well field. The water also shows low sodium hazard and can therefore be used for irrigation without posing much risk to the compaction of soils.

Key words; Sunnuta well filed, Uwa catchment, Ground water recharge estimation, Hydrogeochemistry

Acknowledgment

First of all, I offer my deeply felt thanks to the Most Glorious Ever Virgin Mary, Gracious mother of the Gracious Christ our God for being with me from the very beginning to the end of my carrier.

I am grateful to Dr. Dessa Nedaw my advisor and instructor. I am extremely thankful and indebted to him for sharing expertise, and sincere, valuable guidance and encouragement extended to me. Also I take this opportunity to express gratitude to Dr. Seifu Kebede, Pro. Tenalem Ayenew and all of the Earth science department members for their help and support.

I would like to thank Tilhune Azagegn, for his advice; follow up, facilitation during the thesis work.

This research work could not be performed without extensive field work and field data collection in Afar. Hence, I would like to thank to Ato Mengesta Matiose who have participated on the field work to make the field work and data collection campaign a success.

I would like to express my sincere thanks and appreciation to Ato Shiferaw Lulu from Tam Geo-Engineering Plc. without his advice and guidance, constructive suggestions, extraordinary patience, it would have been impossible to complete this thesis. So, thank you very much Ato Shiferaw Lulu for everything you did to bring me to this level. I would also like to thank ATo Molla Fetene, Ato Molla Mitku From Amhara Water Work Design and Supervision Enterprise and Ato Tekleab from Minster Of Agriculture who provide me with the nessecery data and guidance for this thesis work.

I am grateful to my department friend Keridn Badabo who supported me through this venture.

I also thank organizations: Amhara Water Work Design and Supervision Enterprise, Water Work Design and Supervision Enterprise, Tam Geo-Engineering Plc and Meteorological Agency for providing the required secondary data.

I want to express my love and gratitude to my sister for her support, appreciation and providing me with all necessary facilities and finance. Sis it is your kindness to support me from the very beginning and your good wish to see my upgrade, here is the fruit.

I also thanks my parents specially my brother for the unceasing encouragement, support and attention. I would like to thank my dear friends for their encouragement and love which helped me much to finish my work on time.

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Acronyms

ADSWE	Amhara Design and Supervision Work Enterprise
AET	Actual Evapo-transpiration
BH	Borehole
Co-SAERA	Commission for Sustainable Agriculture and Environmental Rehabilitation in Amhara Region
d	Days
DEM	Digital Elevation Model
EC	Electrical Conductivity
EIGS	Ethiopian Institute of Geological Survey
ETo	Potential Evapotranspiration
E-W, S-N	East-West, South-North
FAO	Food and Agriculture Organization
GES	Geo-Engineering Service
GPS	Geographic Positioning System
K	Hydraulic conductivity
ITCZ	Inter-Tropical Convergence Zone
m.a.s.l	Meter above sea level
MCM	Million Cubic Meters
PT	Pumping test
SAR	Sodium Absorption Ratio
TDS	Total Dissolved Solid
UTM	Universal Transverse Mercator
Q	Pumping rate
WHO	World Health Organization
WWDSE	Water works design and supervision enterprise

CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROUND

Water is life! It is essential for all aspects of our livelihood, from basic drinking-water to food production and health, from energy production to industrial development, from sustainable management of natural resources to conservation of the environment. Water also has religious and cultural values. More than 98% of the available global fresh water is ground water (Fetter, 1994), which is one of the most precious resources that nature has provided and occurs under the ground in rock unit (s) that can store and transmit water at the rates fast enough to supply reasonable amount to wells. It has a number of essential advantages when compared with surface water because it is naturally least direct contact with the activity carried out on the surface. The subsurface storage have also advantages of being free from the adverse effect like inundation of large surface area, loss of cultivable land, displacement of local population, and substantial evaporation losses, and much more uniformly spread over large region than surface water. No gigantic structures are needed to store groundwater. On the other hand, surface water is often in close contact with human activity and/or other natural processes that take place on the earth surface; hence is vulnerable to pollution that makes it unsuitable for drinking and other purpose before treatment. Unfortunately, water is becoming scarce in many areas and regions of the planet. It is obvious that for the full utilization of existing water resources, good understanding of hydro geological systems that control the evaluation of potential water resource of an area is highly important. One way of the useful approach to the study of water-bearing rocks (aquifer) characterization is the use of pumping test analysis; the mechanism of aquifer pumping test are such that water is pumped from the well screened in particular water-bearing zone, for a certain amount of time, and at a specific pumping rate. For this reason, these test are often referred to as pumping test (i.e. the water table and/or piezometric level of confined or semi-confined zones), or drawdown, is measured in the pumped well and in other nearby wells, referred to as observation wells. Subsequently, the hydraulic properties of the aquifer- specifically transmissivity, hydraulic conductivity, and storage coefficient can be estimated from the drawdown observations.

The purpose of this research is to investigate the ground water flow process of the study area, Moreover aquifer characterization, recharge estimation and water quality analysis of the study area which have a significant value for the community of the area, due to increasing demand of ground water for irrigation and domestic water supply.

The study area is located at Uwa woreda of zone 4, Afar regional state. Groundwater is the only source of water for domestic and irrigation purposes in the area due to lack of adequate surface water flows. Modern drought is also expanding in alarming rate in the arid part of the area beside an increased demand of groundwater development. For the future, with increased development and utilization of the groundwater resources, problems such as over exploitation might lead to

environmental damage. Mapping the distribution of aquifers and estimating the hydrolic parameters of the aquifer are the most important steps in controlling the amount of ground water abstraction from the wells. Studies incorporating quantitative characterization of aquifer hydraulic parameters are limited in most part of Ethiopia.

1.2. Objectives of the Study

1.2.1. General objective

The principal objective of the research is to quantitatively characterize the aquifer hydrolic parameters, to estimate recharge and examine the water quality of uwa catchment with special consideration to Sunnuta well filed.

1.2.2. Specific objective

- Characterization of aquifer systems and aquifer units in the study area.
- Evaluation of hydrology of the area providing with identification of water bearing layers.
- Estimation of groundwater recharge.
- Determine groundwater flow direction in the study area
- To prepare hydrologic cross section and hydrogeologic map.
- To determine the hydrochemistry and water quality of the aquifer system.
- To evaluate water quality from domestic and agricultural point of view.

1.3. Significance of the Study

The research findings have the following contribution

- Be helpful to planners in the development and management of aquifer characterization and aquifer related works in the study area.
- Be useful to propose the mechanism of sustaining and obtaining the maximum benefit from the aquifer without adversely affecting the aquifer
- Help to understand water quality distribution of the area.
- Be useful to earth science students, researchers and research institutes such as university they can gain empirical evidence from the research work.

1.4. Research Methodology

To conduct the research the following methodology is followed

1.4.1 Office work – the office work include;-

- Collecting and reviewing of available topographical, geological, hydrogeological maps and reports.
- Collecting metrological data like precipitation, temperature and other from national metrological agency to understand the climate condition of the area.

- Understanding the general geological hydrogeological condition of the area to identify location where representative samples to be collected for water quality analysis.
- Collection of different borehole data such as pumping test, borehole log that are important for characterizing the aquifer.

1.4.2. Field investigation.

During this step intensive field work is carried out to acquire primary data and prove the ground truth that is useful for the objective of the research. In general it consists of:-

- Observation of different geological formation and structure to describe outcrop formation type, frequency of weathering and fracture.
- Measuring of in-situ field parameters of water samples like PH, EC, TDS, and Temperature.
- Collecting water samples for laboratory analysis at representative site selecting during the office work.
- Collecting well completion report including pumping test and borehole data.
- Geo-referencing distribution of metrological station, all water points (borehole, hand pump and springs) using GPS.

1.4.3. Post field work

- Laboratory analysis of selected representative water samples; - analysis of important hydrogeochemical parameters is conducted at Addis Ababa University analytical laboratory and water work design and supervision enterprise.
- Analysis of pumping test and borehole log is conducted to characterize the study area aquifer;- a pumping test is controlled fixed experiment in which a well is pumped at controlled rate and water-level response (drawdown) is measured in one or more surrounding observation well and optionally in the pumped well(control well) itself. Response data from pumping test are used to estimate the hydraulic property of aquifer, evaluate well performance and identify aquifer boundaries. Aquifer test and aquifer performance test (APT) are alternate designation for pumping test.
- Data interpretation, Finalizing and writing the thesis;- different software and computer cod such as Arch Gis, Surfer, aquachem, Aquitest, Global mapper, and Microsoft excel used to develop different tasks.

1.5. Literature Review

Almost no water related studies have been conducted in the study area. However, starting from 2012 Minster of Agriculture has been carrying out groundwater potential assessment project for water supply and irrigation on the study area. Some of the relevant literatures reviewed are as follow:-

(D.Nedaw, 2003) studied to characterize the ground water from geological, hydrogeological and chemical point of view. In his work the mean annual rain fall and mean actual evapotranspiration of the Raya valley are found to be 779mm and 695mm respectively. the surface water outflow of the Raya valley was estimated to be 60Mm³ annually from the basin. The annual recharge to the whole valley was computed to be 129.3Mm³. Based on calculating transmissivity values potentiality of the aquifers of the valley are classified from high(>500m² /day) to weak (<0.5-5m² /day).

Geo Engineering service (GES) study

The Hydrogeological study of GES identified two groundwater sub basins in Kobo valley, which is Waja-Golesha in the northern part and Hormat-Golina in the southern part. The studies further delineate the divide line between the two groundwater basins and identified well fields for groundwater development. The study indicated annual recharge of two groundwater basins to amount 71MCM. Further the study estimated groundwater reserve in the Kobo valley about 4347MCM.

CO-SAERAR study

The study made preliminary estimation of annual recharge capacity of the Kobo, Alawha, Chireti and Gelana sub basins to be 119, 9, 15 & 27MCM, respectively.

EIGS study

Hydrogeological and environmental isotope investigations have been done by Sileshi Mamo from the Geological Survey of Ethiopia (2007), the total dynamic groundwater in the graben sediments estimated to amount 68.9MCM in Kobo valley.

CHAPTER TWO

2. Description of the study area

2.1. Location and accessibility

The study area is located in the Lower Awash Basin in Uwa Woreda, Zone 4 of the Afar National Regional State. The study area is bounded by UTM 588500 E, 1287000N and 652500 E, 1335000N. The area is part of the Afar rift near to the western margin of the rift. The study areas can be accessed through Adiss Ababa-Woldia-Hara-Chifra road of which 640 km is asphalted road and from chifra to sunnuta which is 50km accessed through weathered roads. Almost all of the well sites can be accessed by dry weather earth roads/trails.

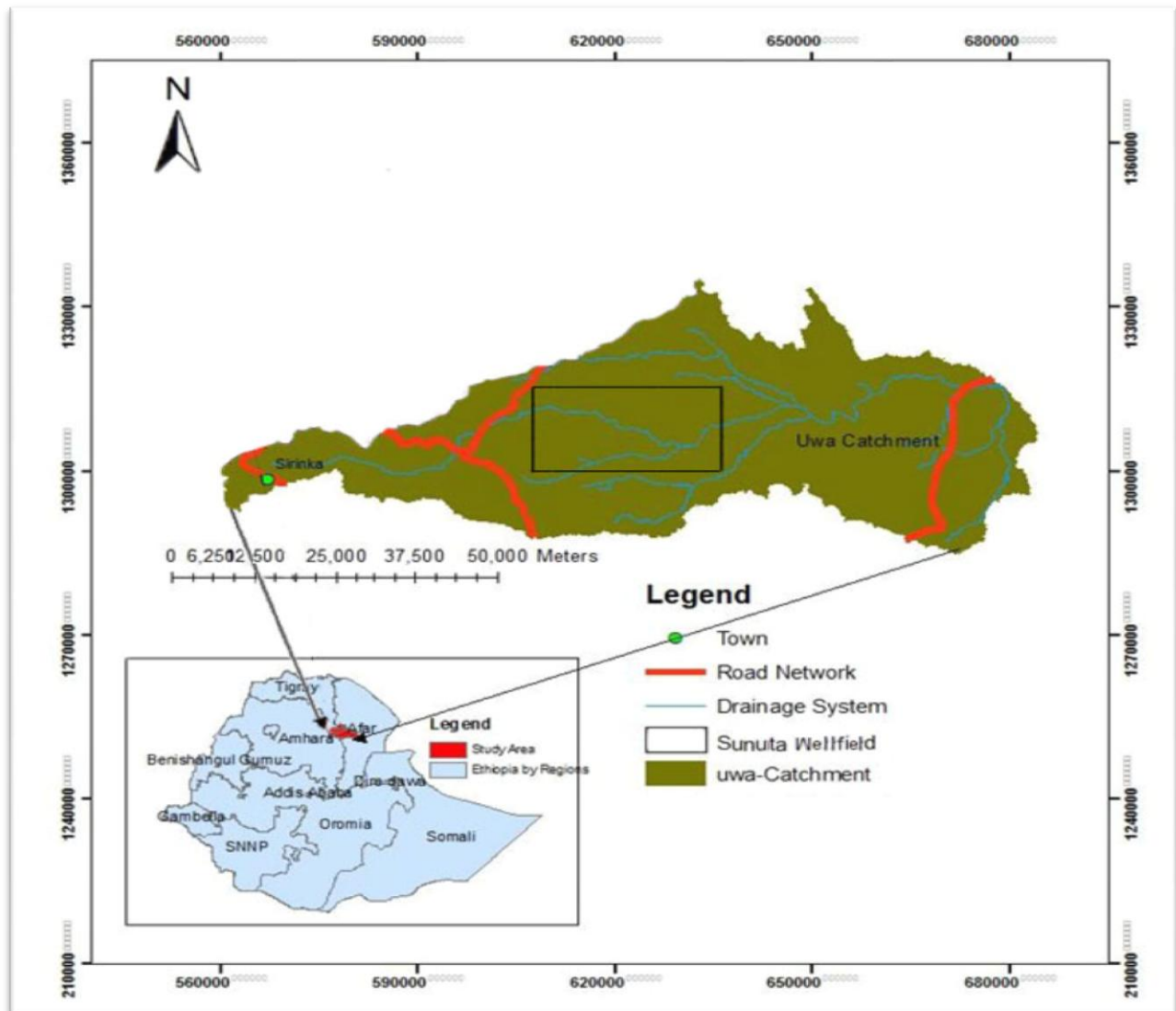


Figure 2.1. Location map of the study area.

2.2. Geomorphology and drainage

2.2.1. Geomorphology

The study area comprises parts of the Afar rift floor and the western rift margin. It is part of the southwestern block of the Afar Depression and separated from the western plateau by NNW-SSE striking western Afar escarpment. This is related to the rift forming tectonic process. On the basis of morphology, topography, drainage system, lithological and structural variation, the study area can be classified into two parts.

- ❖ The Afar Rift Floor (where the sunnuta well field is located)
- ❖ The Western Afar Margin (the main recharge area to the study area)

The Afar Rift Floor: separates the uplifted Western Plateau (Ethiopian) and the Eastern Plateau (Somalian). The elevation of the rift gradually decreases from the western margin 1100 m towards the rift floor 500 m.

The Western Afar Margin and associated grabens: The Afar Depression is separated from the Ethiopian plateau by the Western Afar escarpment. N-S trending marginal basins and hilly terrain of faulted blocks from the western margin of the Afar Depression (Beyene and Abdelsalam, 2005).

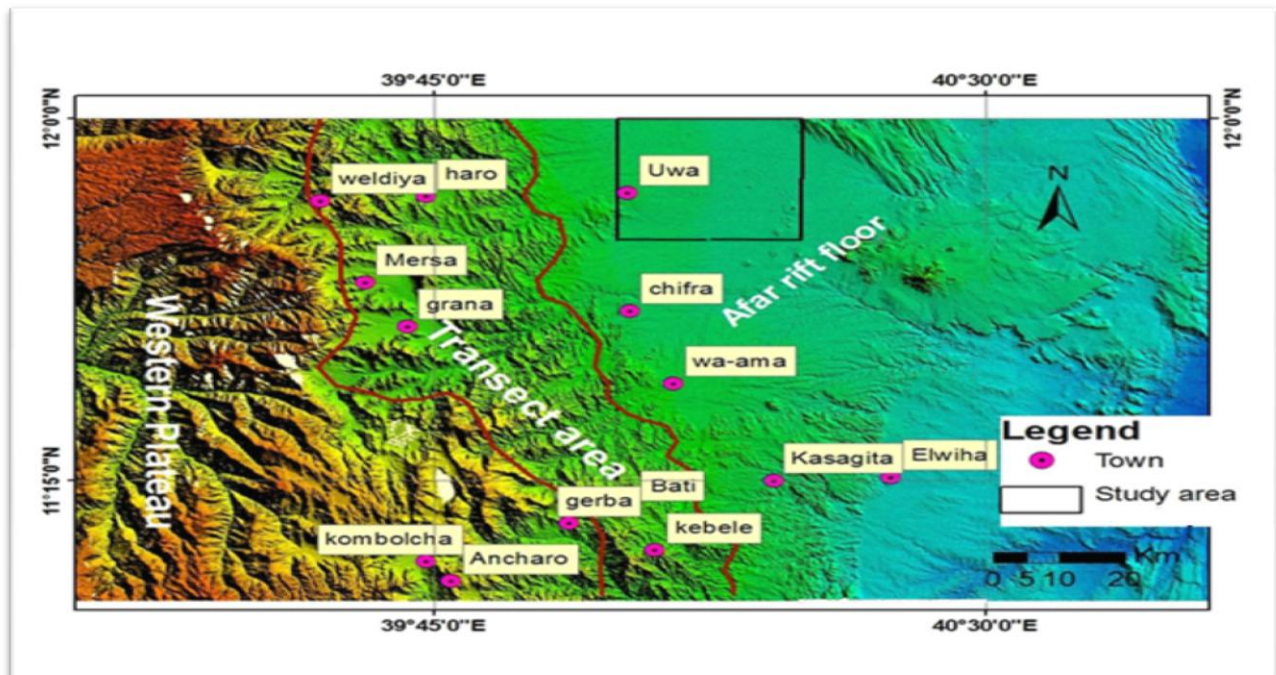


Figure 2.2. Geomorphologic setup of the study area.

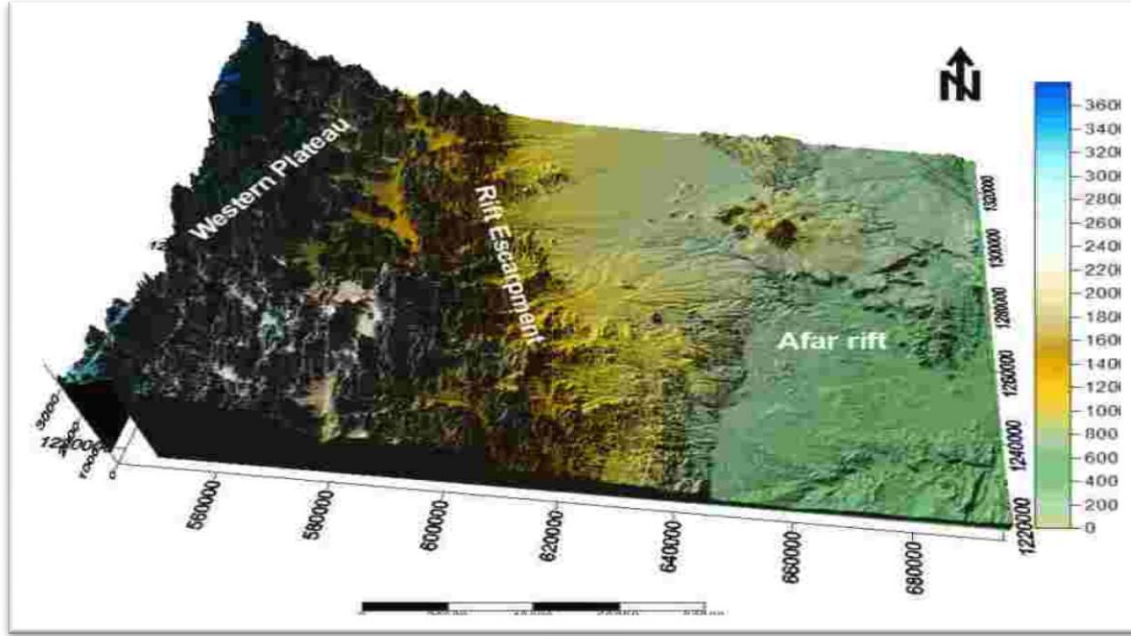


Figure2.3. 3-D View of the study area and the adjacent highland

2.2.2. Drainage

The drainage system is mainly controlled by topography and geological structures. The river in the study area has numerous small tributaries joining at angles to the higher order streams that can be characterized as dendritic drainage system. Most of the streams in the study area are seasonal that flow during wet season that flow towards north east and east directions.



Plat 2.1. Duba intermittent stream in the study area.

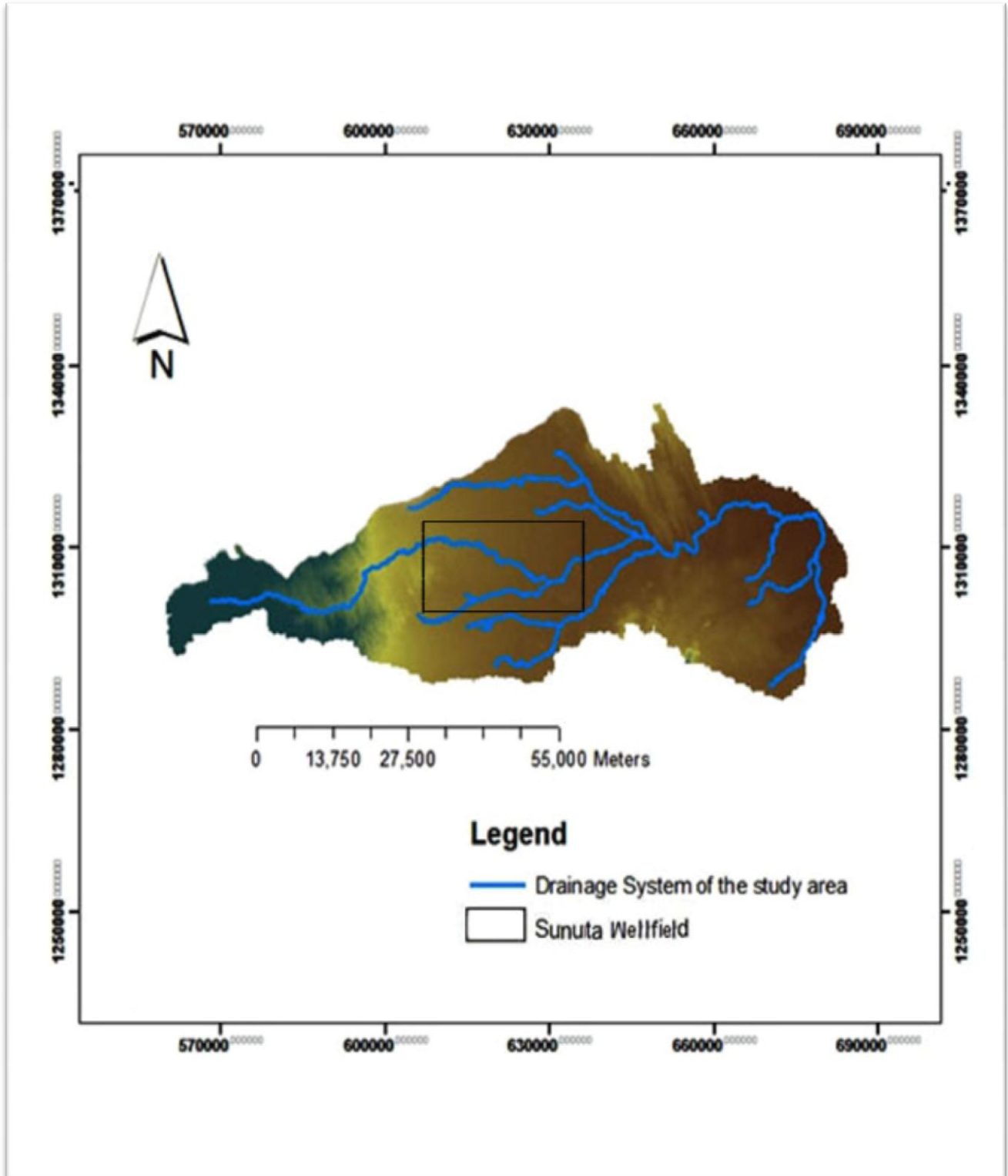


Figure2.4. Drainage map of the study area

2.3. Climates and Hydrology

2.3.1. Climate

The climate of the region varies from semi-arid to arid climate. Like many other parts of the country the climatic nature of the study area possesses two main season that are rainy season which is summer and dry season which is winter.

Table2.1. General Climatic Regions of Ethiopia (Daniel Gamachu, 1977) showing the study area climate region.

Climate regions		Mean annual temperature(0c)	Attitude of regions(m.a.s. l)	Presence in the study area
Kure	Alpine	10 and below	3300 and above	Absent
(Temprate) Dega	Temperate	10-15	2300-3300	Absent
(Subtropical) Weniadega	Subtropical	15-20	1500-2300	Absent
(Tropical) Qolla	Tropical	>30	800-1500	Present
(Desert) Bereha	Desert	>40	Less than 800	Present

The spatial and temporal variation of rainfall in Ethiopia is strongly controlled by the interannual movement of the position of the Inter Tropical Convergence Zone (ITCZ). During its movement to the north and south of the equator, the ITCZ passes over Ethiopia twice a year and this migration causes the onset and withdrawal of winds from north and south. When the ITCZ is located in the south, the Trade Winds from north drifts the equatorial winds. This periodical

anomaly of winds causes seasonal rainfall variability. The big summer rains or *Kiremt rains* occur when the ITCZ is found north of Ethiopia (Daniel, Gemechu, 1977). Climate of the study area ranges from arid in the Sunuta plain to humid in the mountains of the escarpment. The classification is made on the basis of the elevation above mean sea level of the areas. The principal feature of rainfall in the area is seasonal, poor distribution and variability from year to year.

2.3.2. Hydrology

The study area is comprised by Awash River basins with different sub basins and catchment such as Mile, Uwa (the study area catchment) and Awar. West to east flowing U-shaped dendritic to subparallel, Mile, Ledi, Bisitima, wa-ama and Uwa and their tributary streams dissect the low land plain of the afar rift. They drain towards the Awash River starting from Ambasel and Ancharo highlands. The main rivers like Uwa have perennial nature where as their tributaries are intermittent. Most of the streams that drain towards south eastern part of the area die in to the unconsolidated aquifer becoming intermittent.

The western Afar Margin forms the water divide between the eastern Awash River and the western Abay and Tekeze basins.

2.4. Land Use Land Cover

Land use land cover of the area is one of the important input data source in the hydrological study. The area is dominated by Exposed rock surfaces, shrub and bushes, and grass lands the other land use land cover units include cultivated land, forest cover, and wood land with a proportion that cover 1 to 2% of the total study area. The areal distribution of each unit is displayed in figure below.

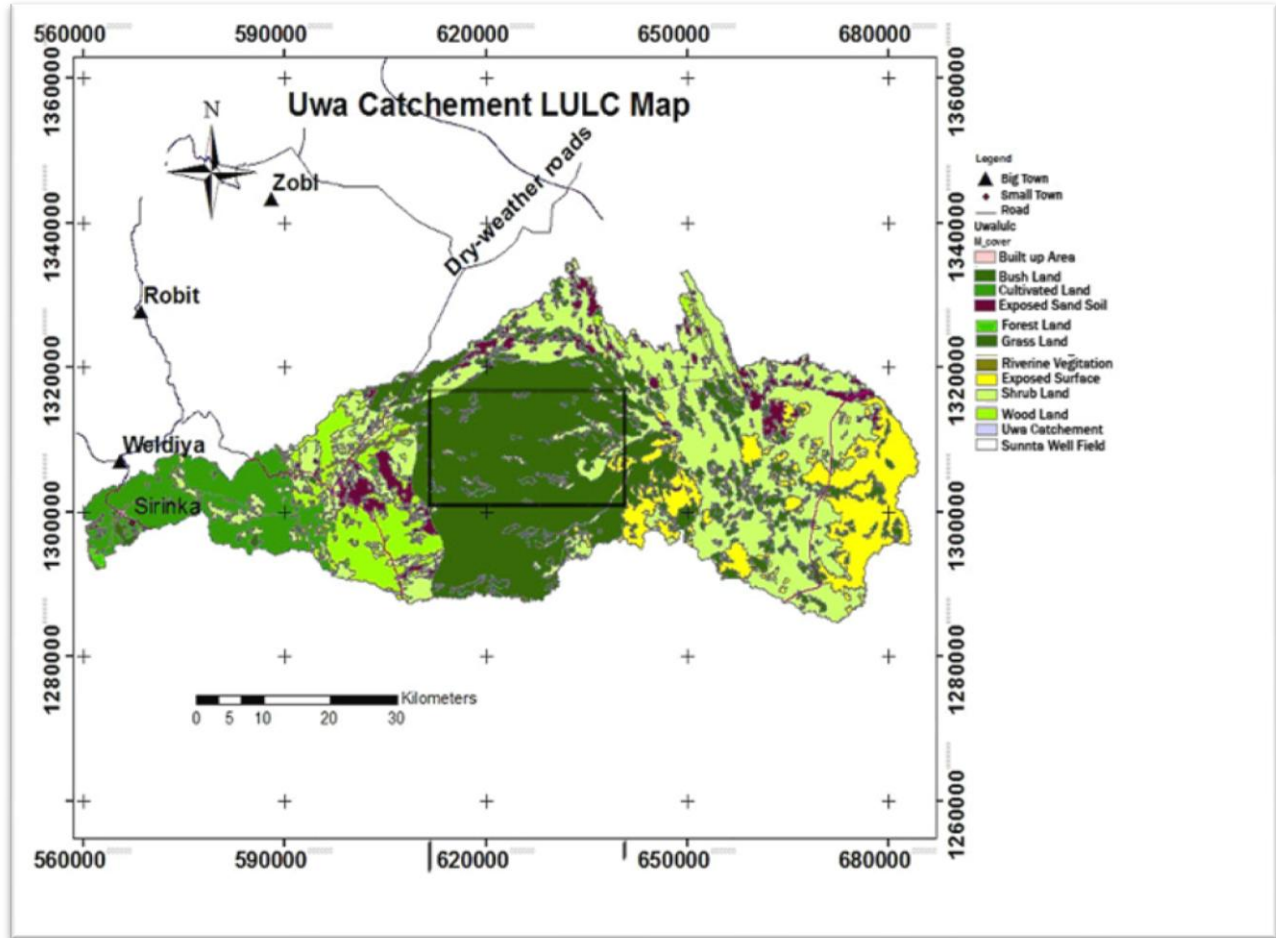


Figure 2.5. Land Use Land Cover Map of the study area

Source: (ADSWE, 2010).

2.5. Soil

Soil units of the study area control the hydrology of a catchment through the variation in water holding and transmission capacities. Hence, studying the spatial variations of the soil types in the study area are important to apply the soils hydrological variables in the water balance analysis of the area. Amhara Design & Supervision Works Enterprise (ADSWE, 2010) studies on the soils, land uses and resources of Eastern Amhara Development corridor & Afara Region were used to determine soil types in the study area. There is GIS digital soil and land use map of the study area. The spatial input data were used for groundwater recharge estimation in the Soil Moisture Water Balance Accounting programme. The textural soil classification as clay, clay loam, silt, silt loam, fine sand and fine sandy loam are important with their corresponding vegetation cover. These are important to determine the available water capacity of the root zone. The major soil

units found in the study area are Eutric Leptosol, Calcaric Fluvisol, Eutric Vertisol and Eutric Regosol. The textural soil classification also includes clay, clay loam, silt loam, sandy loam

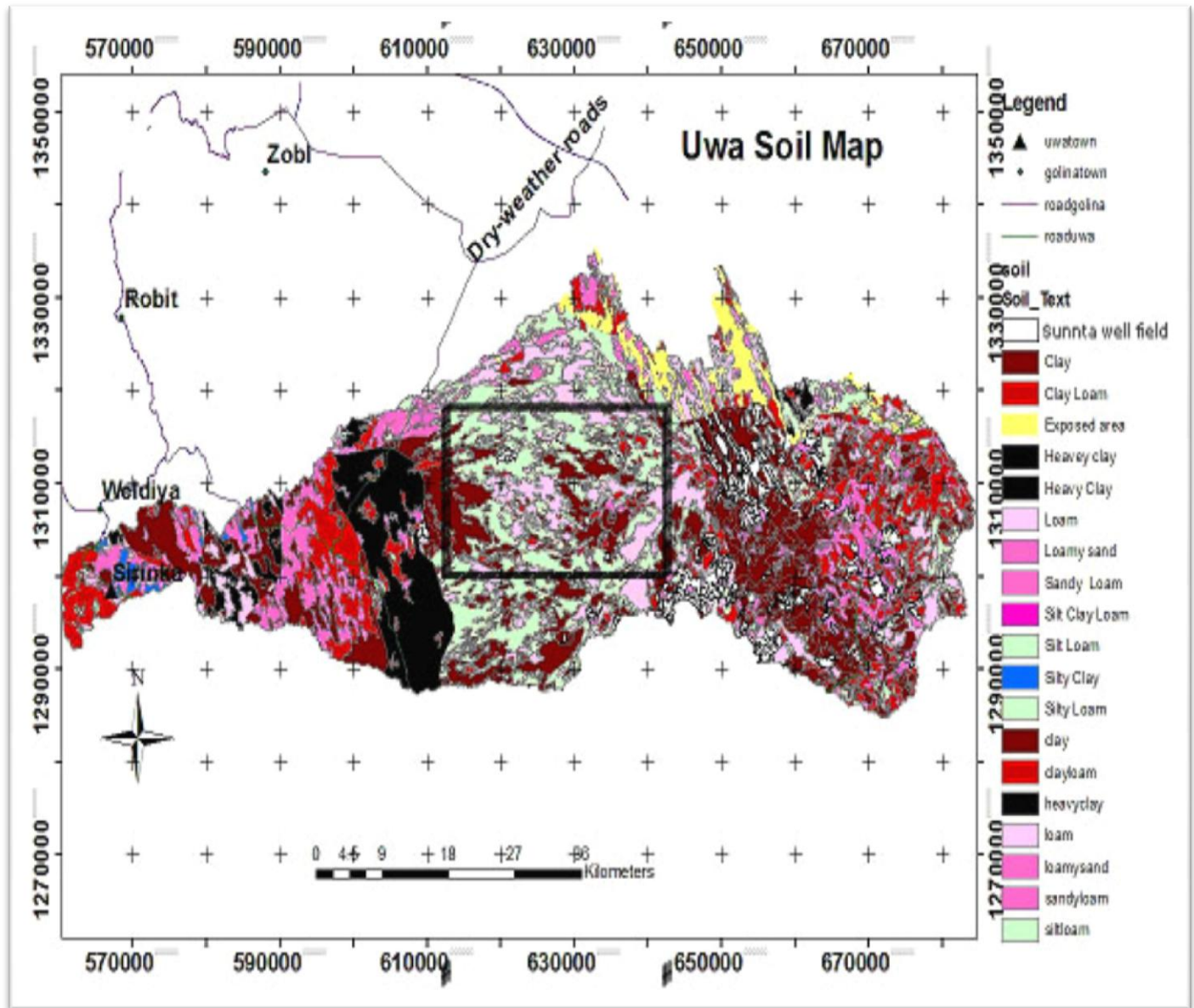


Figure.2.6. soil map of the study area source;(ADSWE,2012)

CHAPTER THREE

3. GEOLOGY AND TECTONIC SETTING

The major geological formations and tectonic features of the research area were adopted from the Report of (ADSWE) 2012 and summarized as follow.

3.1. Regional Geology

Ethiopia can be divided into four major physiographic regions widely known as the Northwestern Plateau and associate low lands, Southwestern Plateau and associate lowlands, the Main Ethiopian Rift and Afar Depression. The Ethiopian plateau is underlain at depth by Precambrian rocks of the Afro-Arabian Shield. The Precambrian basement is covered for the most part by glacial and marine sediments of Permian to Paleogene period and volcanic rocks of Tertiary and Quaternary age with related sediments. The Cenozoic volcanic succession is split apart by parts of the Great East African Rift System in Ethiopia i.e. The Afar Depression, Main Ethiopian Rift and related rifts (Mengesha et al., 1996).

At the end of Precambrian era, 600 million years ago, the crystalline basement complex of the present Afro-Arabian swell had been continued up above sea level for a long time and remained for another 370 million until the end of Paleozoic era. Then a long period of erosion and denudation left the earth's surface almost completely peneplained.

Crustal motion started in the beginning of Mesozoic era, about 225 million years ago. During the late Triassic and early Jurassic periods, a regional epirogenic sinking of the crust commenced causing a progressive transgression of the ocean from the south east that is, from the Indian Ocean coast of present day Somalia in the general direction of Lake Tana in the North West Ethiopia. This downward crystal movement, concomitant with a sedimentation process, started a cycle of marine transgression and recession of Mesozoic sea. Within this large epicontinental sea, extensive layers of sediments were deposited to form hundreds of meters of rocks consisting of sandstone, shale, gypsum, limestone and other varieties of sedimentary rocks. During this transgression-regression period, Mesozoic sediments were formed i.e. Adigrat formation mainly consisting of sandstone and minor lenses of siltstone; Abay formation consisting of limestone, gypsum and shale; Antalo formation mainly consisting of fossiliferous limestone and finally Amba Aradam sandstone.

The crustal movement was reversed into the upward motion during the late Jurassic period, which brought the crust's surface up to sea level by marine regression in late Cretaceous period. This regional uplift resulted in wide spread crustal fracturing during the early Tertiary period. The crystalline and sedimentary rock layers were fissured mostly along or in the vicinity of the zone of maximum uplift, thus allowing outpouring of molten lava to cover the older rock layers. The cause of the major uplift is related to a mantle plume whose decompression melting also generated enormous quantities of basaltic magma and resulted the first eruption of the continental flood basalts. The upraised and up arched land mass fissuring under tension permitted the ascension of voluminous basaltic magma (estimated as 300,000 km³, Mohr, 1983) to form the Ethiopian flood Basaltic Province. These early flood basalts now cover the extensive regions of the northwestern and southeastern plateaus. The most widely distributed early flood basalts Ethiopian flood Basaltic Province locally named are Ashange basalt, Aiba basalt, Alaje formation, Tarmaber formations etc.

Several pulse of volcanic activity which were always related to or preceded by major tectonic movements, were indentified (Zanettin et al., 1974; Kazmin.1979 cited in Mengesha et al., 1996). Earlier volcanic events are correlated in time to rifting in the Red Sea and Gulf of Aden. A migration of the earlier volcanic activity from an area centered at the present Afar Depression due south, east and west was inferred from the spatial distribution of the early flood basalts. The flood basalt volcanism culminated by the formation of alkaline basaltic shield volcanoes (Tarmaber Formation).

Major fault displacement along the Rift Valley was initiated during middle Tertiary period. Subsidence of large crystal blocks along steeply inclined fault zones created graben type depressions along the rift valley. Significant volcanic activity was associated with the formation of graben and young volcanic rocks cover the old Tertiary volcanic in many depressions. These fault displacement create several grabens and aligned escarpments.

After the formation of escarpments, fissural volcanism was confined to the rifts. These new volcanic stage began with the emission of Mabla rhyolitic ignimbrite (14-11 Ma) and the voluminous Fursa flood basalts (12-9 Ma). Many transitional basalts with affinity varying from

tholeiitic to alkaline were emitted in Afar (Lebas and Mohr 1970). They form the Dalha basalts (8-6 Ma), the Afar stratoid Series (4-1 Ma) and the younger volcanoes built on the Axial fissure system of Afar (Barberi, et al., 1975a). The Afar group (Pliocene-Pleistocene) is specially made of basaltic layered sequence, which is accumulated within the floor of the central and southern part of the Afar Rift. The floor of Afar triangle lies between 1000m a.s.l at Awash town and 120m below sea level at Danakil depression. The opening of the Afar Rift seems to have commenced in the Early Miocene (23-25 Ma, Barbieri et al, 1975).

Present day tectonic activity occurs along the Rift Valley as evidenced by numerous earthquakes. More recent volcanism associated with tectonic development activity being concentrated within this structure along the edge of the adjoining plateau.

In the course of the development of the Great Rift System in Ethiopia, varieties of continental sedimentary basins were developed since Miocene. In the Afar Depression, sediments originating from the rapid erosion of the steep escarpment together with abundant volcanic products tended to fill the depression but tectonic deepening was more rapid than volcano-sedimentary filling. The nature of the sediments was dependent on whether the basins are marginal or axial (Mengesha et al., 1996).

In the Afar plains the alluvial distribution was intermittently disrupted by volcanism & faulting. The active geological evolution associated with the pluvial periods severely affected the Awash drainage pattern with blocked drainage continuing & the creation of an extensive lake system, particularly in the upper part of the proto-Awash valley bottom. Lacustrine sediments were deposited in the lakes & have progressively become exposed as the lakes have receded through the Recent, although remnant lakes & marsh areas are still a feature of the Basin.

3.2. Tectonic Setting

Before 30 Ma, the Arabian plate was part of the African plate and the whole of what is today's horn of Africa and Arabia shared similar geological history. The eruption of the Ethiopian traps about 30 Ma ago marked the beginning of the Arabian and African plates breakup. The Afro-Arabian Rift system comprises the Red Sea Rift, the Aden Rift and the East African Rift, the northern most part of which is the Main Ethiopian Rift. The simultaneous interactions between these rifts resulted in the separation of the Danakil and Aysha blocks and their respective counterclockwise and clockwise

rotations leading towards the opening of the triangular Afar depression (Audin et al. 2004). At its southern termination, the southern Red Sea Rift intersects the Main Ethiopian and Aden Rifts forming a 400 km wide triple-junction zone marked by the Afar Depression (McKenzie *et al.* 1970; Manighetti *et al.* 1998).

The Afar Triangle was created 22 Ma. The structural trends of the Western Ethiopian escarpment and associated marginal grabens depict complex structural trends. The trends of the Southern Red Sea (NW-SE), the main Ethiopian Rift (NE-SW), and the Gulf of Aden trend (E – W) are thought to be present in the region. The paleogeographic position of the Danakil block for example is thought to coincide with the western escarpment; this can easily be seen by the geometrical fit of the Danakil block to these areas. Therefore, structures that trend parallel to this orientation is common to get as they are linked to the Danakil horst detachment kinematics. On the other hand, several synthetic and antithetic faults to the border faults of the study area, which change in orientation along strike, could also occur due to the dominant stress regime during rift developments. Moreover, the westward propagating Gulf of Aden could have exerted remote tectonic force to produce structures parallel to its trend. Several joint sets might also developed in response to the regional stresses mentioned above.

The Ethiopian and the Ogaden plateaus are spreading apart. Different scholars have attempted to calculate the rate of the spreading (EVDSA, 1989). Schaefer (1975) estimated the average rate of spreading in the rift valley to be in the order of 3-4 mm/year, while Mohr (1970) estimated the rate of spreading along the rift to be about 15 mm/year. The rifting process was also accompanied by vertical movements as cited by EVDSA (1989); Taieb (1975) estimated the rates of vertical movements to be in the order of 0.2-0.4 mm/year.

The rift faulting, which is always of a normal tensional nature, began in the Pliocene (Mayer, 1975) and reached its climax in the early Pleistocene, and recurred in the early Holocene (= Recent) running along the floor of the rift, forming graben-within-graben structures. As a result, in the rift valley faulting is an on-going process (Ferguson, et al., 2010). Earthquake swarms of the 1969 Serdo and 1989 Dobe correspond to the location of marginal grabens. It is believed that normal and strike-slip faulting generated most of the earthquakes.

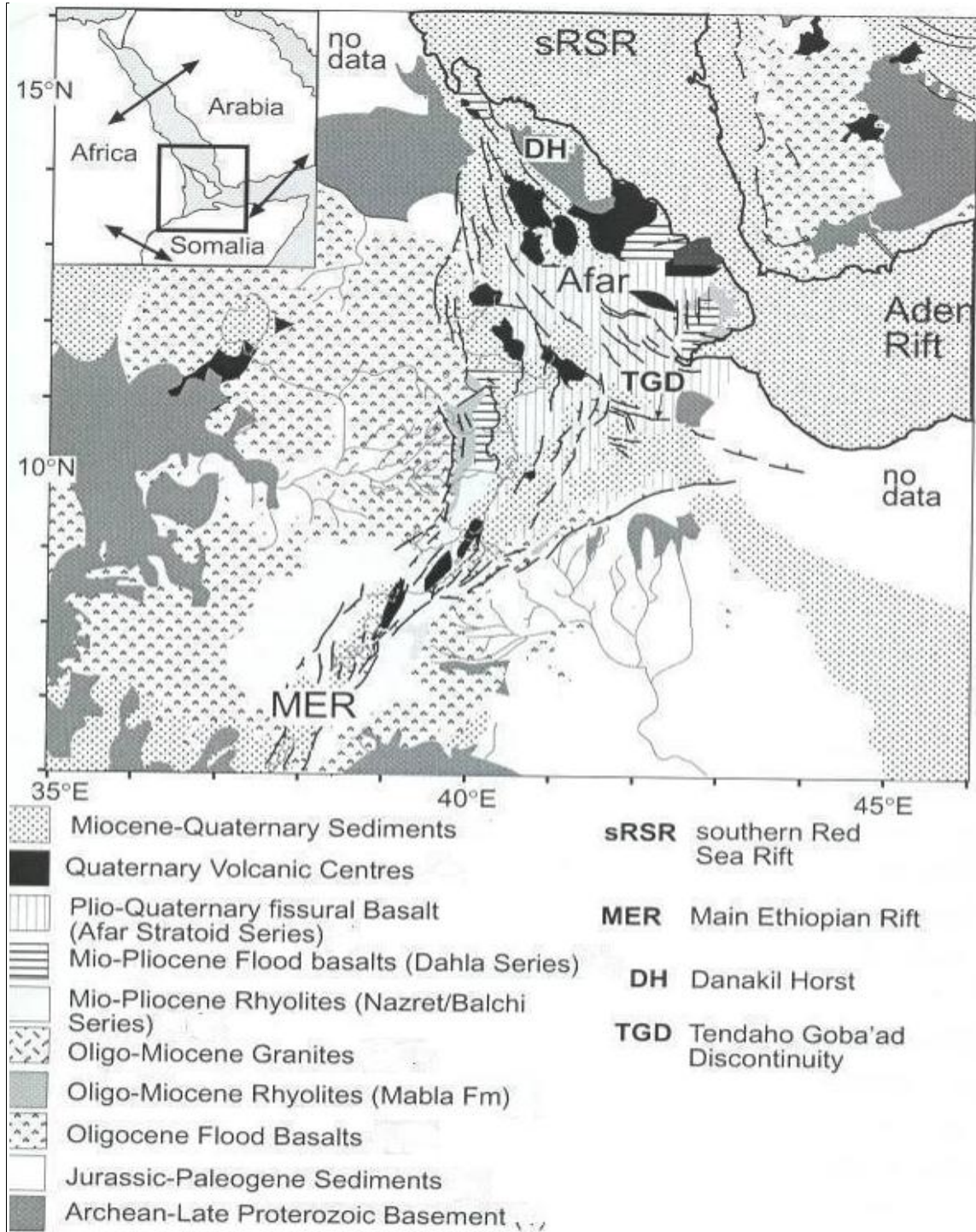


Figure3.1. General geology of Ethiopia, after Wolfenden (2003)

3.3. Local Geology

3.3.1. Upper Sandstone

The Upper Sandstone is exposed in the western escarpment (outside the study area) in a locality called Kerem north of Hara town in Amhara Region (0586386E, 1313315 N) and about 6 km west of Alele Sulula at Messala ridge (059576 E, 1305598 N, 1246m) in Afar Region (within the study area). At Messala the sandstone is observed underlying the Ashange basalts along NNW-SSE trending normal faults and tilted along with the Ashange basalts by about 35° towards NNE. The upper part of the sandstone is red/pink in color, fine to coarse-grained and conglomeratic while the middle part is whitish and pebbly (fig below). At both areas (Kerem and Messala) the sandstone has been exposed on the same NW to SE trending elongated ridges. It is expected that the sandstone had been pushed up by reverse fault to be exposed at this elevation in relation to the surrounding volcanic rocks. This sandstone is highly fractured & might be equivalent to Amba Aradam sandstone.



Plat 3.1. Sandstone exposed at Messala area within Mormore stream channel

3.3.2. Ashange basalt

The Ashange basalts are exposed at Werke, Dodota, Kebenewa, Hamaro and Sodoma chains of ridges that extend north-south direction west of the study area within Amhara region. It is characterized by thinner individual lava flow thickness of about 5 meters and more alkaline affinity. This unit is highly weathered with alteration minerals (zeolites) filling in the vesicles forming amygdales. The individual flows of this unit are known to be continuous only for few kilometers along strike. Here the basalt sequence is strongly faulted and tilted by 20 to 35° towards east.

3.3.3. Andesitic Tuff

This rock unit is exposed at the immediate western flank of Uwa low land plain areas overlaying the Ashange basalt. The rock unit mainly exposed at Dulem, Illala, Dewato-Oror ridges north of Alele Sulula town, Gube, Bilu, Aki Gura and Duba area chain of ridges west south of Alele Sulula. It is highly weathered and fractured due to intensive NNW to SSE faulting and tilted eastwards. It is grey to dark in color and has highly brittle nature so that it is difficult for rock sampling. Isolated ridges of this rock unit are dome shaped and do not show drainage pattern due to high permeability.





Plat 3.2. Andesitic tuff exposed at Bilu area (*top*) and Duba (*bottom*) south of Alele Sulula town

3.3.4. The Mabla Rhyolite

The Mabla Rhyolites consist of thick flows and domes of slightly peralkaline rhyolites and ignimbrite with some intercalated basaltic flows and pumice and cinérites. Its age ranges from 14.2 to 9.7 m.y (Kazmin, 1979). Sheeted flow bands are common in this rock unit. The rock unit is observed in Demea-Gerselo chains of ridges (northeast of the study area).

Like the other units this unit has been affected by intensive NNW to SSE trending faults and as a result it is highly fractured and tilting towards east.



plat 3.3 *Mabla Rhyolitic rock unit exposed at Gobi-Bora ridge.*

3.3.5. The Dalaha Basalt

The Dahala basalt consists of fissural flows of basalt and hawaiites with some intercalated detrital and sediments, rhyolitic flow and pyroclastics near the upper part. This unit is well developed in the neighbouring Djibouti and northern and central Afar and it outcrops also in the western escarpment bordering the Afar triangle. It is slightly tilted ($7-10^{\circ}$) towards the SE in the Western Afar margin area. The Dahala basalt was given an absolute K/Ar age of 8.6 Ma (Varent, 1978 cited in Mengesha et al. 1996).

These fresh looking young basalt that form block stone on the top of the ridges overlays the Mabla rhyolite and exposed at Duba, Regden ridges south east from Alela Sulula, very wide chains of ridges located east of Fiyalu and Debal plains that locally called Besenka, Burka and Dorongot, Sulu adu and Degage ridges. This rock unit is so young and fractured by NNW-SSE faults.



Plat 3.4: *Dahla basalt rock unit exposed at Duba ridge (left) and Besenka ridge (right.)*

3.3.6. The Recent Basalt

The Rift axis passes through the study area and along this axis recent basaltic flows, volcanic center and many open fissures and tension gashes and scoria cones are exposed. Sometimes the cinder and scoria cones form an alignment parallel to the regional trend following pre-existing structure or defining a continuous dike body at depth. These volcanic centers are very young and dominantly basaltic which were emplaced along fissures and faults. These faults have then reactivated at a later stage and opened causing brittle deformation to the initial lava. These openings are again filled by new basaltic eruptions emitted through the faults. This basalt exposed south east of the study area around sunuta and south east of it. The local names of these volcanic cones are Damuta, Meroli, Deta Sunuta, Berentu-Elirebe ridges etc. These volcanic rocks have vesicles and open space.

3.3.7 Fluvio-lacustrine sediments

The western sides of the study area have been on continuous denudation and transportation events while the eastern down thrown part including the study area has been in continuous deposition and volcanism related to the rifting process. The origin of the deposits could be fluvial and/or lacustrine. Recent sediments are commonly found at river courses and flood plains such as Fiyalu-Sunuta and Duba plains. The older sediments consist of layers of slightly compacted gravel, sand, silt occasionally include channel and fan layers and clays with calcite concretions attesting to secondary

processes after deposition. The deposition process appears to be strongly controlled by extensional faults and grabens.

The thickness of these deposits is unknown. Recently drilled borehole logs at Uwa catchment showed deposit thickness of 200 to 245 m. On the other hand because of the continuous deposition and volcanism, alternation of sediments and volcanic flows are expected at depth in the study area which was attested from borehole logs of recently drilled wells at Sunuta. Borehole logs at Sunuta area proved that there are different basaltic flows having thickness ranging from 3 to about 33 m located at different depths interbedded within deposit.



Plat3.5 Alluvial (left) and lacustrine (water lain) deposits (right)

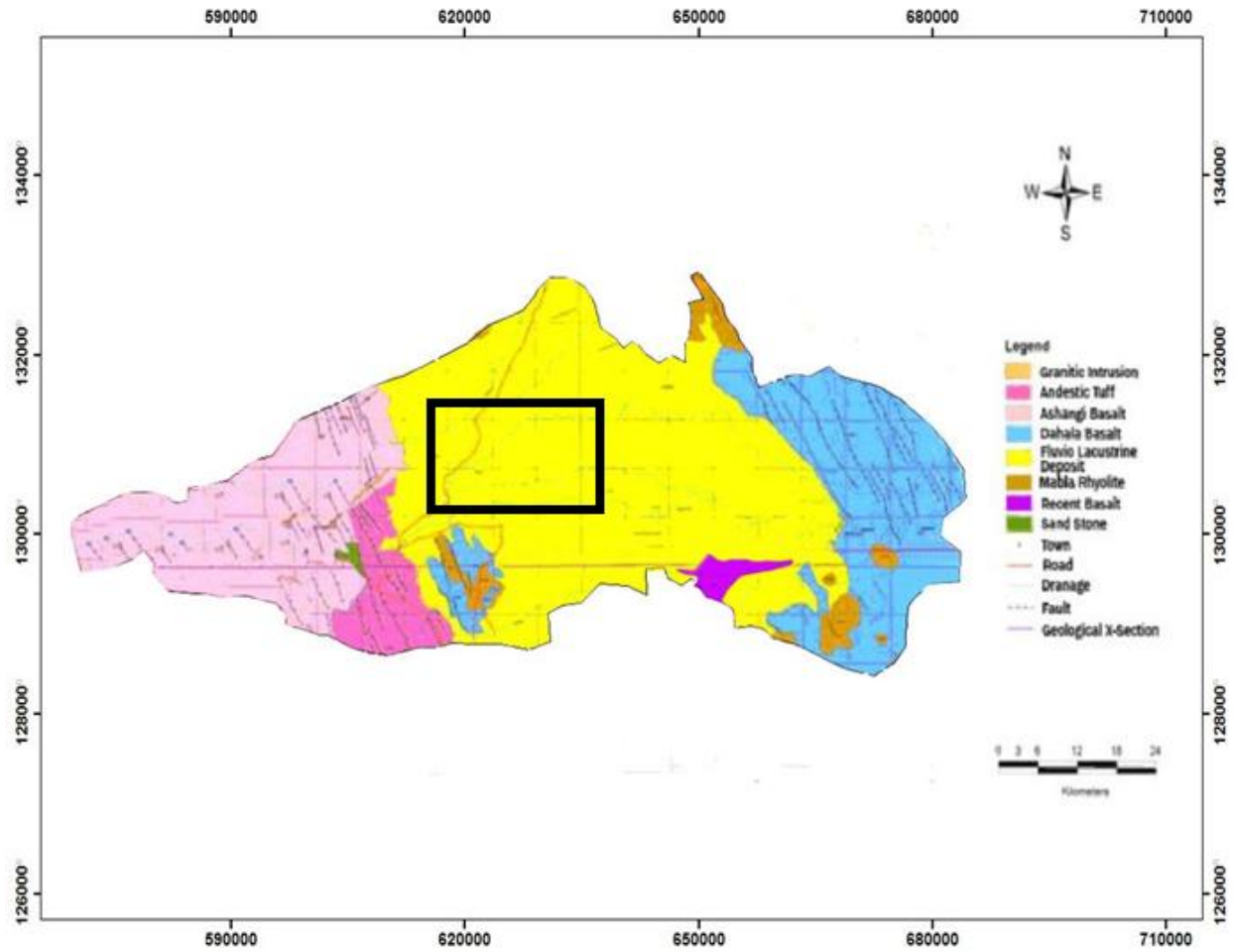


Figure3.2. Geological Mapp of the study area modified from (ADSWE, 2004).

CHAPTER FOUR

4. Hydrometrolog

In order to understand the different parameters of climatic condition of the study area the monthly mean meteorological measurements of parameters were collected from National Meteorological Agency (NMA) and from other different sources. There are very limited meteorological stations within the study area, so that it is obligatory to consider additional stations which are outside but near the study area. Only sirinka station is within the study area whereas the rest found around the study area (Uwa catchment). The parameter considered includes monthly mean Rainfall, the maximum and minimum temperature, relative humidity, wind speed and sun shine hour. However, the data is incomplete, but it will provide basic information regarding the climatic condition of the area. Each parameters of the climate are discussed in brief below.

Table 4.1 Summary of location and acquired parameters of the observed stations

no	Station name	Elevation(m)	UTM (E)	UTM (N)	Observation period	Acquired parameters
1	Eli Whuha	670	111500	0402259	2010-2014	RF & T
2	Kobbo	1470	120800	0393800	1980-2013	RF,T,RH, WINDSPEED& SUNSHIN HOUR
3	Mille	487	112532	0404612	2007-2014	RF,T&RH
4	Semera	590	114536	0410000	2006-2014	RF,T&RH
5	Sirinka	1861	114504	0393651	1980-2014	RF,T,RH,WINDSPEED & SUNSHIN HOUR

4.1. Temperature

The temperature of the area varies with change in altitude and seasonal variation. Throughout the entire area the spatial and temporal temperature shows significant variation from place to place and even in the same station at a significant rate. There is a gradual and significant increment in temperature from the western plateau and highland towards the western Afar rift escarpment and the Afar rift floor. The analyzed data (1981 - 2014) for observed stations show

that the average monthly maximum and minimum temperature of the study area on the western plateau varies between 26.9°C and 13.6°C for Sirinka stations whereas this value increases for stations Mile 37.1°C to 24.3°C and Semera 37.9°C to 24.5°C, which represent the Afar rift floor. The highest temperature recorded in the study area is on the months of May, September and July. While the lowest temperature lies on the months of October, November, December and January. The monthly average temperature for selected stations are plotted in figure below.

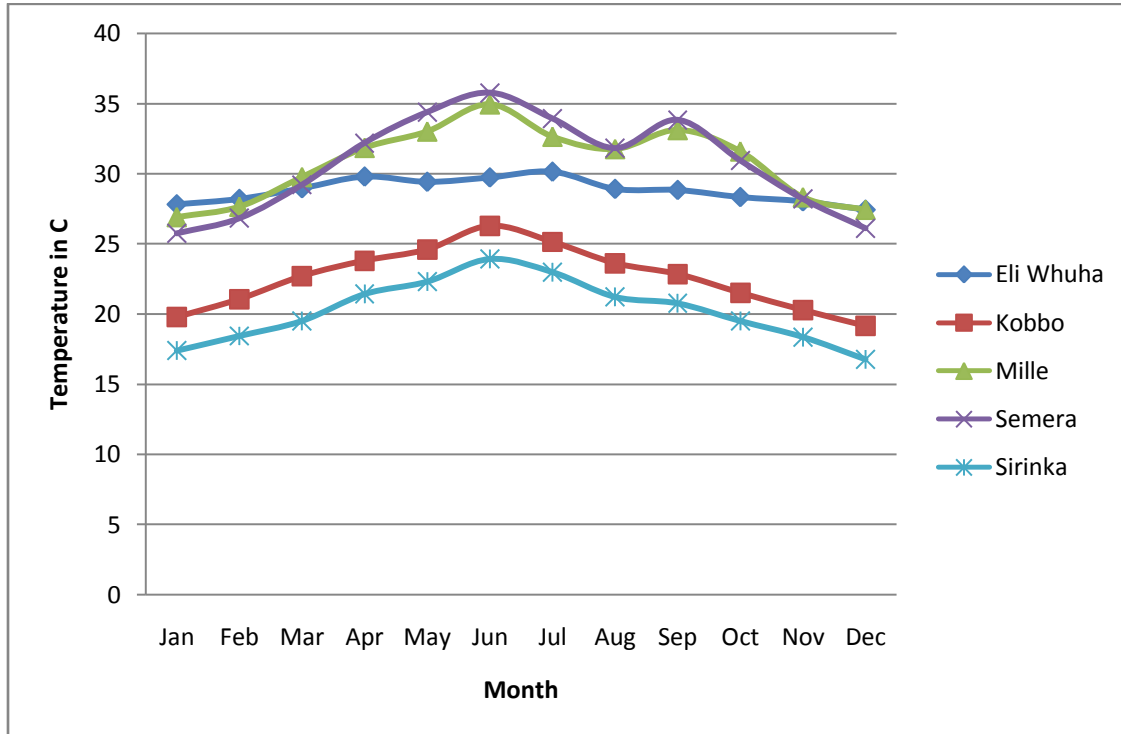


Figure4.1. Long term mean monthly temperature of different meteorological stations around the study area

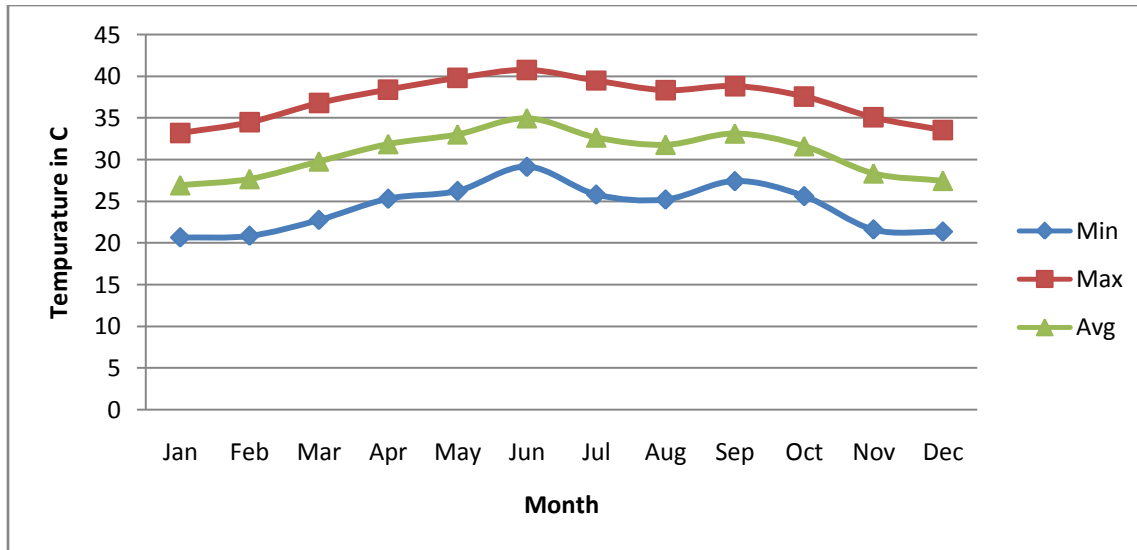


Figure 4.2. The maximum and minimum and mean monthly temperature of milla station

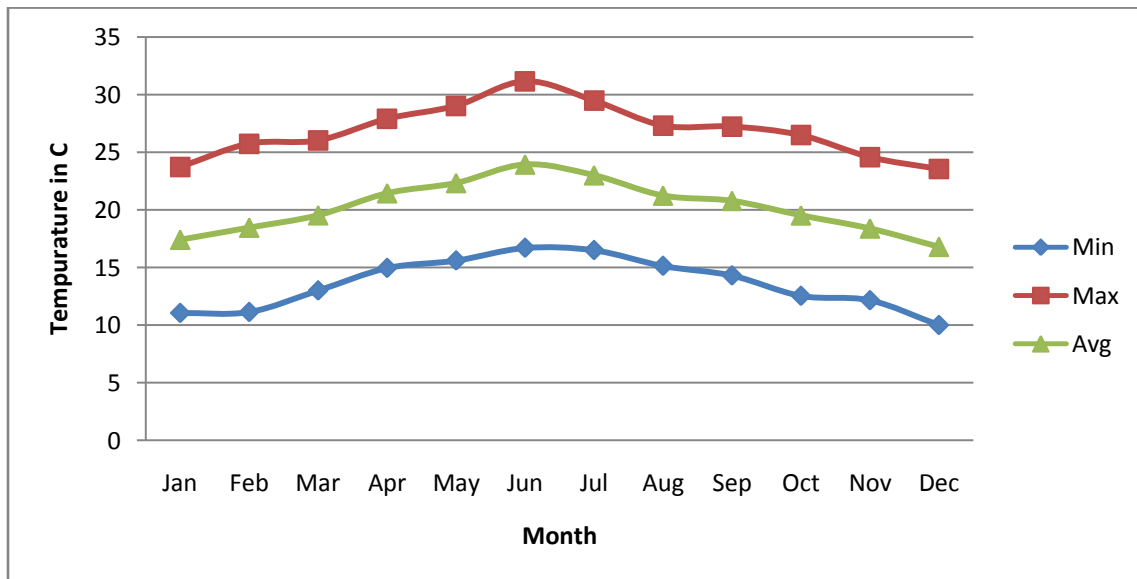


Figure 4.3. The maximum and minimum and mean monthly temperature of sirinka station

4.2. WIND SPEED

Presence of atmospheric turbulence can greatly increase the rate of evaporation by removing vapor from evaporating surface and giving space for fresh air capable of holding additional vapor in the atmosphere. The replacement of saturated air by drier air would enable evaporation to continue. Kobbo and Sirinka station are considered to understand the wind speed of the study

area this is due to data availability. At Sirinka stations, a thirty years record of wind speed has been considered. The mean monthly wind speed of Kobbo station varies from 1 ms⁻¹ in September to 2.2 ms⁻¹ in February with average value of 1.6 ms⁻¹. For Sirinka station, it varies between 0.92 ms⁻¹ in October and 1.5 ms⁻¹ in December and the average value of 1.26 ms⁻¹.

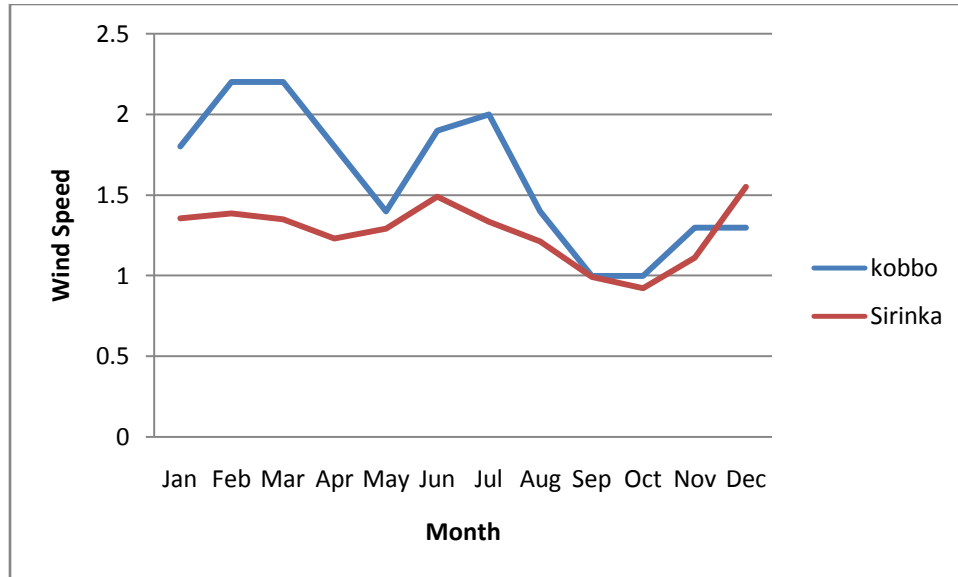


Figure 4.4 Mean monthly wind speed of the study area.

4.3. SUNSHINE HOURS

Since the evaporation requires continuous supply of energy, which is derived mainly from solar radiation will be a factor of considerable importance. Sunshine hour duration data are available for Kobo, Sirinka and Milla stations. Mean sunshine hours determined for the Kobo station was above 9.0 hours in the months of October to November and April to May. The highest cloud cover occurs in January and September. A lesser cloud cover or sunny skies exist in all other months. The mean monthly sunshine durations at Kobo, Sirinka and Milla stations were 8.3, 7.15 and 8.51 hours respectively.

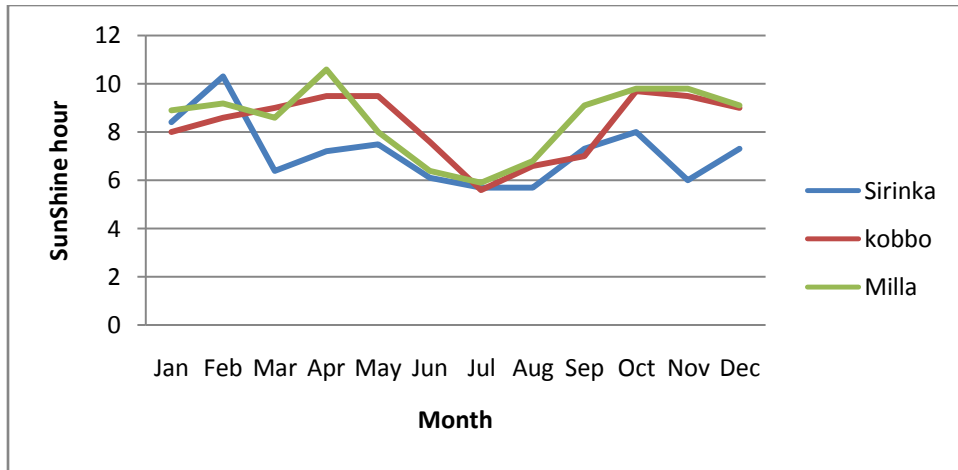


Figure 4.5. Mean monthly sunshine hour of the study area.

4.4. RELATIVE HUMIDITY

Relative humidity is the percentage of moisture in air relative to the amount it can hold at saturation at a given pressure and temperature. The relative humidity of the air is largely dependent on temperature. Data on relative humidity is available for three stations Kobo, Sirinka and Milla. The mean monthly relative humidity for kobo ranges from 48% in May and 80% in July. For Sirinka it ranges from 48% in Jun to 73% in January. For Milla it ranges from 30% in Jun to 64% in August.

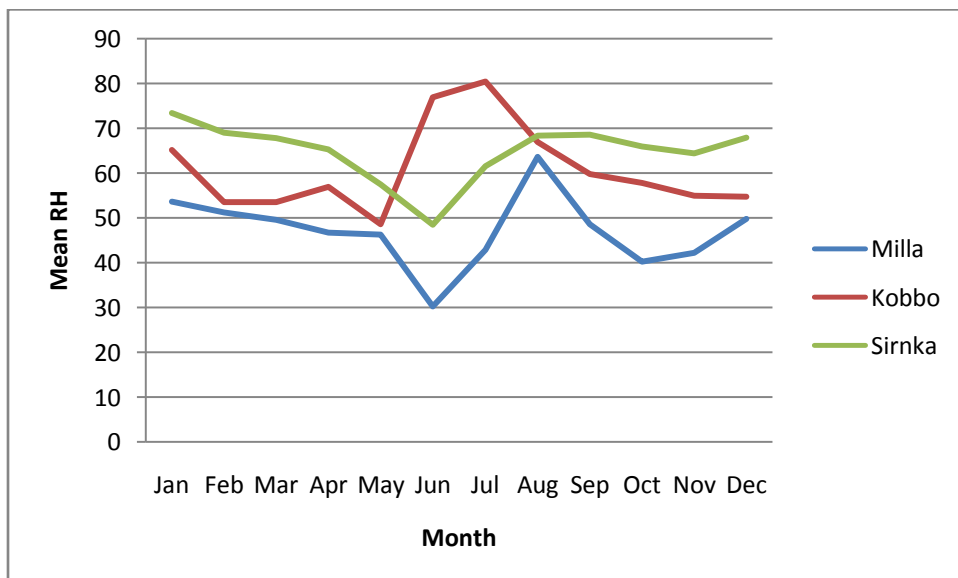


Figure 4.6. Mean monthly relative humidity

4.5. PRECIPITATION

The spatial and temporal variation of rainfall in Ethiopia is strongly controlled by the inter-annual movement of the position of the Inter tropical Convergent Zone ((ITCZ) (Tenalem Ayenew and Tamiru Alemayehu,2001)). During its movement to the north and south of equator, the ITCZ passes over Ethiopia twice a year and this migration causes the onset and withdrawal of wind from north and south. The seasonal variation of rainfall in the study area is dependent on the movement of ITCZ. Very often it is also modified and influenced by altitude variations. As many parts of the country, the study area experienced two main rainy seasons. The main rainy season extends from mid Jun to end of September (summer) and another short period rainy season lies between ends of March to mid May. During winter, October to February, it is sunny, dry with very little or no rainfall (see Figure 4.7).

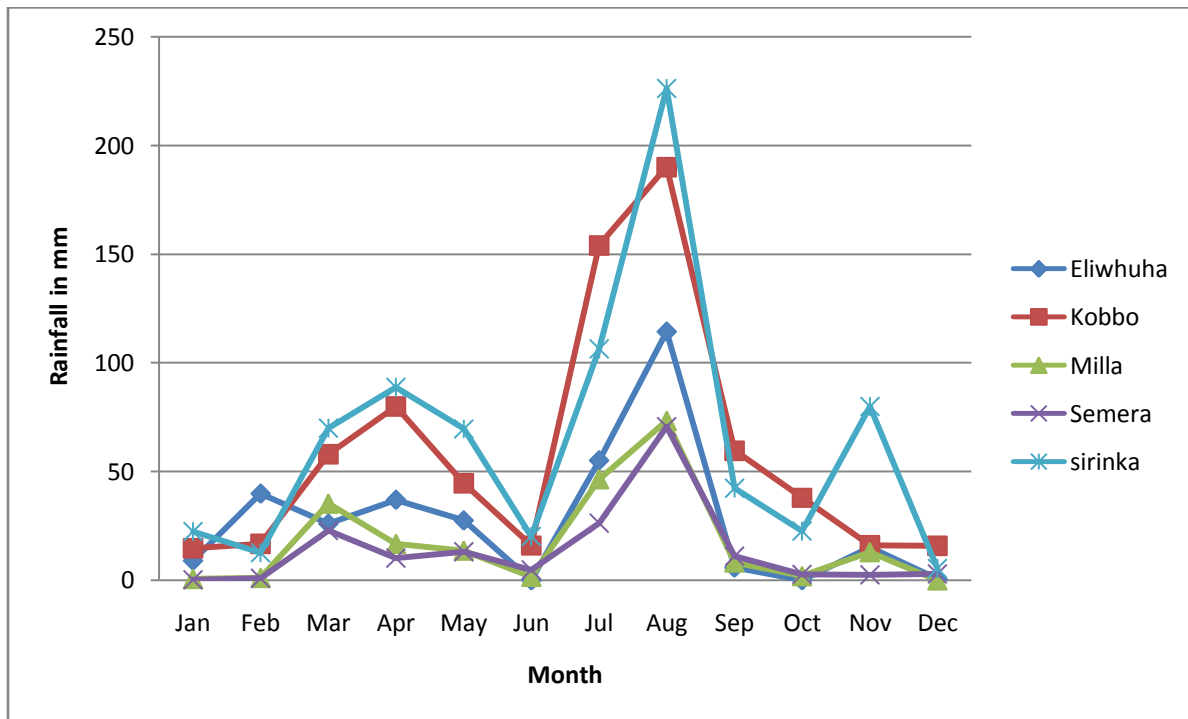


Figure4.7. Long term mean monthly rainfall of different stations within and near the study area.

As it is observed from (figure 4.7) above the area has a bimodal rainfall pattern with its major highest pick mid July to August with smaller pick on December. The lowest rainfall recorded is on the Elwiha, Mile and Semera stations with a value of 6mm, 0mm, 3mm respectively. While the highest is on the adjacent escarpment (srinka) recorded 226mm. In additions the relationship

between rainfalls with temperature is complicated. As it is observed in (figure 4.8) below sometimes seasons with a relatively lower temperature receives lower rainfall on the other hand seasons with high temperature receives low rainfall.

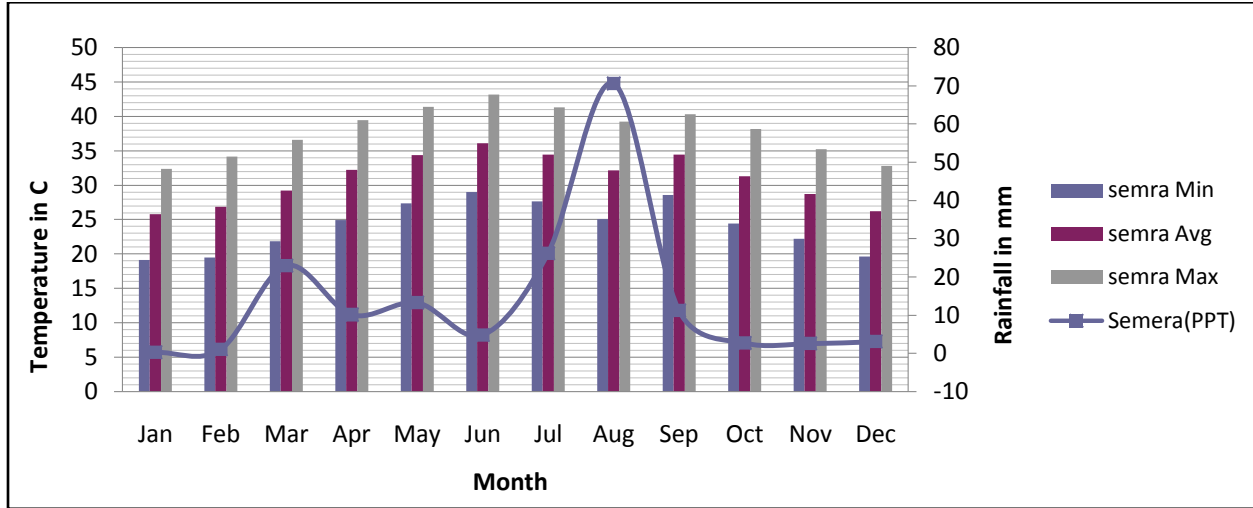


Figure4.8. Relationship between rainfall and temperature at semera station

4.6. ANNUAL AREAL DEPTH OF PRECIPITATION

The rainfall measurement is a point observation and may not be used as a representative value for the area under investigation. Therefore, the point measurements have to be averaged over the study area. To average the point measurements for the study area, three methods have been applied; Arithmetic mean, Thiessen Polygons and Isohytal method. All these used for comparison of one from the other according to the Orographic effect and areal distribution of the stations.

4.6.1. Arithmetic Mean.

Arithmetic mean is the simplest method of determining areal average rainfall. It involves averaging the rainfall depth records at a number of gages. This method is satisfactory if the gages are uniformly distributed over the area and the individual gage measurements don not vary greatly about the mean (chow 1988).

$$P_A = \frac{\sum_{i=1}^n P_i}{n}$$

Where P_A is average rainfall for the total area, P_i is measured precipitation at a given station and time and n is number of rain gages.

Since, the four stations (Kobo, Sirinka, Milla and Eliwhua) are closely and evenly spaced arithmetic mean method was applied to determine the aerial depth of precipitation for the catchment .The Arithmetic mean computed using these four gauges gives a value of **503 mm**.

Table 4.2. Mean annual areal depth of ppt. obtained from arithmetic mean of three different rainfall stations in and around the study area.

Stations	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
Eliwhuha	9	40	26	37	28	0	55	114	6	0	16	6	330
Kobbo	15	17	57	80	45	16	154	190	60	38	16	16	702
Milla	1	1	35.	17	14	2	47	73	8	2	13	0	212
sirinka	22	13	70	89	70	20	106	226	42	22	80	5	766
Mean	12	18	47	56	39	10	91	151	29	16	31	7	503

4.6.2. Thiessen method

Thiessen method assumes that at any point in the watershed the rainfall is the same as that at the nearest gage so the depth recorded at a given gage applied out a distance halfway to the next station in any direction. The relative weights for each gage are determined from the corresponding area of application in a Thiessen polygon network (Chow1988).

$$P_A = \frac{\sum_{i=1}^n P_i a_i}{A_i}$$

Where P_i is observed precipitation, a_i is area where the station found, and A_i is the total area under investigation.

The Thiessen method is generally more accurate than the arithmetic mean method, but it is inflexible, because a new Thiessen network must be constructed each time there is a change in the gage network, such as when data is missing from one of the gages. Also, the Thiesson method does not directly account for orographic influences on rainfall. Thiesson polygon method was applied to see the mean annual rainfall for the entire study area. The weighted mean of the precipitation was calculating using the above equation which resulted in **503.98mm** of mean

annual rainfall for the entire study area. The table used to compute the method is presented below.

Table 4.3. Annual weighted rainfall depth using Thiessen polygon

No.	Station	Area of influence (ai) (km ²)	Catchment area(A) (Km ²)	Weighted area (ai/A)	Annual ppt.(pi)	(ai/A)*(pi)
1	Eliwhuha	94.42	659.7	0.143	330	47.19
2	Kobbo	49.64	659.7	0.0752	702	52.79
3	Milla	234.8	659.7	0.355	212	78.45
4	Sirinka	280.42	659.7	0.425	766	325.55
Total		659.7	659.7	1	2010	503.98

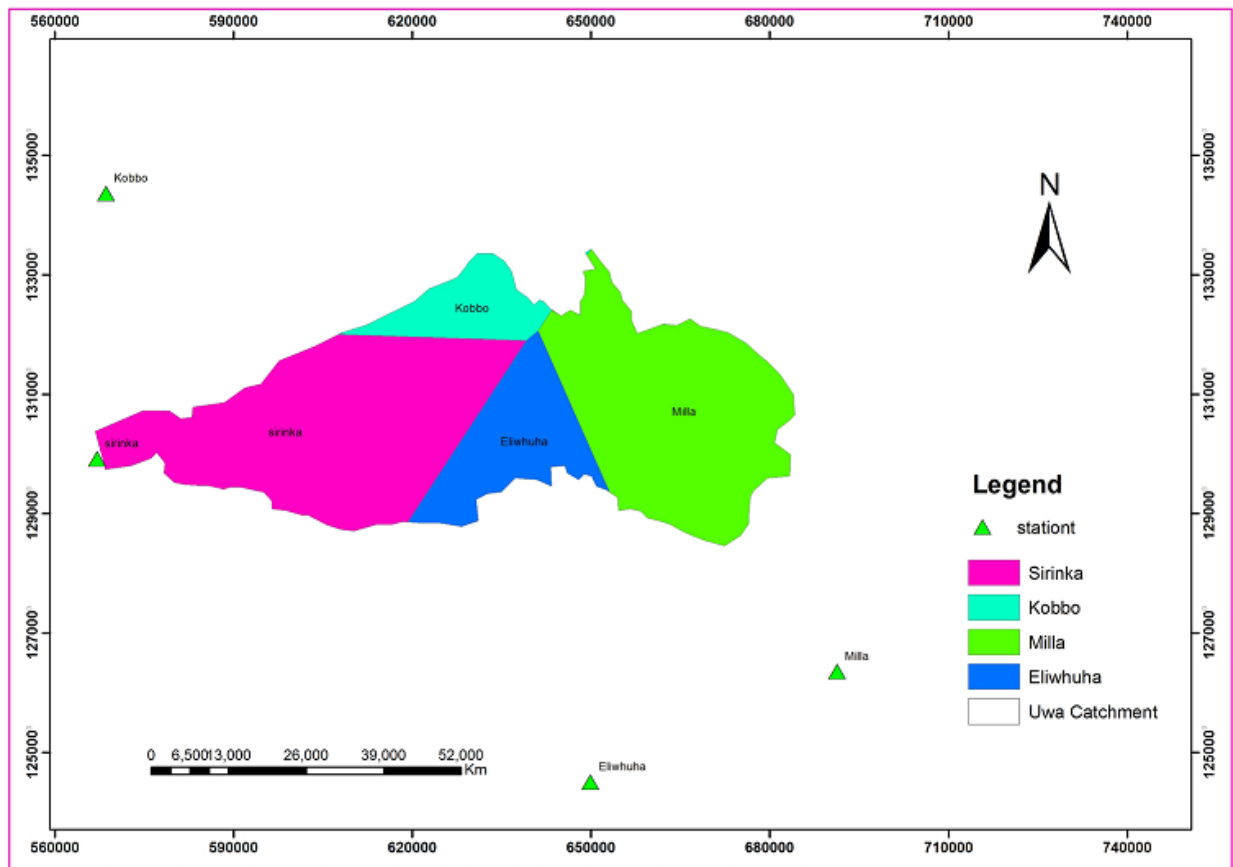


Figure4.9. Thiessen polygon of the study area.

4.6.3. Isohyetal method

Isohyetal method overcomes some of these difficulties by constructing isohyets, using observed depths at rain gages and interpolation between adjacent gages. Where there is a dense network of rain gages, isohyetal maps can be constructed using computer programs for automated contouring (Chow1988).

$$P_A = \frac{P_{1,2} \cdot a_{2,3} + \dots + p_{n-1,n} \cdot a_{n-1,n}}{A_i}$$

Where P_{1,2} is rainfall between isohyets

1 and 2, a_{1,2} is area enclosed by successive isohyets of 1 and 2.

The isohyetal method is flexible, and knowledge of the storm pattern can influence the drawing of the isohyets, but a fairly dense network of gages is needed to correctly construct the isohyetal map from a complex storm. Based on the above formula, mean annual precipitation of the study area has been obtained **497.65mm**.

Table 4.4. Annual weighted rainfall depth using Isohyta method.

No.	B/n contours (mm)	ppt. avg.	ai	A	ai/A	Pi	(ai/A)*Pi
1	283-366	324.5	106.78	659.7	0.16	324.5	51.92
2	366-440	403	109.47	659.7	0.165	403	66.495
3	440-519	479.5	134.21	659.7	0.20	479.5	95.9
4	519-599	559	146.63	659.7	0.22	559	122.98
5	599-682	640.5	105.71	659.7	0.16	640.5	102.48
6	682-765	723.5	54.52	659.7	0.08	723.5	57.88
Total							497.65

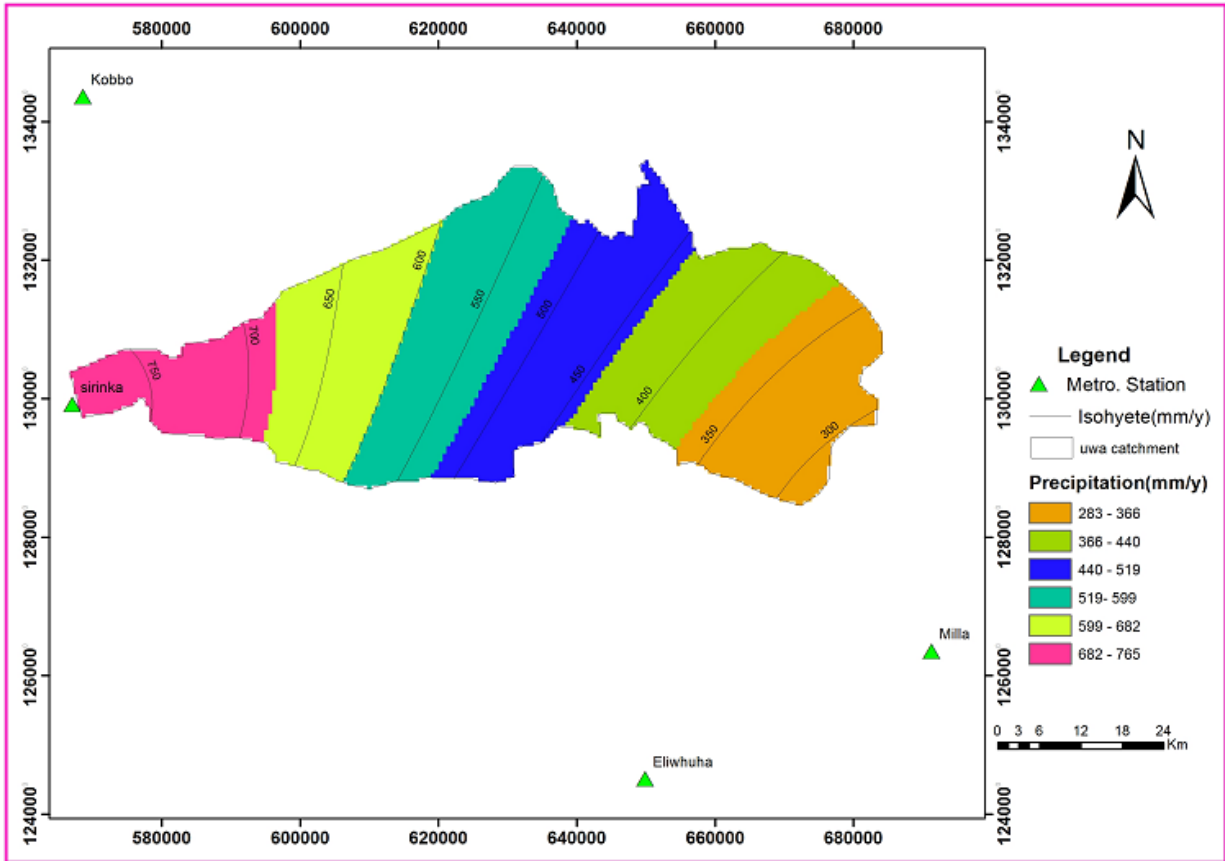


Figure 4.10. Isohyetal map of the study area.

4.7. Evapotranspiration

The combination of two separate processes, whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to as evapotranspiration (ET). Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. At sowing nearly 100% of ET comes from evaporation, while at full crop cover more than 90% of ET comes from transpiration.

4.7.1. POTENTIAL EVAPOTRANSPIRATION (PET)

Potential evapotranspiration is the water loss if at no time there is a deficit of water in the soil for the use of vegetation (Thornthwaite, 1944). PE is dependent on the evaporative capacity of the atmosphere and can be calculated theoretically using meteorological data. The most commonly used methods for calculating PE are those of Blaney and Criddle (1962) and Thornthwaite (1948), which are based on empirical correlations between evapotranspiration and climatic factors, and Penman (1948) and Penman Monteith (Monteith 1965, 1985) which are energy-budget approaches requiring further meteorological data (Kevin, 2005).for the study area to compute the PET Thornthwaite and penman methods are conducted.

4.7.1.1 THORNTHWAITE METHOD

Thornthwaite method is based up on the assumption that potential evapotranspiration is dependent only on meteorological conditions and ignores the effect of vegetation density and maturity. The only necessary factors to calculate PET using these methods are mean monthly air temperature (T), Latitude and month (average monthly sun light) (Thornthwaite and Mather 1955 and 1957). Given the monthly mean temperatures from the measurements at a climatological station, an estimate of the potential evaporation for each month of the year can be calculated (Shaw, 1994). The method has been used widely throughout the world, but strictly it is not valid for climates other than those similar to that of the area where it was developed, the eastern USA. Compared with the estimates from the Penman formula, Thornthwaite values tend to exaggerate the potential evaporation (Shaw, 1994). Contrary to this, in this case it underestimates the PET value of the area.

An estimate of the potential evapotranspiration, PET, calculated on a monthly basis, is given by:

$$PET_m = 16N_m \left(\frac{10T_m}{I} \right)^a \text{ mm}$$

Where: m is the months 1, 2, 3...12,

N_m is the monthly adjustment factor related to hours of daylight,

T_m is the monthly mean temperature °C,

I is the heat index for the year, given by:

$$i_m = [Tm/5]^{1.5}$$

$$I = \sum i_m = \sum \left(\frac{Tm}{5}\right)^{1.5} \text{ for } m = 1 \dots 12 \text{ and,}$$

$$a = 6.7 \times 10^{-7} I^3 - 7.7 \times 10^{-5} I^2 + 1.8 \times 10^{-2} I + 0.49 \text{ (to 2 significant figures)}$$

The Thornthwaite formula above gives PET for standardized month of 30 days and 12 hours of sunlight. While the daylight factors (Nm) are obtained by dividing the possible sunshine hours for the appropriate latitude by 12, this is taken from book of Shaw, 1994.

The latitude of the study area is 11°37'11" to 12°22'1.7", which is very near to 10°N; thus the adjustment factor is taken based on 10°N.

Thus, the PET values obtained by Thornthwaite method for the study area using metrologic station (Sirinka, Kobbo, Eliwhuha and milla) is **1065.67mm**

4.7.1.2. MODIFIED PENMAN METHOD

The most general and widely used equation for calculating PET is the Penman equation.

The Penman monteith variation is recommended by FAO. The FAO Penman-Monteith equation requires air temperature, humidity, radiation and wind speed data.

The basic equation of Penman to calculate potential evapotranspiration, PET^m is:-

$$PET^m = \frac{(\Delta/\square)HT + Eat}{\left(\frac{\Delta}{\square}\right)=1}$$

Penman method is used to calculate the evapotranspiration of the study area using two stations (sirinka and Kobbo) this is because of the data availability. The procedure followed during calculation for the data presented in the annex part. Estimation of annual PET by the Penman method for the study area using sirinka and kobbo is **1246.07mm/y** and **1351.69mm/y** respectively.

4.7.2. ACTUAL EVAPOTRANSPIRATION (AET)

Actual evapotranspiration (AET) is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration. It is therefore, the amount of evaporation

that occurs under a given climate and soil moisture and is less than or equal to potential evapotranspiration. The most popular method of computing actual evapotranspiration is through calculation of potential evapotranspiration. When moisture conditions are suitable, the actual rate of evapotranspiration is equal to the potential rate.

4.7.2.1. EMPIRICAL FORMULA

4.7.2.1.1. TURC METHOD

A widely used formula to estimate annual values of AET for catchment areas and it representing all the different climates including Africa (Shaw, 1994).The formula takes into consideration mean annual precipitation and mean annual temperature of the catchment area.

$$ETA = \frac{P}{\left[\left(1.9 + \left(\frac{P}{L} \right)^2 \right) \right]^{0.5}}$$

Where P is the mean annual precipitation (mm), $L=300+25T+0.05T^3$ (mm) and T is the mean air temperature (°C).

Turc showed that the formula could be applied in humid and arid climates, either hot or cold (Shaw, 1994).

AET of the study catchments is estimated by taking averaging of mean annual Precipitation of Sirinka, Milla, Eliwuha and kobbo stations. Thus, AET values obtained is **363mm**.

4.8. SOIL WATER BALANCE METHOD

Water loss from a catchment area doesn't always proceed at the potential rate, since this is dependent on a continuous water supply. When the vegetation is unable to abstract water from

the soil, then the actual evaporation becomes less than potential. On the other hand when there is abundant moisture in the soil, the actual evapotranspiration rate is equal to potential evapotranspiration.

After rainfall ceases, saturated soil loss water becomes unsaturated until it can just hold a certain amount against the force of gravity; it is then said to be at 'field capacity'. If there is no rain to replenish the water demand of the soil, the soil moisture become depleted by the demands of the vegetation to produce a soil moisture deficit (SMD), with the amount of water required to restore the soil to field capacity.

The values of soil moisture deficit and actual evapotranspiration vary with soil texture and vegetation and Penman (1950) introduced the concept of a 'root constant' (RC) that defines the amount of soil moisture in (mm) that can be extracted from a soil without difficulty by give vegetation (Shaw 1994). Therefore, the soil moisture budget can be made on a monthly basis for various type of vegetation classified according to their root constants.

Based on this Land use Land cover classification discussed in Section 2.4 and reclassified FAO (1975) soil classification Section 2.5 the estimated precipitation and potential evapotranspiration of the area, the actual evapotranspiration has been calculated using Thornthwaite and Mather standard soil water balance model.

Descriptions and computation approaches of each of the main components that basically influence the balance is presented in the following way:

- **P-** The mean monthly precipitation values obtained from Isohyetal polygon method.
- **PET-** The mean potential evapotranspiration calculated by the Penman method.
- **P-PET-** Changes in the balance of the precipitation and potential evapotranspiration of each month.

- **APWL**-The accumulated potential water loss which is obtained by adding the negative values of P-PET of consecutive dry months. The summation begins with the first month of dry season.
- **SM**- The amount of water that will be retained by the soil (soil moisture) for each month.

The soil moisture during the **dry months** is obtained from the following formula:

$$S_m = W \exp\left[-\frac{La_m}{W}\right]$$

Where, S_m : Soil moisture during the month m (mm)

La_m : Accumulated potential water loss at month m (mm).

W : Available water capacity of the root zone (mm)

For each **wet months** the soil moisture(SM) is obtained by adding the excess of rain of the current month to the soil moisture of the month before. However, this sum may not exceed the water capacity and excess is booked as moisture surplus.

- **AET**- Actual evapotranspiration. Monthly actual evapotranspiration (AET_m), The relationship between AET & PET depends up on the soil moisture content. When the soil is saturated or when there is abundant moisture in the soil, $PET = AET$ (Shaw, 1994). On the other hand, when the vegetation is unable to abstract water from the soil, then the actual evaporation becomes less than potential evapotranspiration. Therefore, it is always less than or equal to potential evapotranspiration (PET). Thus, it is found as:

$$AET = PET \quad \text{if} \quad P_m > PET_m$$

Otherwise, $AET_m = P_m + S_{m-1} - S_m$, m stands for month, Where, S_{m-1} and S_m are soil moisture during the month $m-1$ and m respectively.

- **ΔS**-Change in soil moisture. The change in the soil moisture during the month is obtained by deducting the soil moisture of the month under consideration from the soil moisture of the preceding month.
- **SMD**-Soil moisture deficit. Monthly SMD is the difference between PET_m & AET_m
- $S = P - AET - \Delta S_m$
- **TARO**- Total available for runoff. Based on the assumptions of (Thornthwaite and Mather, 1957), 50% of the surplus water that is available for runoff in any month actually runs off, the rest 50% of the surplus is detained in the subsoil, groundwater and channels of the catchment and is available for runoff during the next month. The value is determined, starting from the first month of the water surplus period. The first months surplus is the TARO for that month, and from the surplus, 50% value is detained (D) and carried over to the next month of TARO, and 50% is river discharged (RO). Therefore, the TARO of preceding month is given by the surplus of that month (S_M) plus the detention of last month (D_{m-1}).

Values of the major components of the soil water balance are presented in the Annex table for Moderately deep rooted crop cover (shrub land, Bush land etc.) on clay loam-Silt lome soil with Average rooting depth of 1.25m with an available Average water capacity of 250mm and the remaining indicated under annexes. The calculated result of AEP of the study area is **517.168 mm** which is higher than the perception amount of the area and the value that we get from the turc method is **363mm**. these two methods shows big difference and the Thorntwait-mater metode result is unrealistic. According to David.N, (1990) soil moisture budgeting is developed

for humid climate and has less validate in arid and semi-arid zones and this work best for seasonal patterns of recharge, well developed soil which do not dry completely and when AET is similar with PET with relatively uniform precipitation. Therefore, for the application of water balance calculation in the study area (which is characterized by arid climate) the actual evapotranspiration estimated using Turc formula is more realistic than the water balance method suggested by Thorentwaite and matter.

4.9. SURFACE RUNOFF

Runoff is the component of stream water which is generated from precipitation as flowing water in a basin. Runoff occurs when the rate of precipitation exceeds the rate of infiltration in to a soil. Runoff from a given area due to rainfall depends on climatological and physiographical. The climatological factors that affect the runoff are, type and form of rainfall, evaporation characteristic of the study area, and transpiration. The main physiographic factors on which the runoff characteristics depend on are area and shape, average slope, the permeability of soil and geological characteristics like soil type, land use, position of rock layer and aquifer characteristics, And the presence of depression and natural reservoir in the area.

The study area catchment have no measured flow data because it have not gauged. Therefore the runoff component for water balance of the area was determined using empirical formula of runoff coefficient method (rainfall-runoff relation). The runoff coefficient is the fraction of rainfall converted in to runoff. This method estimates the runoff by multiplying the runoff coefficient to the rainfall depth of the area.

$$R = K * P$$

Where, R = runoff in mm

P = rainfall depth in mm

K = runoff coefficient

Therefore, with the average slope 0.377% and with the type of land uses land cover presented in the catchment, the standard catchment runoff coefficient is 0.08. The total amount of runoff that leaves the study area is the sum of surface inflow from the western highland within the catchment and surface runoff from the plain during *Kiremt* and the *Belg* Rain season and estimated as **32.07MCM**.

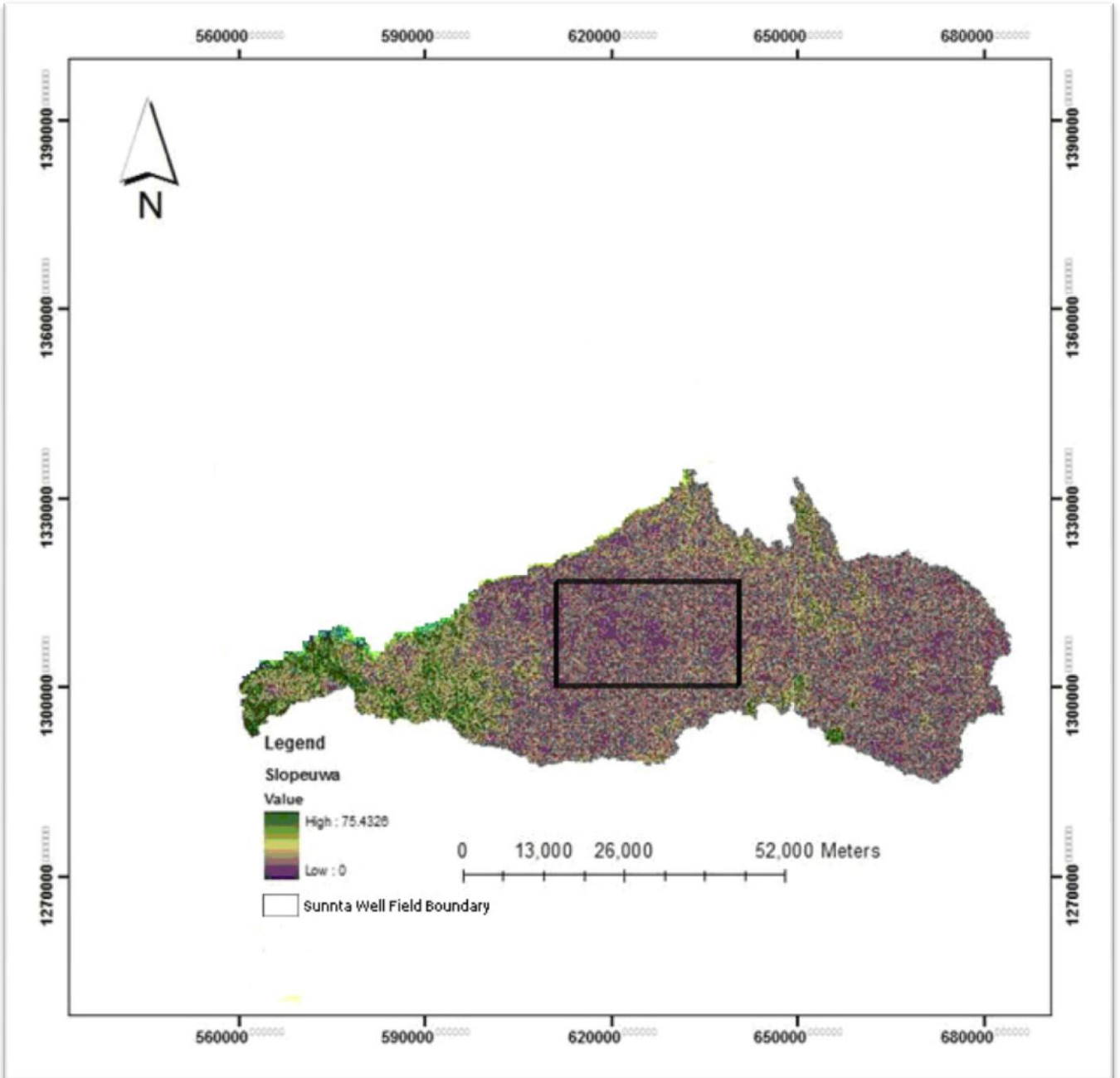


Figure 4.11. Slope map of the study area.

CHAPTER FIVE

5. Hydrogeology

Hydrogeology of Afar region is intimately associated with the geologic history of the rifting including the evolution of the Awash basin. So far there is no clear Picture of the hydrogeology of the region, especially the movement and occurrence of groundwater. The groundwater has highly segmented distribution due to the geological complexity. The presence of variable groundwater chemistry, depth and groundwater occurrence in the region suggests complex groundwater dynamics, often governed by the intensity and attitude of the rift faults and the volcanic stratigraphy and its relation with the various water bodies. Because of disruption of lithologies caused by faults forming the rift, aquifers are often laterally discontinuous. This results in preferential large groundwater movement in regional faults at deeper levels (ADSWE, 2004).

Topography slopes due east from the escarpment towards east where the study is located and it becomes generally flat to undulating with frequent rising fault scarps, volcanic ridges and hills. (see geomorphologic map figure 2.2)

Generally, under localized favorable recharge and topographic conditions, potential groundwater resources would appear to exist in the region.

5.1. Local Hydrogeology

5.1.1. Hydrogeologic Review of the Different Lithologic Units

5.1.1.1. Upper Sandstone

The upper sandstone covers only very small part of the study area so that it is not considered to have significant importance in groundwater accumulation. However, the unit is coarse grained, highly fractured and is tilting towards east. Due to these characteristics the unit has hydrogeologic significance in facilitating percolation and movement of groundwater towards the lowlying area where the study area is located.

5.1.1.2. Ashangi basalts

The Ashangi basalt covers western and elevated part of the study area and it is affected by the rifting activity and is highly fractured tilting towards east, i.e. towards the area under investigation. Due to the high fracturing and tilting of the unit it has hydrogeologic significance

in facilitating recharge and movement of groundwater from the recharge area (the western highland) towards east, i.e. towards the study area. However, the unit is not considered to have significant importance for groundwater accumulation as it is tilting and located at topographically high areas.

5.1.1.3. Andesitic tuff

Like the Ashangi basalt the Andesitic tuff covers western and elevated part of the study area. Being affected by the rifting activity and due to its brittle nature the Andesitic tuff became highly fractured and tilted towards east. Since it is highly fractured and tilted towards east the unit has hydrogeologic significance in facilitating recharge and movement of groundwater from the recharge area (the western highland) towards the study area. However, the unit is not considered to have significant importance for groundwater accumulation as it is tilting and located at topographically high areas.

5.1.1.4. Mabla Rhyolite

The Mabla rhyolite is found at different places mainly at the northeast and south west of the study area and in the middle of the alluvial plain as ridges. Being affected by the rifting activity the Mabla rhyolite became highly fractured and tilted towards east. Because of the high fracturing, the unit has hydrogeologic significance in facilitating recharge, movement and accumulation of groundwater in the study area.

5.1.1.5. Dahala basalt

The Dahala basalt is found mainly at the eastern part of the study area. It is also found at different places in the middle of the alluvial plain forming ridges. The unit is composed of basaltic and rhyolitic flows intercalated with detrital sediments and pyroclasts. Like the other rock units it has been affected by the rifting activity and became highly fractured and it is commonly observed as heaps of detached boulders.

Because of interbedded nature of the unit and the high fracturing, it has hydrogeologic significance in facilitating recharge, movement and accumulation of groundwater in the study area.

5.1.1.6. Recent basalt

The Recent basalt is mainly composed of scoriaceous basalt which is found west of the study area in the middle of the alluvial plain as separate volcanic centers (scoria cones). However, they have

small aerial extent. Like the other rock units it has been affected by the rifting activity and became highly jointed/ fractured.

Because of their smaller aerial extent they are not considered to have significance in accumulating potential groundwater, but due to the presence of primary openings (vesicles) and high fracturing, this unit has hydrogeologic significance in facilitating recharge and movement of groundwater.

5.1.1.7. Fluvio-lacustrine deposit

The vast plain area covering more than 55% the study area is Fluvio-lacustrine deposit. It is composed of sediments having variable sizes ranging from pebble to Sand and at some places it contains clay layers with calcite concretions.

Actual thickness of the deposit is not known, but borehole logs of deep wells in the study area show deposit thickness of 34.5 to 245m. Owing to the flat topography areas covered with thick coarser deposits in general have hydrogeologic significance in facilitating infiltration, movement and accumulation of groundwater and are considered to have higher productivity than those covered with finer ones.

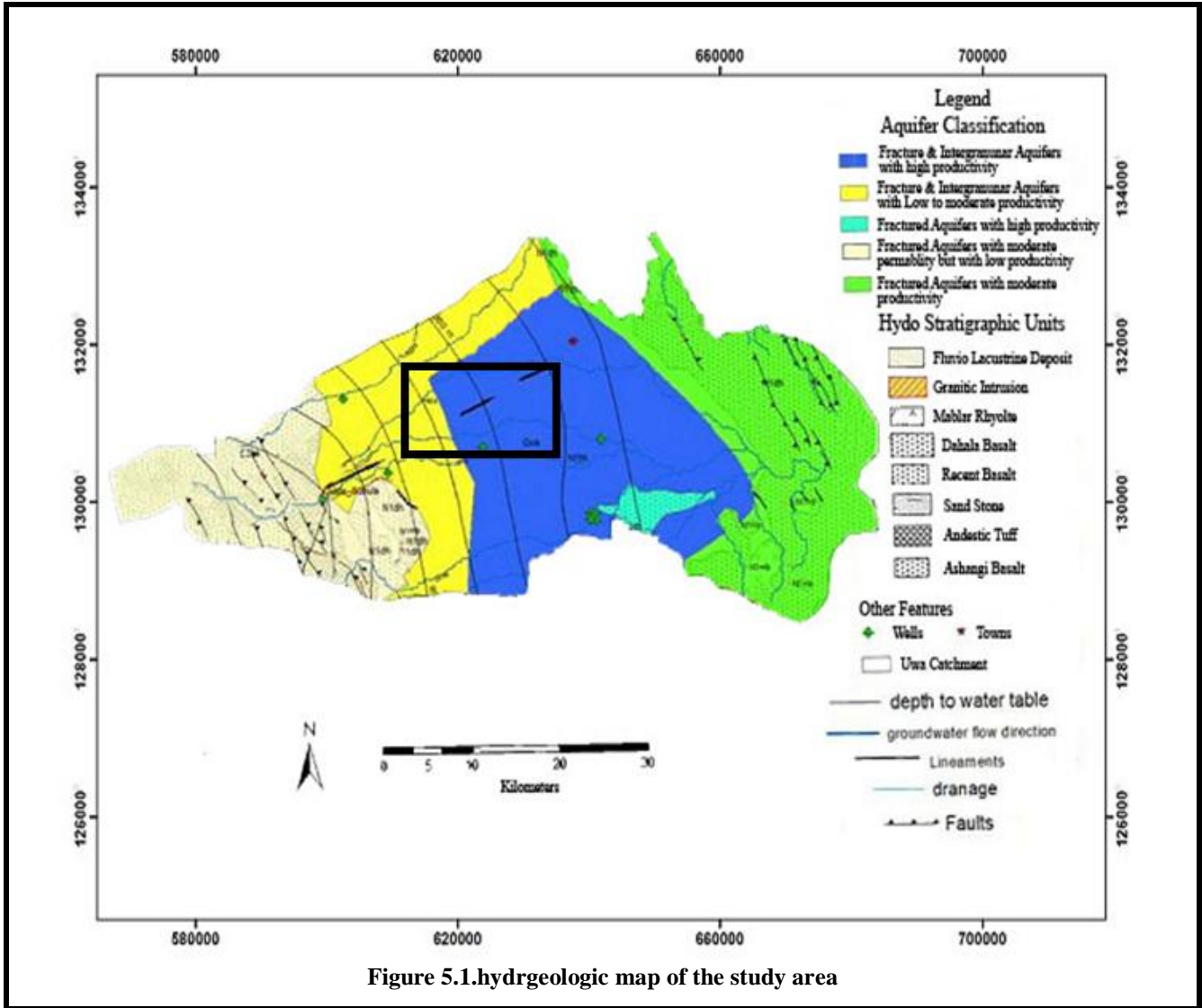


Figure 5.1. hydrgeologic map of the study area

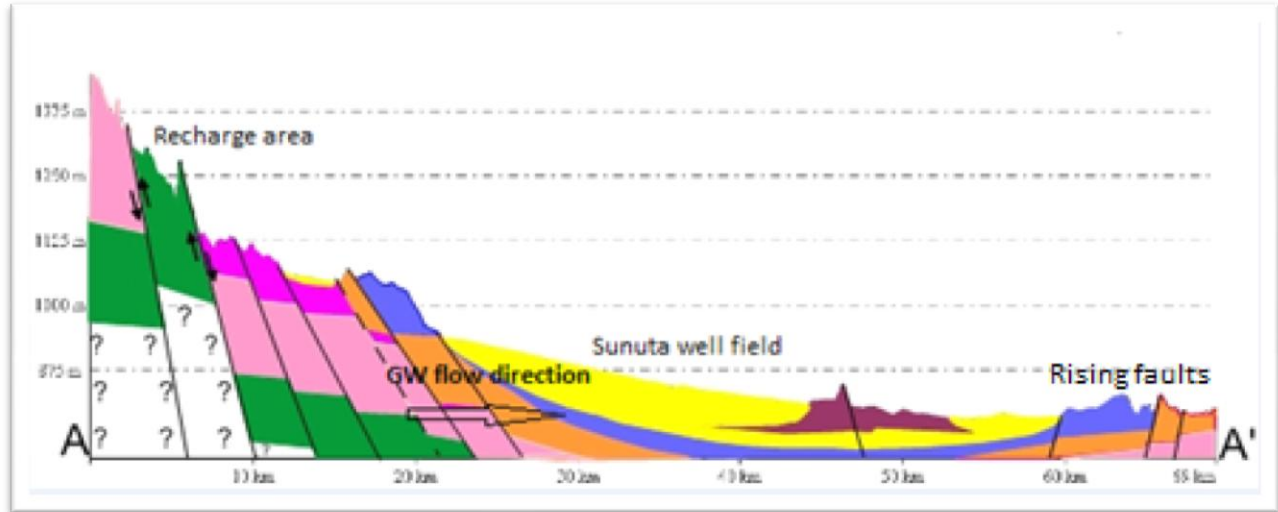


Figure 5.2. Hydrogeological cross-section of the study area.

5.2. GROUNDWATER HYDROLOGY

5.2.1. GROUNDWATER RECHARGE-DISCHARGE MECHANISM

The groundwater flow in the study area is significantly influenced by geomorphology, geological structures the nature and orientation of faults, fractures, joints and lineament, availability of impermeable layers and hydraulic property and continuity of the aquifers,

In order to trace out the groundwater flow directions and identify the recharge and discharge areas several parameters are considered. The following are the main parameters and data used:-

- Slope gradient and geomorphology
- Geological structures
- Hydrogeochemical data

The study area is highly affected by tectonic structures that are associated with the formation of the Afar rift except the western part where it is more or less stable. The major tectonic structures are NW- SE trending faults, escarpments that separate the western plateau from Afar rift and resulted in tilting blocks of tertiary basalts, and controls the regional groundwater flow by making regional groundwater divide. Those faults create the pattern of groundwater flow from western escarpment, towards East to the Afar rift floor.

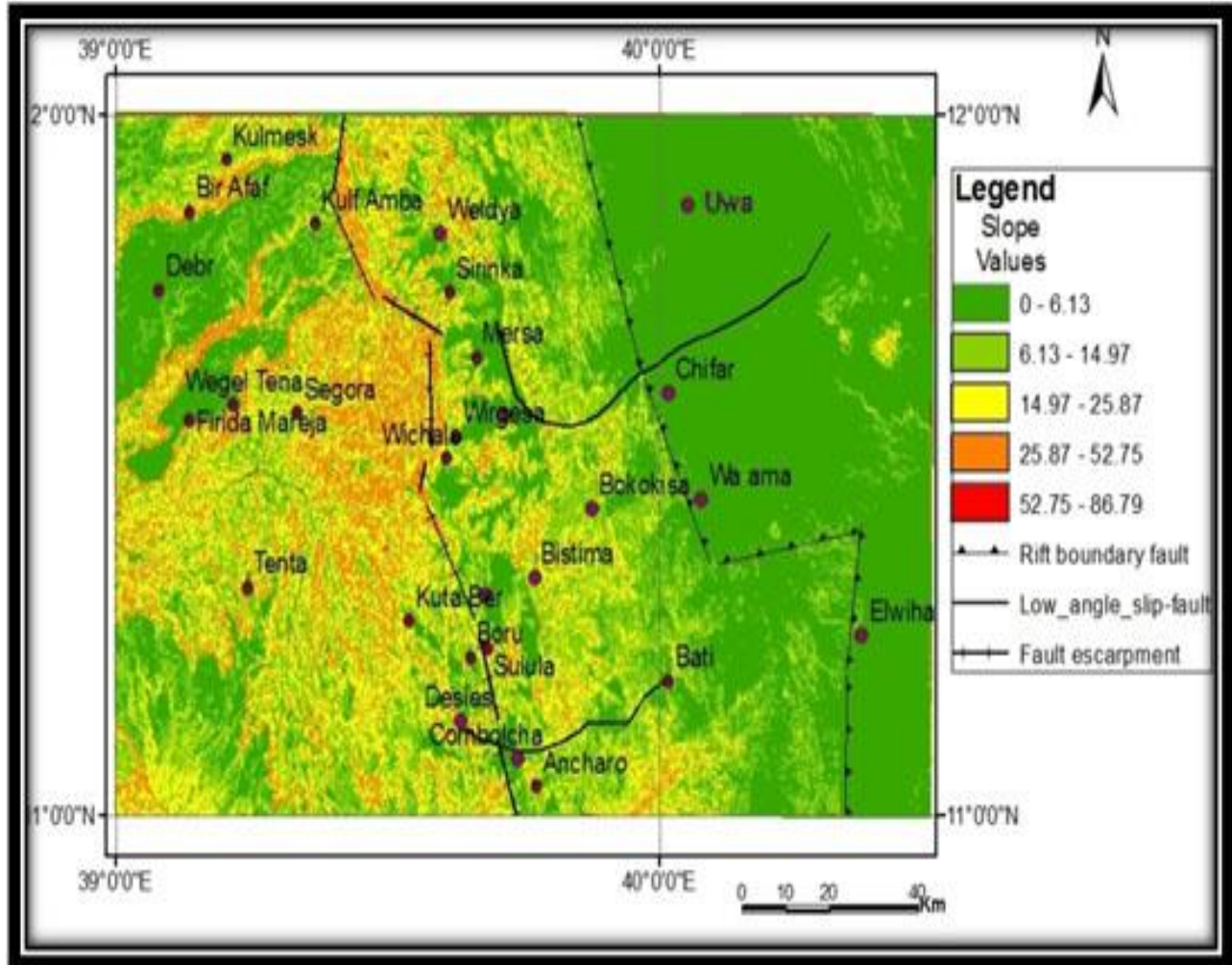


Figure.5.3. Slope map of the study area and the associated western margin and highland showing the slope variation between the western highlands and the afar rift floor indicating the possible ground water flow direction.

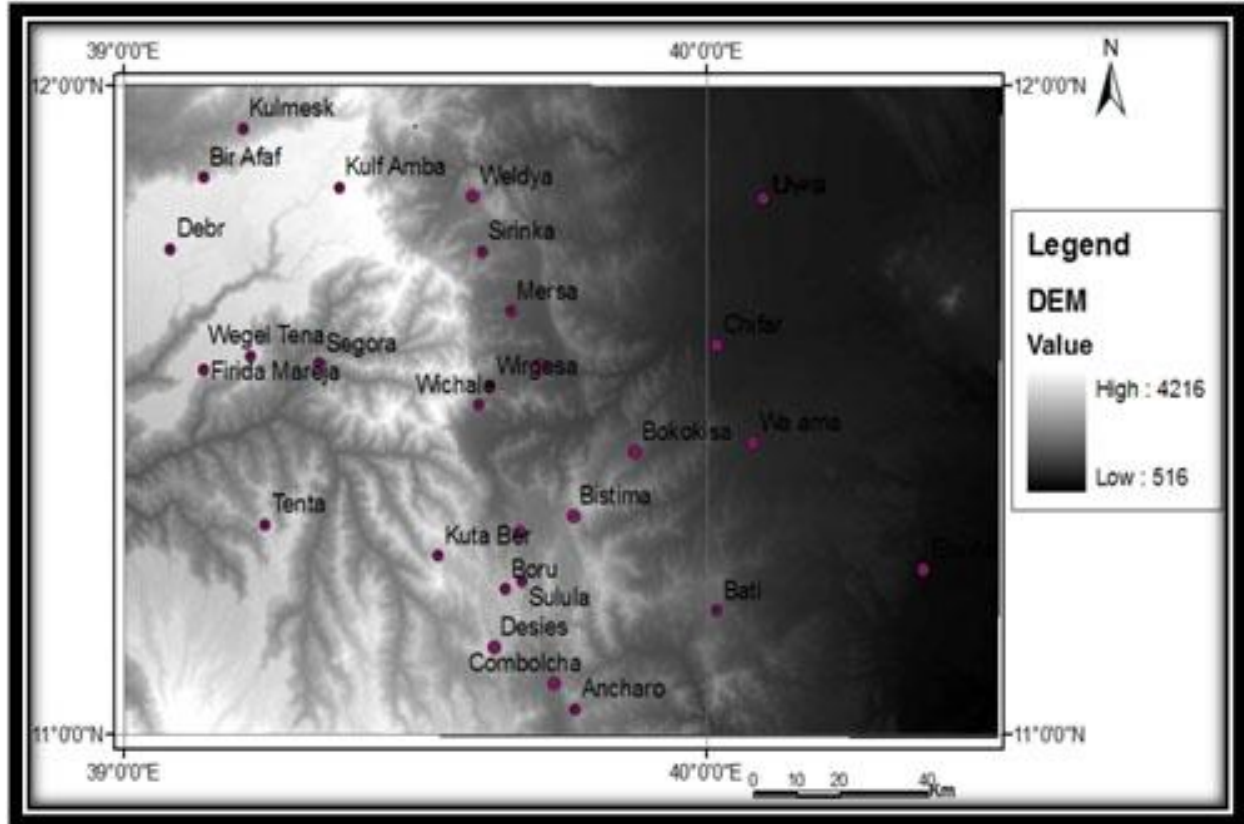


Figure 5.4. Digital elevation model map of the study area and adjacent western margin and highland.

Identification of the groundwater flow as well as recharge and discharge condition is also supported by the hydrochemical data especially the distributions of TDS. The high elevated areas have low TDS values than the relatively low laying lands hence they are considered as the recharge areas whereas the Afar rift floor where the well field is located have high value of TDS which is the discharge area.

5.2.2. GROUNDWATER FLOW DIRECTION

In area where the water table or potentiometric surface has a shallow gradient, the groundwater contours will be spaced well apart. If the gradient is steep the groundwater contour will be closer together. Groundwater will flow in the general direction that the water table or potentiometric surface is sloping (Fetter, 2001). A groundwater flow line is an imaginary line that traces the path that a particle of groundwater would flow as it flows through an aquifer. Flow lines are helpful for visualizing the movement of groundwater. Flow lines will cross equipotential lines at right angles.

The groundwater contour map (Figure5.5) of the study area was constructed using the field inventory data that have static water level and elevation above sea level. The Study area groundwater flow is governed by the prevalent geologic structures and intruded volcanic mounds and hills (under alluvial deposits). According to some studies conducted in the region at few areas (Currey, 1973; UNDP, 1973; Halcrow, 1989; WWDSE, 2000, 2003), the regional groundwater flow is evidently from the western escarpments towards east in to the rift valley. From drilled boreholes data the general groundwater flow direction in the study area is confirmed to be from SW- NE.

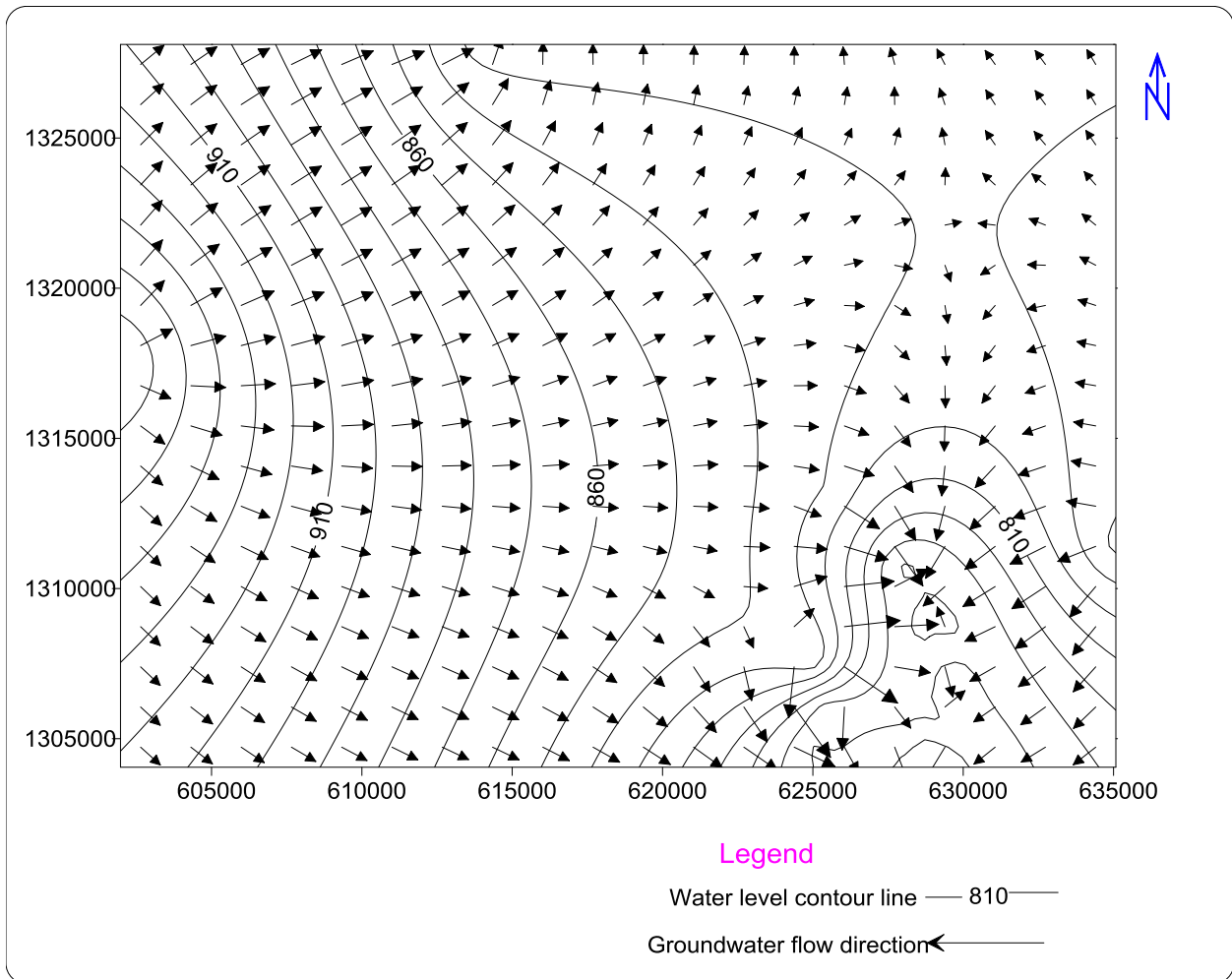


Figure5.5. Groundwater level contour map show interpreted groundwater flow directions.

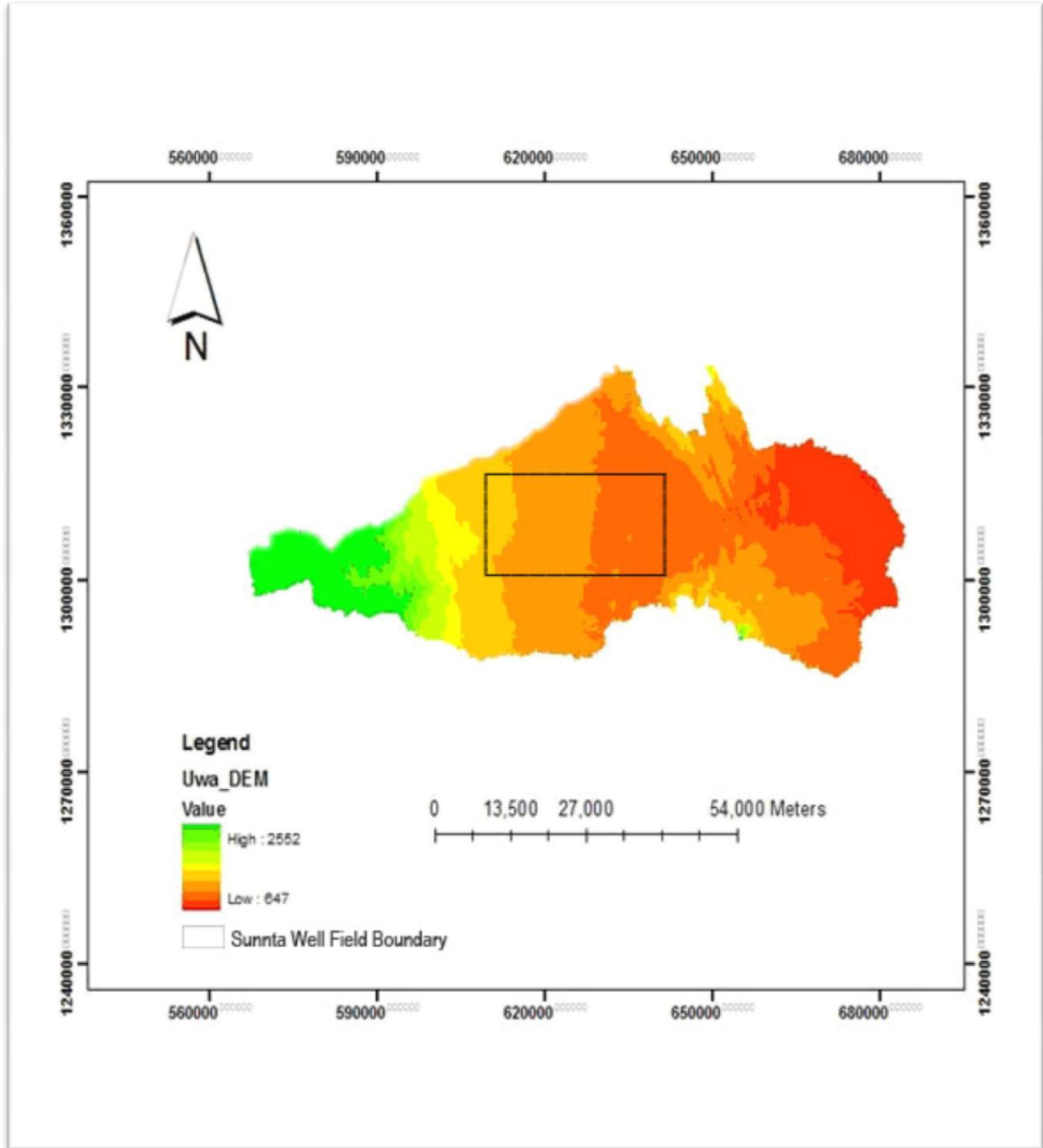


Figure5.6. digital elevation model of the study area catchment .

5.3. HYDRAULIC CHARACTERISTICS OF AQUIFERS

5.3.1 TYPES OF AQUIFER

The water bearing materials in the study area are unconsolidated thick sediment and interbedded fractured basaltic flows. The aquifers in all the wells are made up of both the volcanic rocks and the alluvial deposits. The basalts represent highly permeable zones characterized by pore spaces resulting from lava flows, fractures and joint openings. The acidic rocks such as the rhyolite, tuff and welded tuffs are also characterized by open fractures and joints forming porous and permeable layers. The aquifer thickness was determined mainly based on drilling data. Length of the screens is also taken in to account in determining aquifer thickness.

Accordingly, the aquifers are found to be at different horizons of the sediment and the volcanics in the depth range of 62 to 257 m and the average aquifer thickness in the study area appears to be about 64 m. The total number of wells inventoried in the study area are 50 and out of them fifteen wells have relatively full pumping test data including geological descriptions. In this section those wells with pumping test data have been given the main emphasis in analyzing the aquifer system. The data were compiled by different governmental and nongovernmental organizations such as brotherhood drilling plc, TAM Geo-Engineering Plc, Afar water work design and supervision enterprise and Amhara water work design and supervision enterprise.

5.4. AQUIFER CHARACTERISTICS

The nature and distribution of aquifers and aquicludes in a geologic system are controlled by the lithology, stratigraphy and structures of the geologic deposits and formations (Freeze & Cherry, 1979). The aquifer system in the study area could be broadly classified as the unconsolidated thick sediment aquifers and volcanic aquifers. From borehole loge the type of aquifer is mainly semi-confined aquifer. Aquifer Classification was done from the information of surface geology, borehole lithologic log data, and pump test data. Based on these information major units are described below.

5.4.1. UNCONSOLIDATED SEDIMENT AQUIFERS

Fault block valleys are created by down-dropping of large crustal pieces along faults. Erosion of the mountains creates sediments that is carried in to the valley, forming talus slopes, alluvial

fans, and alluvial and lacustrine deposits (Fetter, 2001). The sediments like alluvial fan gravels, and channel deposits can be very coarse, with high hydraulic conductivities and lacustrine clays, on the other hand can be fine, with low conductivity. Gravel aquifers confined by lacustrine sediment are quite typical of such basins (Fetter, 2001). According to Fetter, in semiarid to arid region groundwater is recharged by precipitation in the mountains, bed rock beneath the mountains may receive direct recharge and then feed the valley-fill sediments. Stream originating in the mountains may also lose water to the alluvium when the flow goes across the rift floor bottoms.

The fluvio- lacustrine sediments occupy 55% of the study area. Geological logs of the boreholes show that the thickness of the sediments of the Sunnuta plane vary from an average of 139.75m with a maximum 245m to a minimum 34.5m.

5.4.2. VOLCANIC ROCK AQUIFERS

The storage and transmission of groundwater in the volcanic rocks largely depends on type of porosity and permeability formed during and after the rock formation. This group includes various lithological units belonging to different series, but from the hydrogeological point of view, they are grouped together and described here as the volcanic aquifers. Recent basalt, Ashangi basalt and Dahala basalt, Malbala rhyolite and Andestic tuff are members of this unit. Due to the prevailed tectonic events in the past related to rift forming process, these formations are moderately to highly fractured. The volcanic rock that forms step and elevated mountainous terrain position has a very limited recharge capacity resulting in high surface runoff to the sunnuta plane. This recharge-discharge condition in the elevated volcanic is revealed by the absence of high yielding springs in the immediate escarpment zones and foot hills bordering the sunnuta plain. Several large springs emanate from big fractures and join together to form Perennial Rive to the Rift floor where the well field is located. The volcanic rocks in the area are also the basal formation beneath the alluvial cover, in some cases they are encountered at shallower depth but later alteration has filled the fractures with secondary minerals making them poor aquifers.

Table 5.1.well log of sw-35

Geologic Log			
Depth (m)		Lithology	Geologic Description
From	To		
0 m	6 m	Alluvial Sediment	<u>Clay</u> :- Clayey Silt and Silty Clay
6 m	16m		<u>Sand</u> :-
16 m	28m		<u>Sand</u> :- Clayey sand
28m	32 m		<u>Sand</u>
32m	40 m		<u>Sand</u> :- With minor silt and clay
40 m	60 m		<u>Sand</u> :- with minor silty clay between 42 and 44m, and silty sand between 56m and 60m
60 m	78 m		<u>Silt</u> :- With sand between 66m and 68 m, and clayey silty sand 68m to 78m
78 m	86 m		<u>Sand</u> :- Poorly sorted medium to coarse grain sand
86 m	100 m		<u>Sand</u> :- Clayey Silty Sand
100m	130m		<u>Silt</u> :- Clayey, sandy silt and silty clay between 112m & 114m, and 128m and 130m
130m	138m		<u>Sand</u> :- With little clay
138m	148m		<u>Clay</u> :- Sandy silty clay
148m	154m		<u>Sand</u>
154m	190m		<u>Silt</u> :- Clayey, sandy silt and sandy silty clay
190m	196m	<u>Sand</u> :- clayey sand and sand 192m to 196m	
196m	202m	Volcanic	<u>Basalt</u> :- Moderately Weathered
202m	206m		<u>Sand</u> :- clayey sand
206m	235m		<u>Basalt</u> :- Weathered basalt with scoria between 220m and 224m

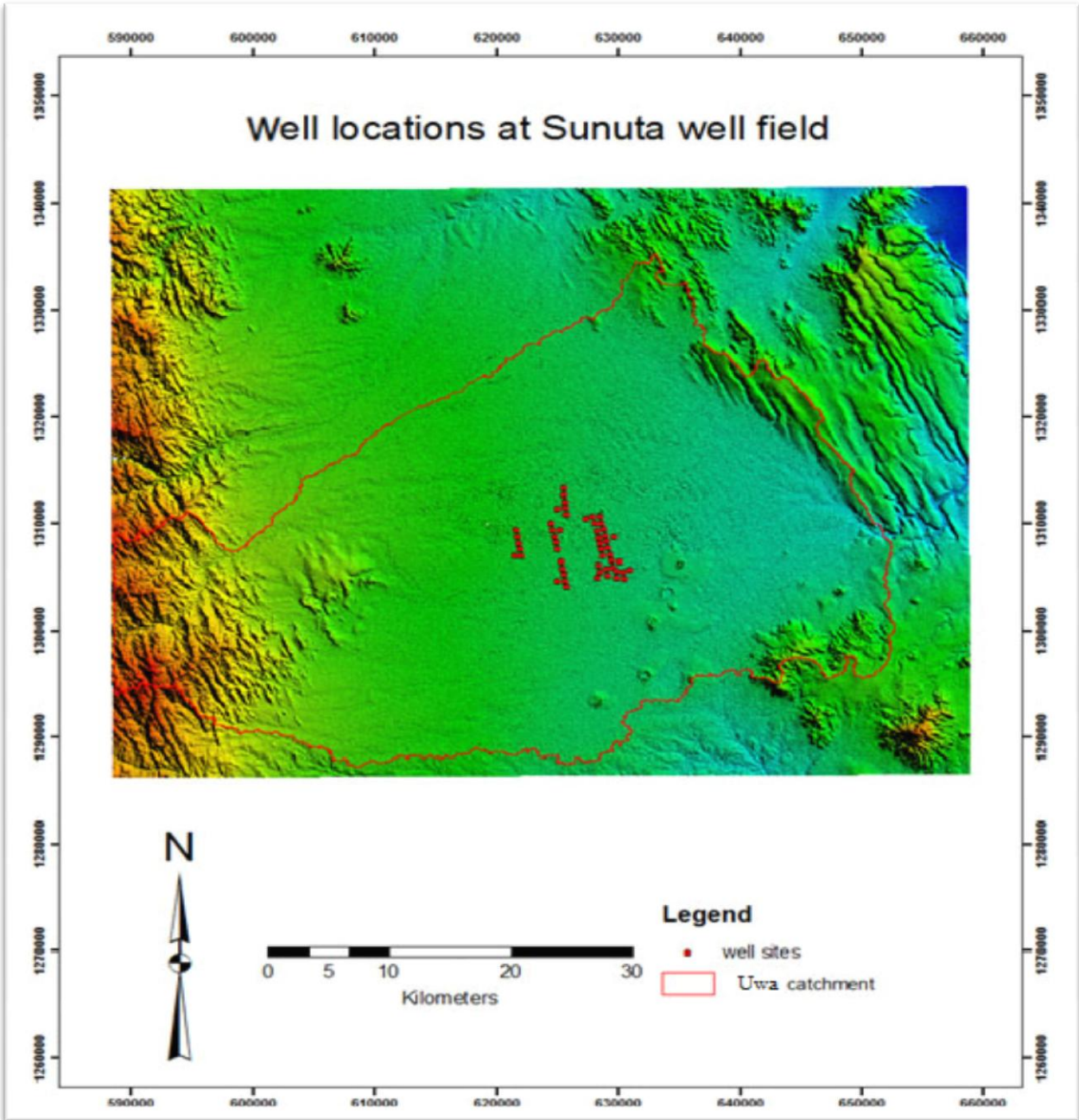


Fig5.7. Location map of boreholes at Sunuta well field

5.5. ESTIMATION OF HYDRAULIC PARAMETERS

Pumping test is a critical task where very important information and data are collected regarding the overall groundwater condition of the given area. The subsurface water condition may not be defined properly apart from conducting pumping test operation, the respective evaluation and analysis of results.

The role of pumping tests in evaluation of aquifer parameters and boreholes yield is very significant. The principle of a pumping test is that if we pump water from a well and measure the discharge of the well and the drawdown in the well and in piezometers at known distances from the well, we can substitute these measurements into an appropriate well-flow equation and can calculate the hydraulic characteristics of the aquifer. Pumping test is one of the basic in situ filtration tests, which is conducted in borehole to characterize the hydraulic properties of aquifers. Analysis of pumping test data depends on the following factors, that are objective of the test, construction scheme, phase of study, duration of test, penetration of the aquifer and flow condition.

5.5.1. Constant Rate Test

This test is performed by pumping the well with a significant length of time with a constant rate. The main purpose of the constant rate discharge test is to determine the optimum sustained design yield of the well for permanent pumping of the aquifer without mining it. We can also calculate the transmissivity (T), hydraulic conductivity (K) and storativity (S) of the well.

5.5.1.1. TRANSMISSIVITY (TD or T)

It is the product of the average hydraulic conductivity K and the saturated thickness of the aquifer (D). It is the rate of flow under a unit hydraulic gradient through a cross – section of unit width over the whole saturated thickness of the aquifer (Kruseman and Ridder.1994) the transmissivity of the Sunnuta well field resulted from the constant rate test ranges from **144.00 m²/d -5533.56 m²/d** with average value of **2543.86 m²/d**. For the purpose of qualitative analysis the transmissivity values of the wells can be categorized into five groups as follows.

- very low: <100m²/d

- low : 100m²/d to 250 m²/d
- medium: 250m²/d to 500 m²/d
- high : 500 m²/d to 1000 m²/d
- very high: >1000 m²/d

Aquifers with transmissivity greater than 149.2m²/d can be sustain irrigation development (Johnson, 1966, as cited Sileshi Mamo, 2007). Accordingly the average value of Sunuta well field categorized as very highy transmissivity.

5.5.1.2. HYDRAULIC CONDUCTIVITY (K)

Hydraulic conductivity is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (Kruseman and Ridder 1994). It determines the ease by which water can move through aquifers. It therefore, determines the productivity of the aquifer. The conductivity of the Sunnta well field resulted from constant rate test ranges from **2 m/d -77 m/d** with average value of **39.5 m/d**.

For the purpose of qualitative analysis the Conductivity values of the wells can be categorized into different groups as follows.

- Low: <5 m/d
- Medium: 5-10 m/d
- High: 10-20 m/d
- Very high: >20 m/d

Accordingly the above classification Average conductivity value of sunnuta well field is categorized as very high.

5.5.1.3. SPECIFIC CAPACITY

The specific capacity of a well is the yield per unit drawdown, and is determined by dividing the pumping rate at any time by the drawdown at the same time. The specific capacity of a well depends both on the hydraulic characteristics of the aquifer and on the construction, pumping rate, and other features of the well. Specific capacity of the well field resulted from constant rate taste ranges from **85.89 M3/day/m -5040 M3/day/m** with average value of **890.81 M3/day/m**

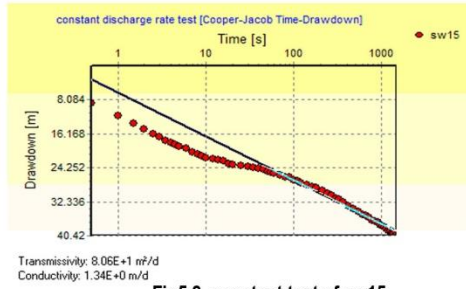


Fig5.8. constant test of sw15

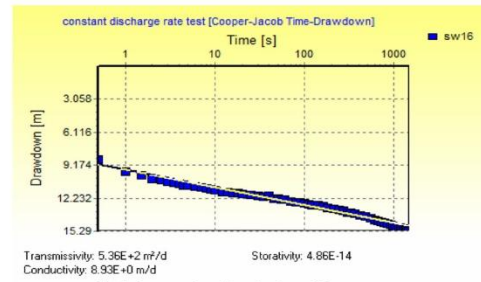


Fig5.9. constant test of sw16

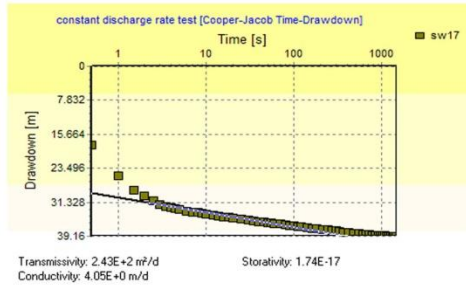


Fig5.10. constant test of sw17

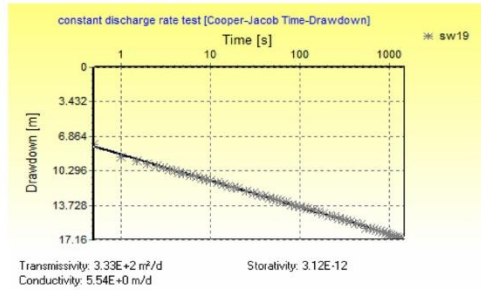


Fig5.11. constant test of sw19

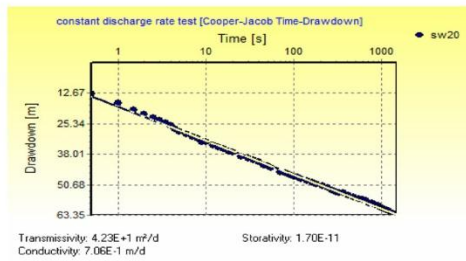


Fig5.12. constant test of sw20

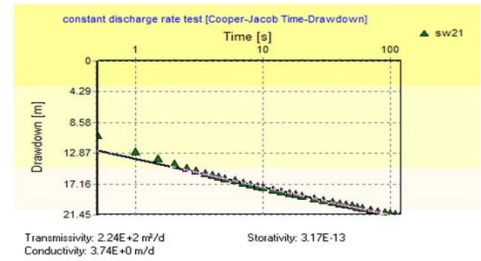


Fig5.13. constant test of sw21

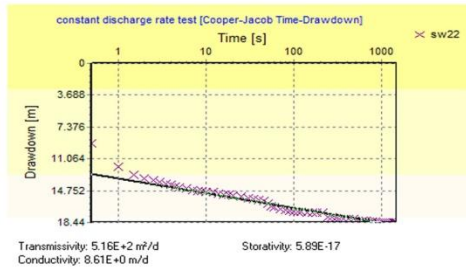


Fig5.14. constant test of sw22

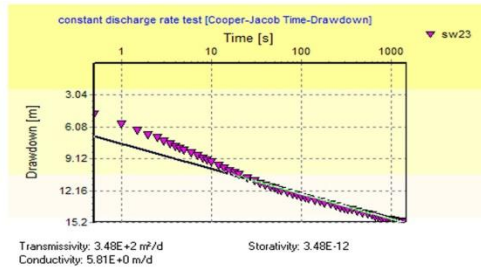


Fig5.15. constant test of sw23

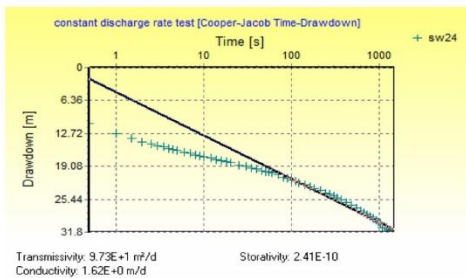


Fig5.16. constant test of sw24

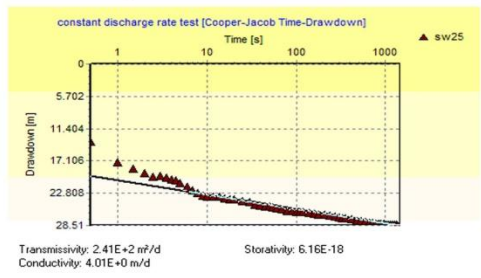


Fig5.17. constant test of sw25

5.6. GROUNDWATER RECHARGE ESTIMATION

The amount of water that may be extracted from an aquifer without causing depletion is primarily dependent upon groundwater recharge. Thus, a quantitative evaluation of the spatial and temporal distribution of groundwater recharge is a prerequisite for operating a groundwater resources system in an optimal manner. When estimating groundwater recharge it is essential to proceed from a good conceptualization of different recharge mechanisms and their importance in the study area. Besides this conceptualization the objectives of the study, available data and resources, and possibilities of obtaining supplementary data should guide the choice of recharge estimation methods (Sophocleous, 2004).

5.6.1. WATER BALANCE APPROACH

Water balance represents the hydrological gains and losses of a given system (reservoirs, column of soil, aquifer, river basin, etc) over a specific period of time. Quantification of the rate of natural groundwater recharge is a basic pre-requisite for efficient groundwater resource management. Water balance models were developed by Thornthwaite (1948) and revised by Thornthwaite and Mather (1955). The method is essential procedure, which estimates the balance between the inflow and outflow of water. Generally, water balance has the following form:

$$\text{Inflow} = \text{outflow} \pm \text{change in storage}$$

This could be rewriting for the calculation of groundwater recharge as follow

$$\text{Groundwater recharge} = (\text{precipitation} + \text{surface water inflow} + \text{imported water} + \text{Groundwater inflow}) - (\text{Evapotranspiration} + \text{reservoir evaporation} + \text{surface water outflow} + \text{exported water} + \text{Groundwater outflow} + \text{withdrawal}) \pm \text{Change in storage (Fetter, 2001)}.$$

The main purpose of this computation is to make a quantitative evaluation of the amount of water that percolates in to the ground to recharge the groundwater circulation occurring in the investigating area. Therefore, assumption made to derive the water balance equation for the study area, are summarized as follows:

- a) Since the computation is made annually, net change of the soil moisture and groundwater storage is assumed to be zero.
- b) The area is part of the regional groundwater flow system and groundwater is not in closed system. Therefore, groundwater inflow from adjacent basin or area is equal to groundwater outflow in the adjacent basin or area.

For a long term calculation on annual bases the above equation could be rewritten as follows:

Infiltration (recharge) = Precipitation –(Actual Evapotranspiration + surface outflow) ± Change in storage.

As explained on the above change in storage is assumed to be zero.

The annual basin precipitation as calculated using isohythal method is found to be **497.5mm (400.9MCM)** the total area of the catchment is 659.7km².

The annual actual evapotranspiration for the catchment computing from Turc method is found to be **363mm (292.56MCM)**. The annual surface outflow is approximated to be **32.07MCM**.

$$I = P - (AET + Q) = 400.9\text{MCM} - (292.56\text{MCM} + 32.07\text{MCM}) = 76.27\text{MCM}$$

From the water balance equation we found that **76.27MCM** water recharge annually that is 19% of the precipitation recharge the aquifer, 72.9% loss as AET and 8% runoff.

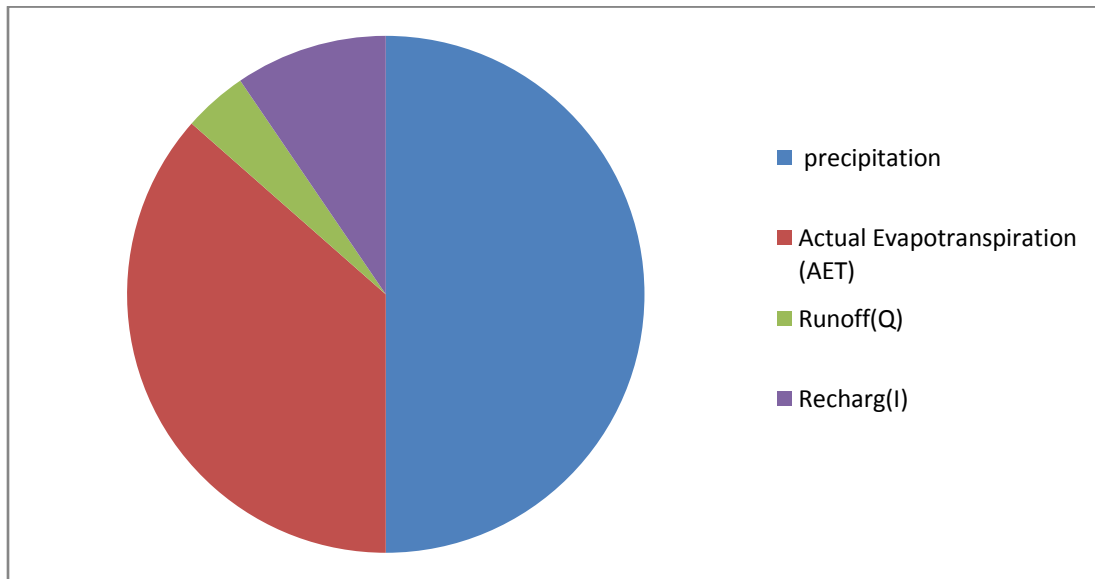


Figure 5.18 pie diagram showing hydrological gains and losses of Uwa catchment over a specific period of time.

CHAPTER SIX

6. Hydrogeochemistry

6.1. General

The main factors that control the groundwater chemistry are lithology, structure of the rock strata, climate, topography, chemistry of rainwater, biochemical effects, subsurface resident time of water (Hem, 1989). In the study area the water geochemistry is mainly controlled by the occurrence of basic and acidic volcanic rocks, major tectonic discontinues, soil type and topographic setup.

6.2. Ground water sampling

The groundwater chemical behavior changes due to, displacement and replacement reaction between ions, duration and interaction between rock and water type of rock that the water interact with for such reasons. The groundwater quality analysis was conducted on the different geological and geomorphologic setup of the study area. During field work the major physical parameters of water like PH, Temperature and Electric Conductivity (EC) have been measured. After conducting the measurement of physical parameters water samples are taken from different water manifestation sources for complete chemical compositions analysis in laboratory. The analysis for major cations and anions was done in Addis Ababa University Analytical laboratory and (WWDSE) Water work design and supervision enterprise laboratory. For the detail hydrogeological and Hydrogeochemical investigation of the study area a total of 41 samples data were collected from (AWWDS) Amhara water work design and supervision enterprise and from ministry of agriculture. For fulfill the gap where there where data scarcity, seven water samples are taken from different part of the study area like hand pump well, hand dug, river water and borehole.

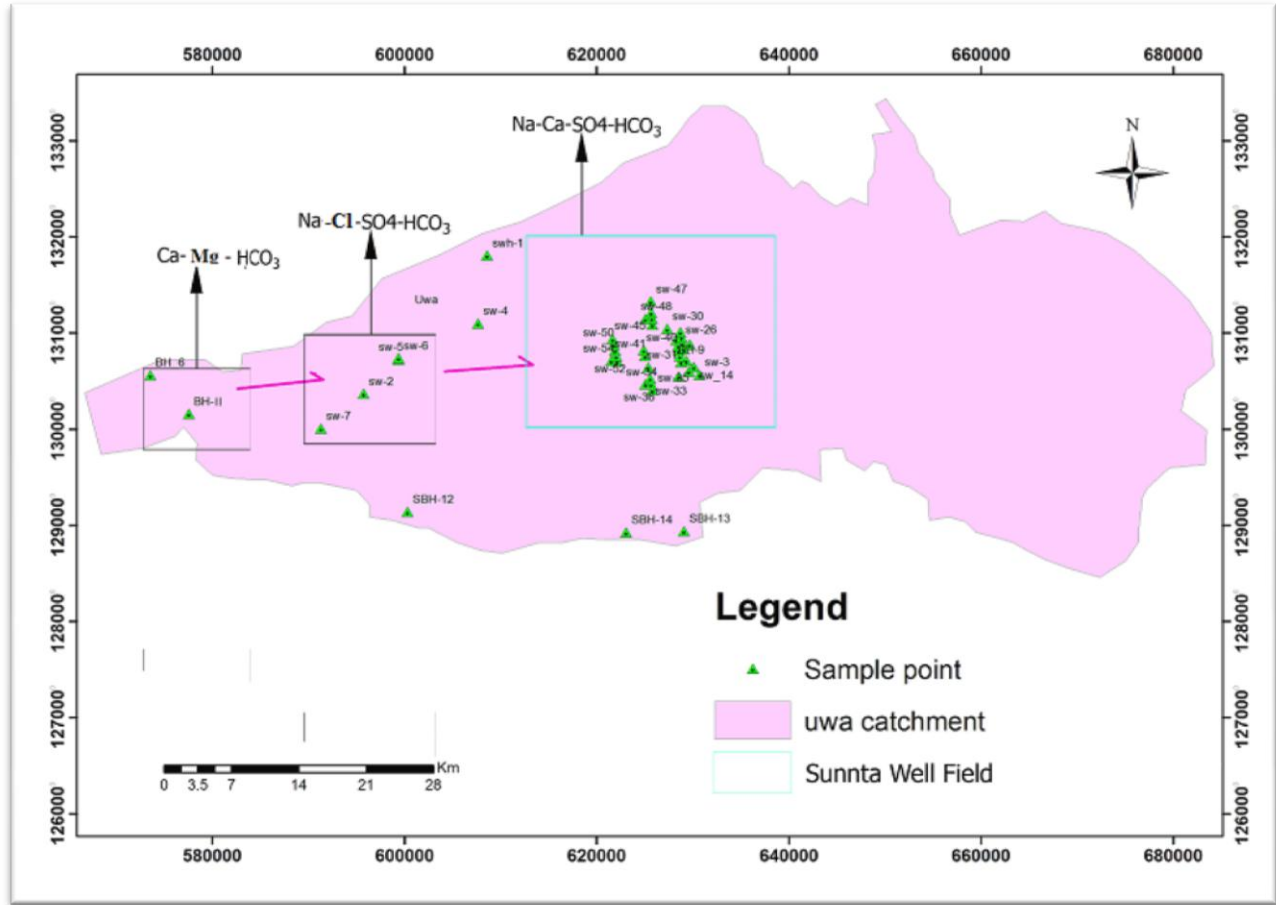


Fig.6.1.water sampling point

6.3. Classification of Natural Water

Using the result of the laboratory analysis of samples we check the reliability of result using cation-anion balance. It is calculated by converting the sum of all anions and cations from mg/l into meq/l and plugging the results into the absolute value of the following formula.

$$\text{Electro neutrality} = [(C-A)/(C+A)] * 100\%$$

Where A = Concentration of anions in meq/l

C= Concentration of cations in meq/l

Table6.1. Reliability of samples

Electro neutrality	Number of samples	Percent (%)	Remark
<5	29	68.29	Excellent
5-10	10	24.39	Good
>10	2	4.87	Poor

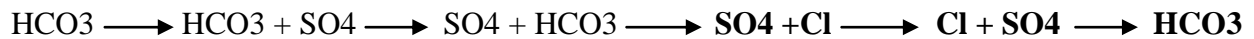
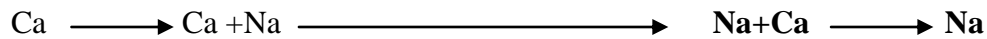
As shown in the above Table among the total samples of 41- 39 are reliable whereas 2 sample is not reliable. Therefore 39 reliable samples are entirely used in subsequent processing and interpretation.

Table6.2. Summary of statistics of the groundwater sample result from the recharge area.

Summary statistics of the groundwater sample result from the recharge area				
Constituent	Unit	Minimum	Maximum	Mean
EC	µS/cm	611	835	717
TDS	mg/l	548.83	742.89	663.14
PH		7.23	8.22	7.76
Ca ⁺²	meq/l	0.68	6.56	2.68
Mg ⁺²	meq/l	0.41	5.34	1.85
Na ⁺	meq/l	0.73	32.31	6.06
K ⁺	meq/l	0.01	1.59	0.21
HCO ⁻³	meq/l	1.32	5.99	7.22
NO ⁻³	meq/l	0.44	49.67	16.68
Cl ⁻	meq/l	0.51	8.09	2.94
F ⁻	meq/l	0.06	2.66	0.92
SO ⁻² ₄	meq/l	0.20	9.14	2.31
SAR	Meq/l	0.76	7.12	3.95

6.4. Geochemical Evolution

The particular characteristics and contrasts in the chemical composition of groundwater is a result of different origins and dynamics of water in the aquifer, different lithologies intersected materials, variable degree of interaction between groundwater and the field, water mixture of different backgrounds (A. Clay, et al. 2004).The groundwater in volcanic aquifers unconsolidated aquifers are believed to receive their recharge form adjacent mountains and western highland and also from direct precipitation. The recharge from those sources infiltrates and then percolates through inter granular spaces, fractures, joints and weathered surfaces. Along its flow path the groundwater will dissolve different minerals and substances and being enriched and/or depleted by different chemical constituents. The parent rocks of the unconsolidated sediments are different volcanic rocks including basalt, rhyolite and volcanic tuff and ash. Accordingly the groundwater chemistry shows significant variation throughout the flow direction. In addition the groundwater of the study area is also affected by climatic conditions. The hydrochemistry of shallow aquifers on the unconsolidated sediments are dominated by climatic effect while the deep fractured aquifers are dominated by lithologic effect. . In the study area the chemical evolution show a major ion change process along flow path. From piper plot diagram the evolution sequence shows change is as follows.



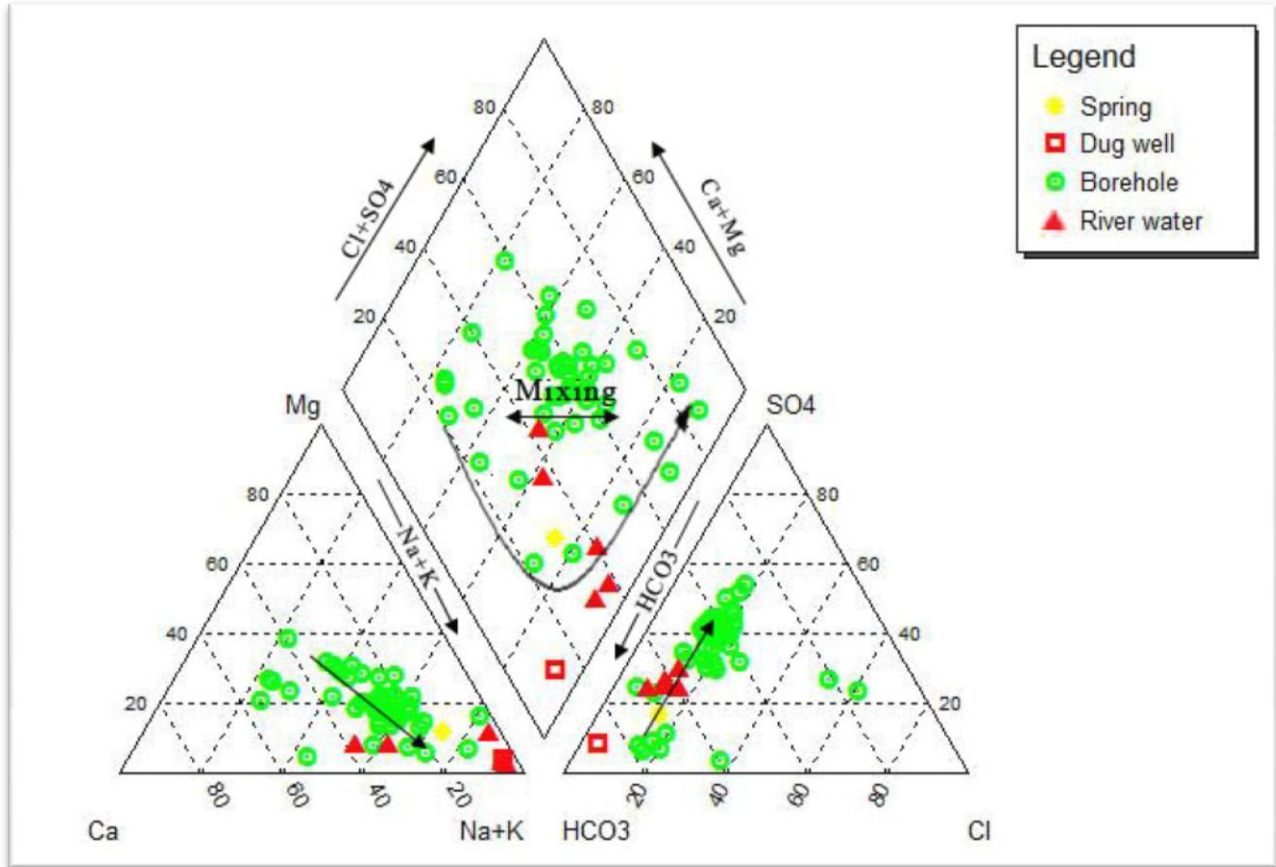


Figure 6.2. Piper diagram of natural water showing the geochemical evolution along flow path

In (figure 6.2) piper plot shows the evolution of ions, the arrows show the evolution from Ca and Mg to Na and HCO₃ to Cl and SO₄ types. In additions on the diagram samples along the mixing line are indicators of mixing between different hydrologic compartments. The groundwater flow along its flow path changes from calcium and bicarbonate rich to sodium and sulfate rich water down to the discharge area. The line of mixing indicates that the availability of some direct recharge from stream flow and precipitation which is believed to be the main recharge of groundwater of the study area. (Seifu Kebede, 2010) stated that Isotopic Evidence show that there is no strong evidence for the existence of a major subsurface groundwater link between the deep thermal groundwater of Afar and the present meteoric recharge of the NWP. However infiltration from evaporated flood waters and wadis draining the escarpment seems the major sources of recharge in Afar. as seen from the result of the water balance in chapter Four the annual amount of precipitation specifically in the study area (sunnuta well field) is very low due to the climate condition resulting in a very low perception but in the catchment (Uwa) were

sunuta wellfield is located receive high precipitation on the part located in the western escarpment around sirinka. Due to difference in slope (see fig.4.11) the water that came from precipitation on the western escarpment (un fractured volcanic mountains) run down through streams to the rift floor where the well field is found and percolate to the ground. The study area is characterized by very potential groundwater and one of this sources is confirmed by the geo-chemistry result plotted on the piper diagram. The following picture shows adding of water through intermittent streams and Perennial River from the Western escarpment during summer time.



Plat 6.1. uwa river on the western escarpment (riecharge area)



Plat 6.2. uwa river daying around the sunuta plane (wellfield)



Plat 6.3. duba intrmitent stream



Plat 6.4. duba intermittent stream showing the bridge is collapsing(because the huge amount of flood at summer time that comes from western escarpment).



Plat 6.5 uwa river showing bridge collapses because of flood in summer time.

6.5. Hydrogeochemistry of sunuta wellfield

6.5.1. EVALUATION OF PHYSIOCHEMICAL PARAMETERS

6.5.1.1. PH

The PH value ranges from 6.86 to 8.15 and has a mean and median value of 7.46 and 7.38 respectively. Indicating that it has a normal distribution. All tested samples have PH greater than 7.0 except sw-44.

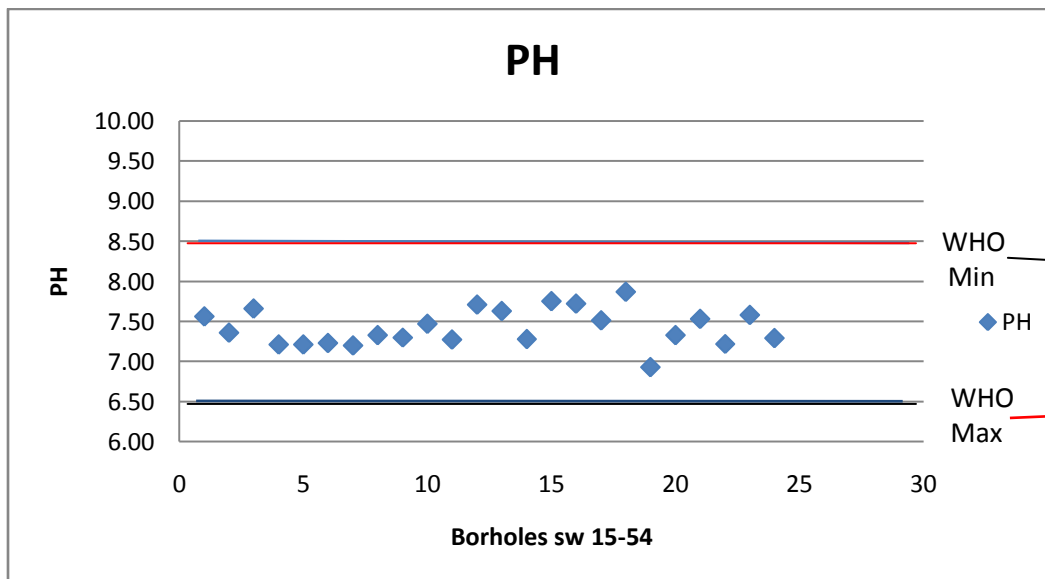


Figure 6.3 PH value of Sunnuta well field

6.5.1.2. ELECTRICAL CONDUCTIVITY (EC)

Electrical conductivity is the ability of a substance to conduct electric current (Hem, 1985). The presences of charged ionic species in water make it conductive. In other words, EC is a measure of the total concentration of ion. Conductance is expressed as micro Siemens, and is used as an indirect measure of TDS (mg/l). The conductivity of the groundwater in the well filed ranges from 580 μ S/cm to 1321 μ S/cm(see table 6.4). Higher conductivities are observed in sunnuta wells fields when compared to those located at the western escarpment(recharge area). This increase in conductivity could be associated with the geology, the ground water flow direction and possible evaporation. The groundwater was found to flow from the western escarpment towards the well filed. Generally, dissolved solid concentrations in groundwater increase along flow paths, from the surface to the saturated zone and through the aquifer, due to the dissolution of minerals (Freeze and Cherry, 1979).

6.5.1.3. TOTAL DISSOLVED SOLID (TDS)

Total Dissolved Solids concentration is approximately equal to the sum of the concentrations of all dissolved ions. From the water quality analysis result of the study area, there is a clear zonation in TDS following the direction of the groundwater movement from the highlands to the rift where the rainfall is low and the evaporation is very high the TDS varies in general ranging from minimum values for a relatively fresh groundwater of 611 to 835mg/l in the area close to the escarpment and recharge zone for the plain (see Table6.2.). The well field TDS value ranges from 585.94-1046.31(see Table 6.4).Shallow groundwater in recharge areas is lower dissolved solids than the water deeper in the same system and lower in dissolved solids than water in shallow zones in the discharge areas (Freez and Cherry 1979).This implies that as the water goes from the highland through fractured and unconsolidated sediments it acquires dissolved solids more and more depending on all the parameters that govern the evolution of groundwater chemistry. The western escarpment area is the recharging zone and the afar rift floor which the well filed plain is located is discharge zone.

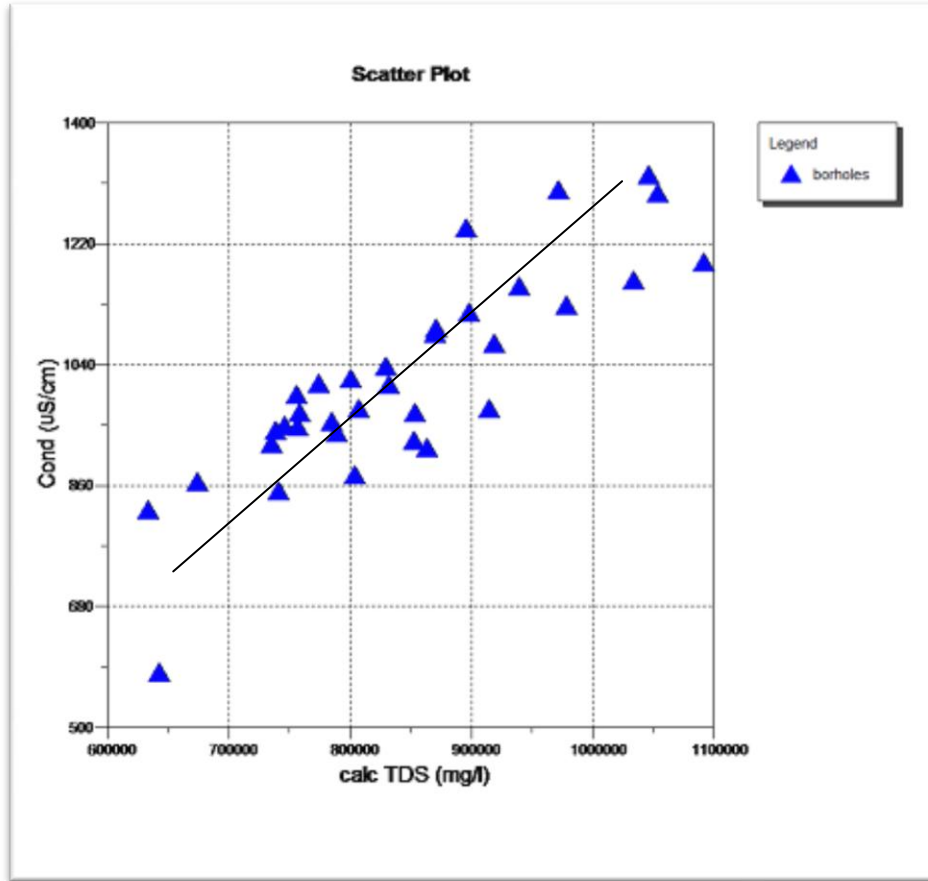


Figure 6.4.-TDS – EC correlation for the water sample of sunnuta wellfield.

6.5.1.4. HARDNESS

Hardness of water is defined as its content of metallic ions which reacts with sodium soaps to produce solid soaps or scummy residue and which react with negative ions, when the water is evaporated in boilers, to produce solid boiler scale (Camp, 1963). It is predominantly caused by divalent cations such as calcium, magnesium, alkaline earth metal such as iron, manganese, strontium, etc. It is a water quality indication of the concentration of alkaline salts in water, mainly calcium and magnesium. Hardness is normally expressed as the total concentration of Ca^{2+} and Mg^{2+} as milligrams per liter equivalent CaCO_3 . The total hardness is defined as the sum of calcium and magnesium concentrations, both expressed as CaCO_3 in mg/l. It can be determined by substituting the concentration of Ca^{2+} and Mg^{2+} , expressed in milligrams per liter, in the expression $\text{Total Hardness} = 2.5 (\text{Ca}^{2+}) + 4.1 (\text{Mg}^{2+})$

Table 6.3.-Total hardness of water sample collected from study area.

Sample ID	Total Hardness (CaCO3) mg/l	Sample ID	Total Hardness (CaCO3) mg/l	Sample ID	Total Hardness (CaCO3) mg/l
HD-2	437.2042	Sw-30	382.0694	Sw-52	157.1552
sw_14	286.3455	Sw-31	206.8057	Sw-53	183.128
sw-09	270.5264	Sw-33	205.0837	Sw-54	260.6218
sw-12	254.437	Sw-34	158.8772		
sw-15	230.25	Sw-35	230.5734		
sw-16	320.8468	Sw-36	214.9671		
sw-17	377.4369	Sw-40	171.3147		
Sw-19	258.1994	Sw-41	296.7369		
Sw-20	217.2106	Sw-43	274.3312		
Sw-21	351.2187	Sw-44	302.3655		
Sw-22	230.25	Sw-45	393.5475		
Sw-23	173.0323	Sw-47	219.2661		
Sw-24	222.5767	Sw-48	438.2478		
Sw-25	218.6233	Sw-49	218.8144		
Sw-26	208.374	Sw-50	188.7821		
Sw-26	208.374	Sw-51	186.8691		

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According to Sawyer and McCarty (1967) Hardness classification of water (mg/l) given by:-

Hardness range CaCO₃ (mg/l)

- 0 to 75soft
- 75 to 150.....Medium-hard
- 150 to 300.....Hard
- >300.....Very hard

As can seen from table - all water samples fall in the range of hard to very hard. That high hardness credited to the geological formations that characterize the area which composed of sediments which are derived from basalt. The dominant cations of the study area are sodium and calcium.

6.6. MAJOR IONS

6.6.1. SODIUM AND POTASSIUM

Sodium is the most abundant cation in the wellfield (Table 6.4). In the samples examined it ranges from 51mg/l in sw-25 to 148 mg/l in sw-52. The mean is about 122.67mg/l. Na⁺ concentration shows in general an increasing tendency from the west escarpment towards the rift floor where the study area is located (see Table 6.2 and Table 6.4). This is because of water-rock interactions and ionic exchange. The main source of sodium in the study area could be sodium plagioclase (albite) and to some extent sodium may be retained by adsorption on mineral surface of lacustrine deposits having high cation exchange capacities such as clay before directly recharge to groundwater. Potassium is lower than sodium because it is resistant to chemical attack and species containing sodium and calcium are more susceptible to weathering. The low concentration of potassium in general could be attributed to the lesser proportion of potassium feldspar.

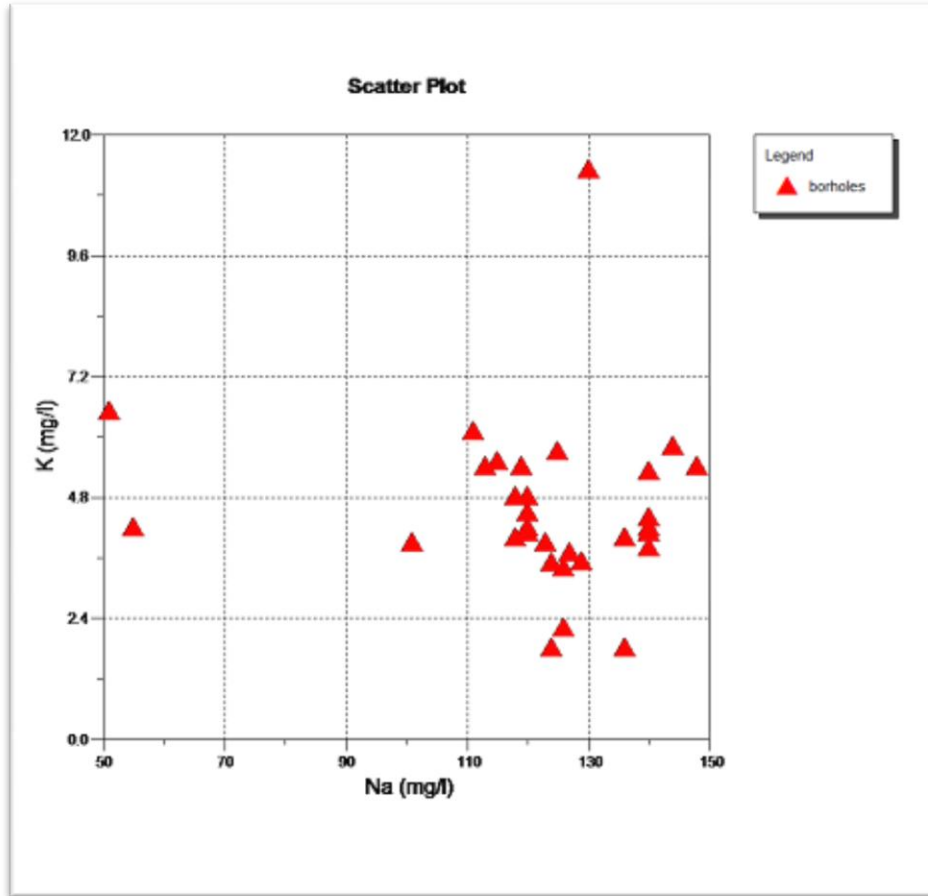


Figure 6.5. scatter plot showing Na vs K

6.6.2. MAGNESIUM AND CALCIUM

Calcium is the second abundant cations next to sodium in the study area as per concentrations in milligram per liter. Because of their similar geochemical behavior calcium and magnesium are treated together. On recharge area it is the first abundant cation. Some of the samples in the study area are calcium and magnesium bicarbonate water types. In sunnuta well field Calcium ranges from 28 mg/l in sw-34 to 104.88 mg/l in sw-14. Magnesium ranges from 5.93mg/l in sw-14 to 52.92 in sw-48. The main source of Calcium in the study area could be weathering of calcic plagioclase and calcium rich pyroxene.

6.6.3. CARBONATES

Carbonate in the area is mainly in the form of bicarbonate. Bicarbonate is the major ion in the groundwater. The concentration of bicarbonate in boreholes ranges from 183 mg/l in sw-40 to 348.92mg/l in sw-30. The mean concentration for the boreholes is about 279.95 mg/l. Bicarbonate is by far the first largest anion in the study area. All samples that show higher TDS with high concentration of HCO_3 and the lower TDS shows low concentration of HCO_3 .the water that precipitate in western escarpment have Ca- HCO_3 type and this water flow through intermittent stream and percolate to the ground mainly in Sunnuta well field and source of HCO_3 is believed to be sourced from this kind of water.

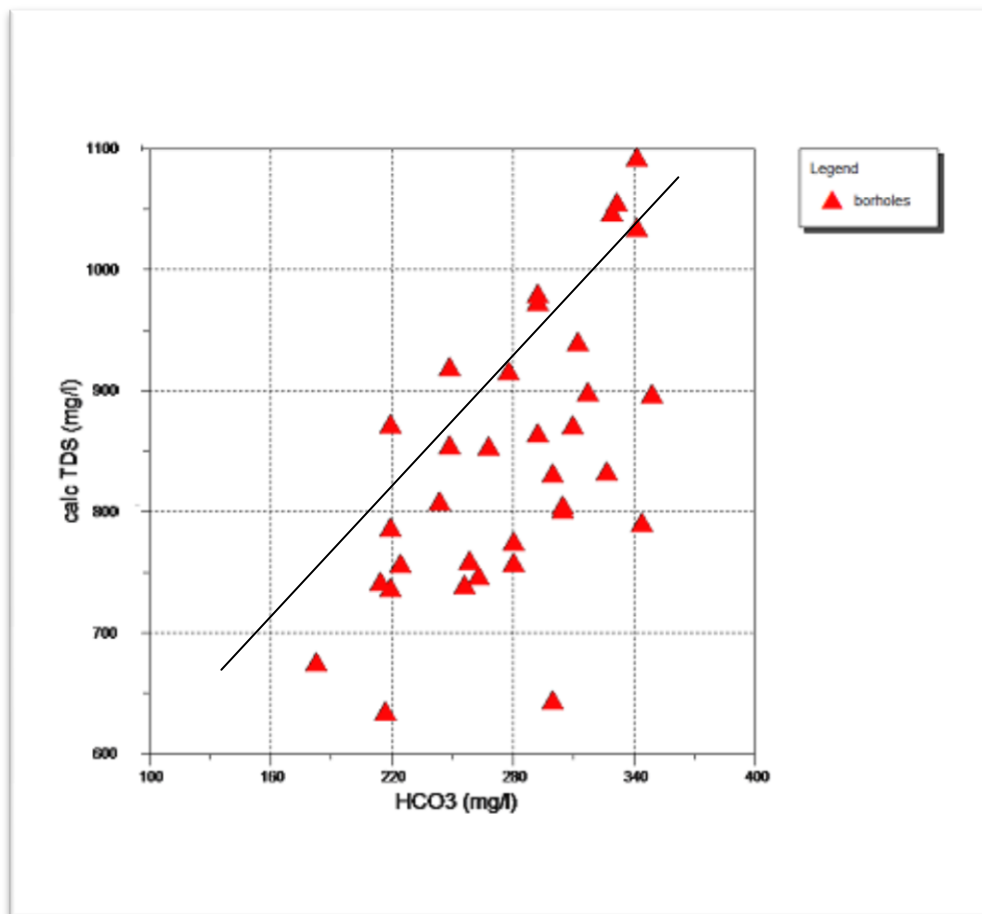


Figure 6.6.Scatter plot showing relations of bicarbonate and total dissolved solutes

6.6.4. SULPHATE AND NITRATES

Sulphate is the second most abundant anion in the study area and major ion in the river water. In the boreholes examined it ranges from 82.22 mg/l in sw-25 to 344.32 mg/l in sw-48. The mean is about 211.75 mg/l. The mean concentration of nitrate is found to be 17.10 mg/l in the study area. It ranges in the boreholes from 0.78 mg/l in sw-25 to 49.67 mg/l in sw-21. The relative lower concentration of Nitrate in boreholes is related to the absence of deep aquifers affected by anthropologic source related to agricultural fertilizers and animal manures. The source of sulfate in the groundwater of study area could be deep groundwater circulation, silicate weathering and could also related with geo-thermal activity.

6.6.5. CHLORIDE

Chloride is a conservative tracer that has frequently been applied in flow path tracking and recharge estimation. The mean concentration of chloride is 67.21 mg/l. In the boreholes it ranges from 14.56 mg/l in sw-25 to 101.02 mg/l sw-22. The chloride concentration increases from west to east as the general groundwater flow Direction.

Table 6.4. Summary statistics of the groundwater sample result of sunuta well filed.

Summary statistics of the groundwater sample result (sunuta wellfield)					
Constituent	Unit	Minimum	Maximum	Mean	Median
EC	µS/cm	580	1321	1016.55	985.3
TDS		585.94	1046.31	816.80	815.71
PH		6.86	8.15	7.46	7.38
Ca ⁺²	mg/l	28	104.88	59.08	55.2
Mg ⁺²	mg/l	5.93	52.92	27.27	24
Na ⁺	mg/l	51	148	122.67	125.5
K ⁺	mg/l	1.8	11.3	4.42	4.15
HCO ⁻³	mg/l	183	348.92	279.95	286.7
NO ⁻³	mg/l	0.78	49.67	17.10	9.61
Cl ⁻	mg/l	14.56	101.02	67.21	67.80
F ⁻	mg/l	0.5	2.45	0.68	0.64
SO ⁻² ₄	mg/l	82.22	344.32	211.75	214.47
SAR		1.50	5.13	3.52	3.68

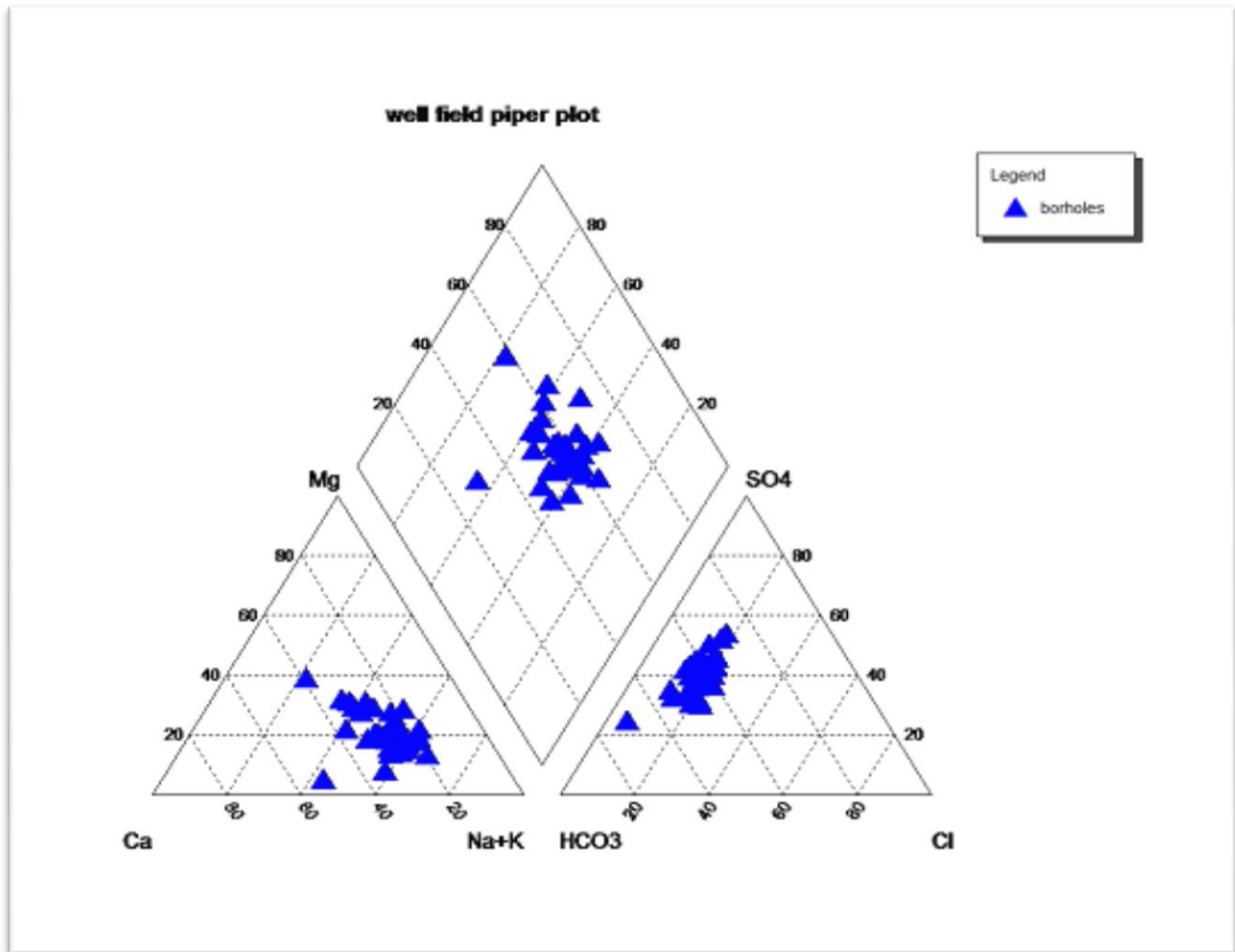


Figure 6.7. Piper plot diagram of natural water on Sunuta wellfield

The majority of groundwater samples of the sunuta wellfield falls into the Na-Ca - SO_4^{2-} - HCO_3^- type in the above Piper plot (figure 6.6), as the dominating cation is Sodium (Na+) and Calcium (Ca+), while bicarbonate (HCO_3^-) is the principal anion followed by SO_4^{2-} .

The majority of the springs, hand dug wells and boreholes water samples in the plain close to western highland escarpment are Ca- HCO_3 / Ca-Mg- HCO_3 type indicating this area receives high recharge. The surface water sample also show intermediate nature of Ca-Na- HCO_3 water

type near to the western escarpment while the Na-Ca-SO₄-HCO₃ type around the rift floor. The well field dominantly show Na-Ca-SO₄⁻²-HCO₃⁻ type water.(see piper plot of geochemical evolution figure 6.2).

Due to groundwater recharge from rainfall and low ground water residence time the TDS is mostly less than 600 mg/l in the highland/escarpments. The high Ca and Mg content in the highlands are related to the dominance of the basic volcanics (basalt). Groundwater chemical evolution model (Edmunds and Smedley, 2000) as cited in Ayenew et al, these types of waters are often regarded as recharge area waters which are at their early stage of geochemical evolution. They are rapidly circulating groundwater which has not undergone a pronounced water-rock interaction. The total ionic enrichment follows the groundwater flow path from the western highland escarpment toward the rift floor where the Snnuta wellfield is located.

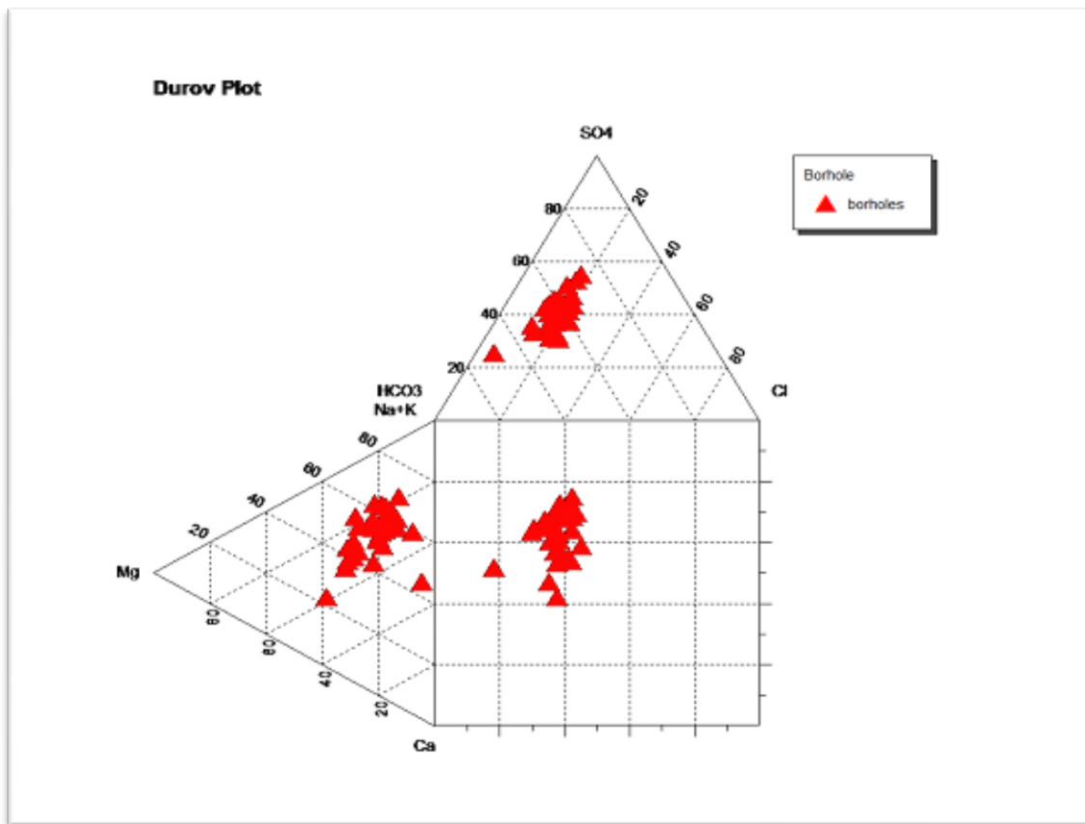


Figure 6.8. durov plot of sunuta wellfield

6.7. Factors governing water chemistry

The mechanism controlling water chemistry and the functional sources of dissolved ions can be assessed by plotting the ratios of Na^+ to $(\text{Na}^+ + \text{Ca}^{2+})$ and SO_4^{2-} to $(\text{SO}_4^{2-} + \text{HCO}_3^-)$ as functions of TDS (Gibbs, 1970). Gibbs diagram of the water samples of the study area clearly shows that the majority of samples have become from rock water interaction and very close to evaporative enrichment. The dominance of water rock interactions tells the long residence time of water favored the interaction between rock and water and also the study area is highly segmented because of the rifting activity the different structures and fractures open a door to the interaction.

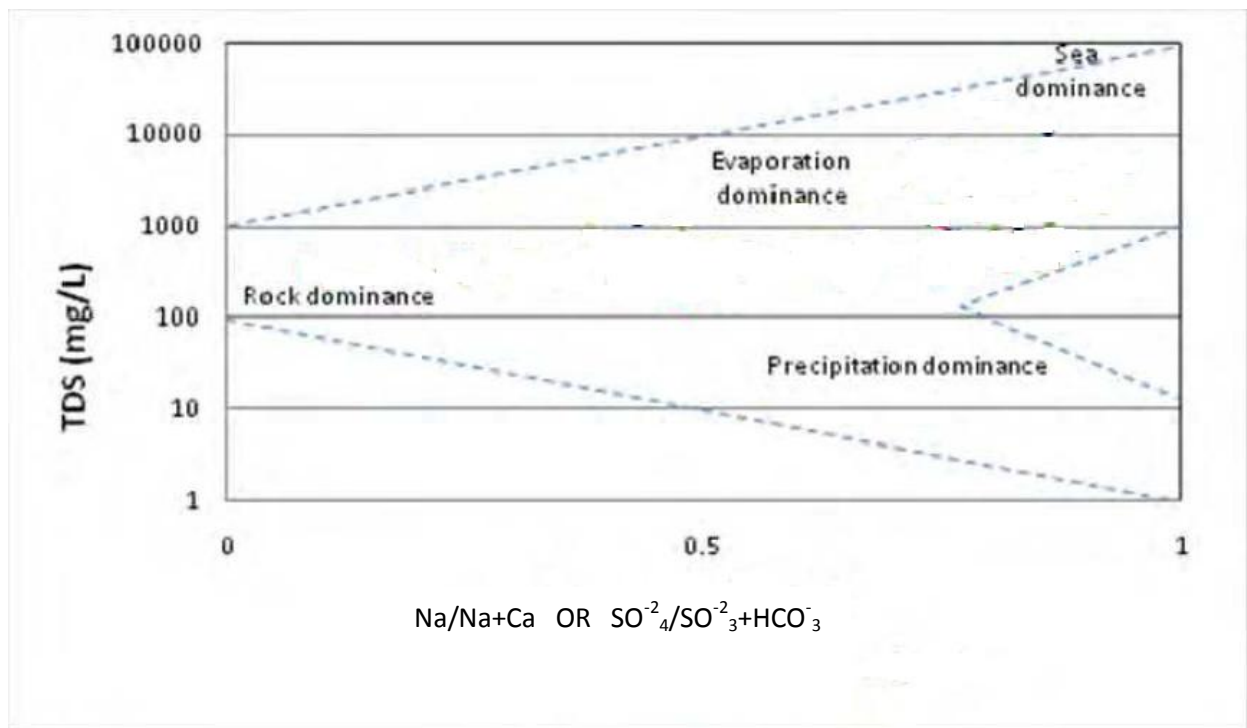


Figure.6.9. Gibbs diagram TDS Vs Ions.

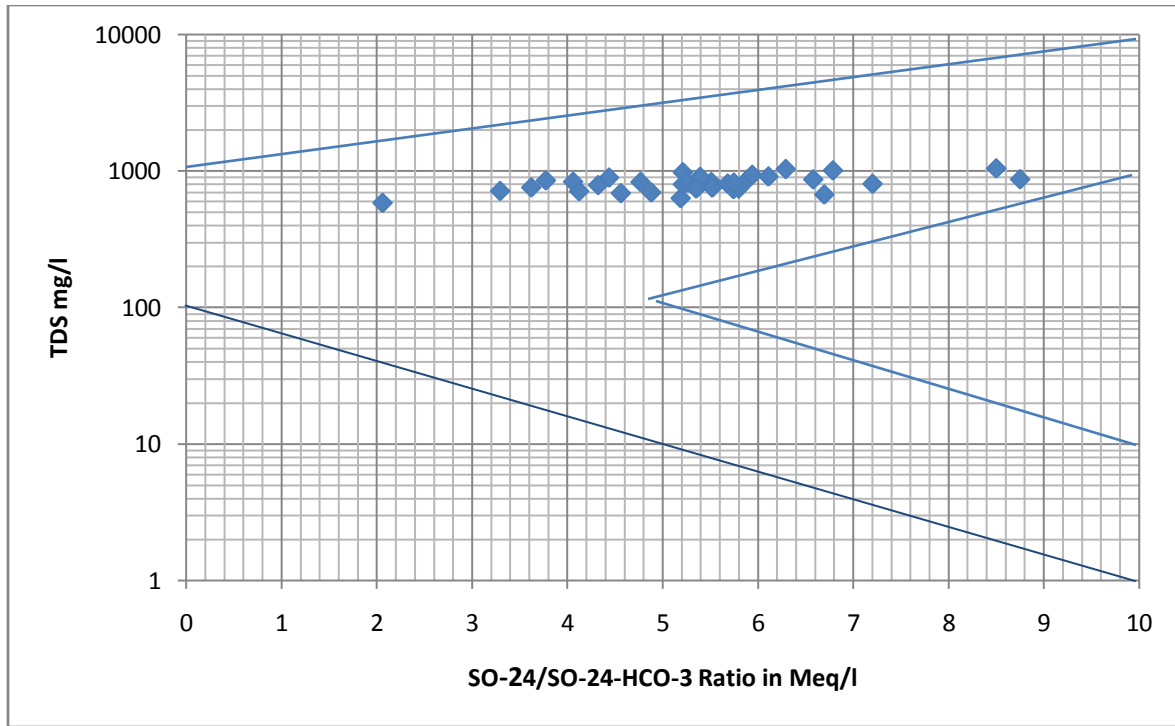


Figure.6.10. Gibbs diagram of sulfate to bicarbonate plus sulfate ratio

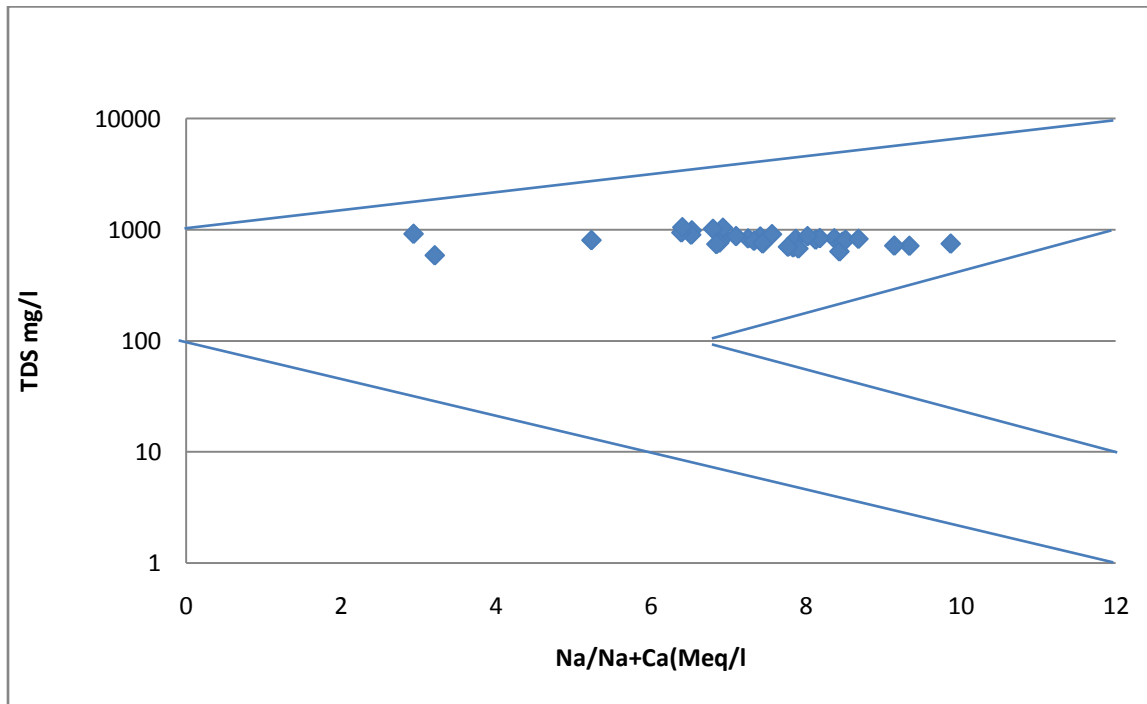


Figure.6.11. Gibbs diagram of sodium to sodium plus calcium ratio

6.8. WATER QUALITY ASSESSMENT

In water resource potential evaluation, the quality of water is as important as the quantity. Groundwater is mainly used for drinking, irrigation and industrial purposes. Therefore, quality criteria depend on the use of water for a particular purpose, and quality standards have to be maintained in water supply for different uses to avoid deleterious effects. In this section the quality of water assessed from drinking water point of view and from agricultural point of view.

6.8.1. DRINKING WATER QUALITY ASSESSMENT OF SUNNUTA WELL FIELD.

Groundwater forms an important source of water for drinking and other domestic purposes. Therefore, groundwater, in general, is safer for use than surface water especially from the point of view of bacterial pollution; but the chemical composition of water is also important, as certain chemical constituents become toxic beyond a particular concentration, although they may be beneficial in lower amounts. Prescribed standards for drinking-water vary from country to country, depending upon economic conditions, climate, food habits and geographic location. There is also conflicting evidence with respect to safe limits for certain constituents. The chemical analysis results from the water samples in the study area (sunuta-hida dubla wellfield) have been evaluated and compared with WHO (2008) and Ethiopian guideline values for water quality standards to observe the level of pot ability of the water with respect to some major ionic constitutes like Fluoride, sodium, chloride, sulfate and etc that are the major threat in relation to health problem. As can be seen from water quality data, the major anions and cations of most of the sampled water fall with the range of WHO and Ethiopian guideline values.

Table6.5. Comparison with water quality standards for drinking water

Element	WHO guideline mg/l	Total% of water samples above WHO guideline	Ethiopian guide line mg/l	Total% of water samples above Ethiopian guideline
Fluoride	1.5	9.7	3	0
Sodium	200	0	358	0
TDS*	1000	0	1776	0
Chloride	250	0	533	0
Sulfate	500	0	483	0
Nitrate	50	0	50	0

*WHO guideline (1984)

6.8.2. WATER QUALITY FOR IRRIGATION PURPOSES

Irrigated agriculture is dependent on an adequate water supply of usable quality. Just as any water is not suitable for human beings, in the same way, any water is not suitable for plant life. Water containing impurities, which are injurious to plant growth, is not satisfactory for irrigation, and called unsatisfactory water.

Water quality for agricultural purposes is determined on the basis of the effects of the water on the quality and yield of the crops, as well as the effects on drainage efficiency and characteristic changes in the soil (Wilcox, 1955). The quality standards for irrigation water are based on: (1) total dissolved solids which may affect the intake of water and other nutrients by plants through osmosis; (2) the relative concentration of alkalis and alkaline earths which affect the soil texture due to cation exchange, and thereby its permeability and drainage characteristics; and (3) the concentration of specific ions, viz. boron, selenium, cadmium etc., which are toxic to the growth of plants beyond certain levels. Soil scientists use the following categories to describe irrigation water effects on crop production and soil quality:

- Salinity hazard - total soluble salt content
- Sodium hazard - relative proportion of sodium (Na⁺) to calcium (Ca²⁺) and

magnesium (Mg²⁺) ions

- pH
- Alkalinity - carbonate and bicarbonate
- Specific ions: chloride (Cl), sulfate (SO₄²⁻), boron (B), and nitrate-nitrogen (NO₃-N).

Other potential irrigation water contaminants that may affect suitability for agricultural use include heavy metals and microbial contaminants.

6.8.2.1. SALINITY HAZARD

The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (EC_w). The primary effect of high EC_w water on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought). The higher the EC, the less water is available to plants, even though the soil may appear wet. Because plants can only transpire "pure" water, usable plant water in the soil solution decreases dramatically as EC increases.

Table 6.6. Suggested criteria for irrigation water use based upon conductivity.

Classes of water	Electrical Conductivity(μS/cm)
Excellent	≤250
Good	250 – 750
Permissible ¹	750 – 2000
Doubtful ²	2000 – 3000
Unsuitable ²	≥3000

¹Leaching needed if used, ²Good drainage needed and sensitive plants will have difficulty obtaining stands.(Sources: Bauder et. al., 2003)

Based on EC as an index of salinity hazard (Table 6.6), the water samples of the study area can be classified as follows:

Water samples	Ranges of EC ($\mu\text{S}/\text{cm}$)	Water class
Sw-25	580	Good
Sw-15,sw-16,sw-23,sw-20,sw-21,sw-22,sw-24,sw-19,sw-17,sw-51,sw-43,HD-2,sw-49,sw53,sw-52,sw-54,sw-50,sw-44,sw-45,sw-40,sw-41,sw-47,sw-48,36,sw-09,sw-12,sw-14,sw-26,sw-30,sw-31,sw-33,sw-34,sw-35	822-1321	Permissible ¹

6.8.2.2. SODIUM HAZARD

While EC_w is an assessment of all soluble salts in a sample, sodium hazard is defined separately because of sodium's specific detrimental effects on soil physical properties. The sodium hazard is typically expressed as the sodium adsorption ratio (SAR). This index quantifies the proportion of sodium (Na⁺) to calcium (Ca⁺⁺) and magnesium (Mg⁺⁺) ions in a sample. Calcium will flocculate (hold together), while sodium disperses (pushes apart) soil particles. This dispersed soil will readily crust and have water infiltration and permeability problems. General classifications of irrigation water based upon SAR values are presented in Table 6.7.

Table6.7. General classification of water sodium hazard based on SAR values.

(Sources: Bauder et. al., 2003)		
SAR values	Sodium hazard of water	Comments
1-9	Low	Use on sodium sensitive crops must be cautioned.
10-17	Medium	Amendments (such as gypsum) and leaching needed.
18-25	High	Generally unsuitable for continuous use.
>26	Very High	Generally unsuitable for use.

However, many factors including soil texture, organic matter, crop type, climate, irrigation system and management impact how sodium in irrigation water affects soils. Additionally, at the same SAR, water with low EC_w (salinity) has a greater dispersion potential than water with high EC_w.

Table 6.8: suitability of Groundwater of the study area for irrigation purpose based on SAR

Water samples	Range of SAR	Water class
Sw-15,sw-16,sw-23,sw-20,sw-21,sw-22,sw-24,sw-19,sw-17,sw-51,sw-43,HD-2,sw-49,sw53,sw-52,sw-54,sw-50,sw-44,sw-45,sw-40,sw-41,sw-47,sw-48,36,sw-09,sw-12,sw-14,sw-26,sw-30,sw-31,sw-33,sw-34,sw-35,sw-25	1.5-5.13	Low

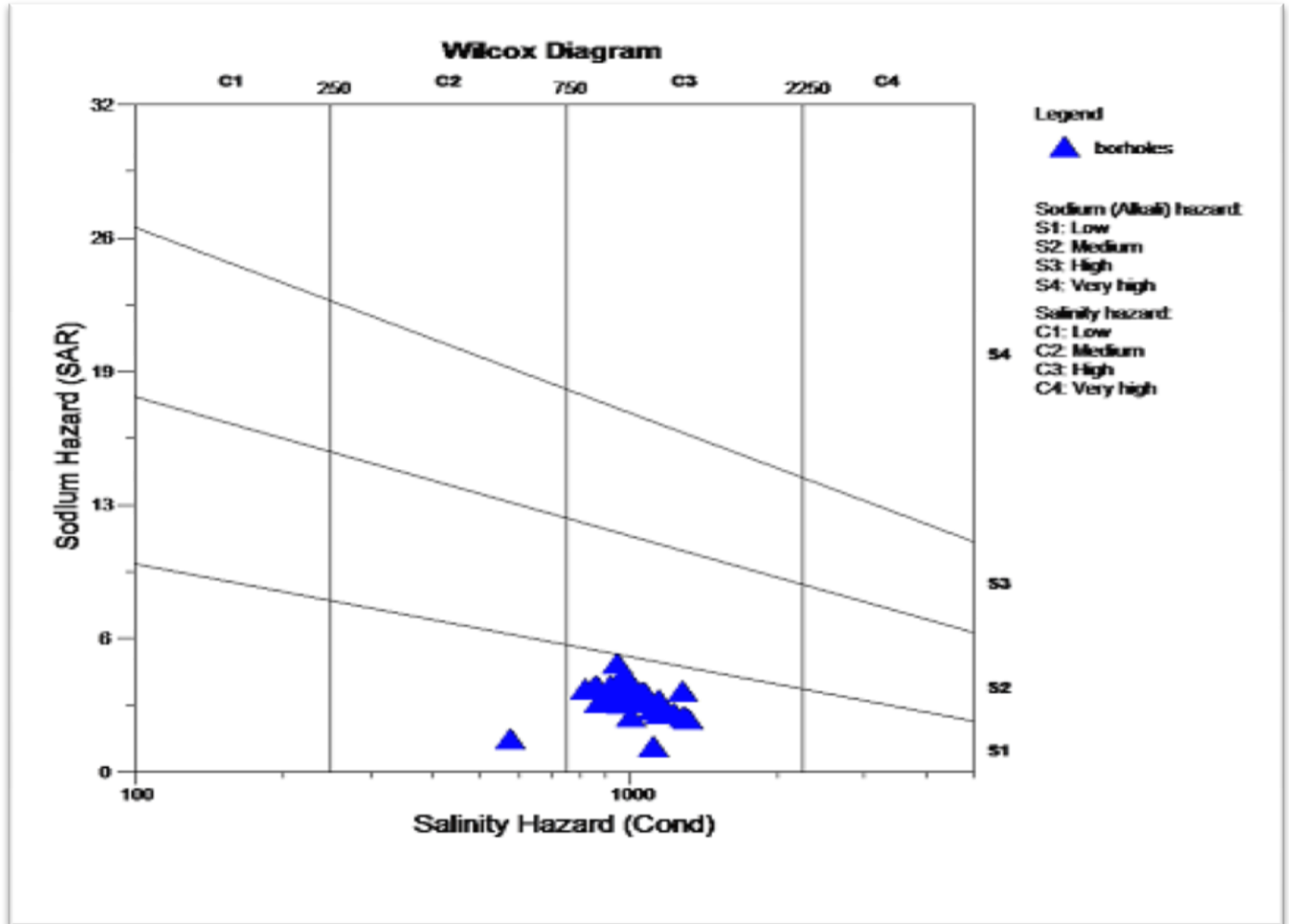


Figure 6.12. irrigation water classification on samples collected from Sunuta-Hida Dubla well field.

6.8.2.3. TOXICITY PROBLEMS

Toxicity problems occur if certain constituents (ions) in the soil or water are taken up by the plant and accumulate to concentrations high enough to cause crop damage or reduced yields. The degree of damage depends on the uptake and the crop sensitivity. The permanent, perennial-type crops (tree crops) are the more sensitive. Damage often occurs at relatively low ion concentrations for sensitive crops. It is usually first evidenced by marginal leaf burn and interveinal chlorosis. If the accumulation is great enough, reduced yields result. The more tolerant annual crops are not sensitive at low concentrations but almost all crops will be damaged or killed if concentrations are sufficiently high. The ions of primary concern are chloride, sodium and boron. Although toxicity problems may occur even when these ions are in low concentrations, toxicity often accompanies and complicates a salinity or water infiltration problem.

Table 6.9. Chloride classification of irrigation water.

Chloride (mg/l)	Effect on Crops
Below 70	Generally safe for all plants.
70-140	Sensitive plants show injury.
141-350	Moderately tolerant plants show injury.
Above 350	Can cause severe problems.
Chloride tolerance of selected crops. Listing in order of increasing tolerance: (low tolerance) dry bean, onion, carrot, lettuce, pepper, corn, potato, alfalfa, sudangrass, zucchini squash, wheat, sorghum, sugar beet, barley (high tolerance). Source: Mass (1990).	

The chloride concentration of the borehole samples in the study area is suitable for irrigation from the point of toxicity.

Table 6.10. Suitability of Groundwater of the study area for irrigation purpose based on chloride

Water samples	Range of Chloride (mg/l)
Sw-15,sw-23,sw-20,HD2,sw-25,sw-24,sw-19,sw-43,sw-53,sw-40,sw-47,sw-36,sw-9,sw-12,sw-14,sw-14,sw-26,sw-33,sw-34,sw-35	Below 70
Sw-16,sw-21,sw-22,sw-17,sw-51,sw-52,sw-54,sw-50,sw-44,sw-45,sw41,sw48,sw-31	70-140(most of the borehole have a concentration less than 90mg/l

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CHAPTER SEVEN

7. Conclusion and recommendation

7.1. Conclusion

Sunnuta well field is found in Afar region, Ethiopia. It is bounded with uwa catchment it covers area of about 659.7Km² (Uwa catcment) of which 20 km² takes the sunuta wellfield . The river catchment has two climatic zones. The mountains and the escarpments characterized humid while the rift floor where the Sunuta well field is located characterized with arid -climatic zones. The western highland part of the area receives relatively higher precipitation 766 mm and the rift floor receives 212 mm precipitation. The area shows bimodal rainfall pattern. The long term mean annual minimum and maximum temperatures of semera station are 24.5⁰C -37.9⁰C. The groundwater in the region shows highly segmented distribution due to the geological complexity. However, the vast alluvial plain of the study area get recharged through perennial rivers & seasonal runoffs that come from the western highlands, as well as from groundwater inflow from the western highland and locally from direct rainfall.

Since the penman method take in to account several climatic factors to compute PET, it is considered to be the most reliable method. For comparison different methods have been examined and compared. Estimation of annual Potential Evapotranspiration by Penman method for Kobo plain is 1351.69 mm and for Sirinka 1246.07mm. For the same plain the Thornthwaite formula gives a value of 1065.67 for both stations using their mean annual temperature.

The Actual Evapotranspiration of the area was calculated using Turc empirical method and Thornthwaite and Mother Methods (soil water balance method). AET for the whole catchment using Turc empirical method and soli water balance method are 363mm and 517.16mm respectively. The value obtained by Turc emperical method is assumed to be the AET of the area. The hydrogeological mapping was performed by classifying the Hydrogeological units based on surface geology, borehole lithologic log, pumping test data and remote sensing data of the area. In the study area majorly there are two aquifer units; the unconsolidated thick sediment aquifers and volcanic aquifers. The data of 15 aquifer pumping tests were analyzed with appropriate method. The transmissivity ranges from 144.00 – 5533.56 m²/d. the transmissivity of

the well field is categorized as very high. The hydraulic conductivity also ranges from 2 – 77 m/d and the Hydraulic conductivity is also categorized as very high in the well field.

Regarding the groundwater recharge and discharge zone of the area, direct recharge in to groundwater is insignificant in the wellfield area. This is not due to high evaporation rate and low permeability of lacustrine sediments it is because of low precipitation on the area. However, the contribution of tectonic structure particularly fault/fractures that tilled to the study area have significant role in downward movements of water from water bodies that accumulated during flood period. In general groundwater recharge to the study area is from direct percolation of precipitation through fluvio-lacustrin deposits that cove 55% of the study area and mainly the water that flow through intermittent streams during kirmt and bulg time from the western escarpment to the sunnuta plan. Due to the slop value varation which is near to zero at the sunnuta plan and nature of the geology this kind of water will get enough time to percolate to the ground as well as to evaporate (temperature is more than 39.7°C) this is the reason why the study area account high value of infiltration and evaporation than other parameters. The regional Groundwater flow direction is generally from west to east and on the study area it is from SW-NE. Water Balance method is used to estimate the groundwater recharge of the catchment which is used to plan how to use the resource without harming. Water balance methods gives 76.27MCM/y of ground water recharge. The hydrochemical evolution analysis of water samples in the area revealed that the water samples from deep wells and springs adjacent or close to the western highland escarpment have relatively lower values of TDS, EC, PH, sodium, chloride etc. Generally, the ion concentrations increase when one is moving from the highland escarpment to the rift floor where sunnuta wllfield is located indicating that the increased dissolution along the flow paths from recharge to discharge areas. The piper plot of the water chemical analysis shows that Na-Ca -SO₄²⁻ - HCO₃⁻ water type on the well field. And the plot shows Mixing of water from direct precipitaion and streams this result elaborate more about the recharge of the ground water through intermittent stream. In general the groundwater samples show concentrations below the maximum allowable limits (WHO guide line) i.e., the borehole waters could be used safely for drinking. From agricultural point of view; the groundwater in sunnuta well field are low in the sodium adsorption ratio (SAR) values making them favorable for irrigation. The main danger posed with respect to irrigation is the medium to high values of salinity as evidenced by the conductivity measurements.

7.2. Recommendation

- In this study it is understood that there is limitation of hydrometeorological data due to absence of adequate number of meteorological and river gauging stations to get reliable output in the study area. Therefore; it is recommended that to install new meteorological and hydrometric stations for future investigations.
- Sunnuta well field is being developed for large scale irrigation project, care should be taken related to usage of pesticides, over fertilizing and over irrigating that causes groundwater contamination.
- To avoid collapse of formations because of the geology and undesirable difficulty in inserting production casings reverse circulation mud rotary drilling method is recommended.
- As the water type is Na-Ca-SO₄-HCO₃ the source of sulfate need further investigation
- Even though the average drilling depth in the area is 225 m, it is recommended to test the presence of additional aquifers at depth. This helps to have fully penetrating wells and minimizes well interferences by creating different aquifer systems.
- For proper pumping test analysis and aquifer characterization certain observation wells should be drilled in the well fields at representative locations.
- For further groundwater resource development plans in the study area, it is important to take into account the balance between the groundwater recharge and the intended abstraction rates both for irrigation and domestic water supply to ensure the sustainability of the resource in the area.

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Appendix: 1 Mean Annual Temperature of ELIwhuha, Kobbo, Milla, Semera, Sirinka

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Eli Whuha	27.8125	28.2	28.9625	29.8	29.425	29.7375	30.15	28.9175	28.84	28.3325	28.0275	27.42
Kobbo	19.78864	21.06742	22.71087	23.8087	24.60625	26.2913	25.14545	23.626	22.85217	21.51522	20.2865	19.154
Mille	26.93167	27.67333	29.77917	31.86	33.02083	34.95417	32.65	31.7725	33.12667	31.60567	28.34467	27.45
Semera	25.75714	26.83333	29.21905	32.20119	34.39	35.77232	33.93333	31.82143	33.83333	30.94405	28.20833	26.116
Sirinka	17.4	18.45	19.525	21.4375	22.325	23.9375	23	21.23333	20.775	19.51667	18.375	16.783

Appendix:2 Mean Annual Rainfall of ELIwhuha, Kobbo, Milla, Semera, Sirinka

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Eliwhuha	9	39.83333	26	37	27.5	0	55.1	114.3	5.8	0	15.25	0.6
Kobbo	14.575	16.5409	57.816	79.9083	44.5833	15.8428	154.085	190.112	59.54762	37.8181	15.8739	15.7333
Milla	0.66	1.125	35.3	16.8	13.7	1.65	46.54	73.4	8.25	1.96666	13	0
Semera	0.21428	1	22.9333	10.0714	13.2	4.7625	26.15	70.6166	11.12	2.67142	2.5	3
sirinka	22.275	12.5333	69.9	88.7	69.55	20	106.4	226.333	42.3	22.4333	79.85	5.26666

Appendix:3 Mean Annual Relative Humidity of Milla, Kobbo, sirnka staion

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Milla	53.6	51.2	49.5384 6	46.6923 1	46.2	30.2	42.875	63.6	48.5	40.25	42.2	49.8
Kobbo	65.2	53.6	53.6	57	48.6	77	80.5	67	59.8	57.8	55	54.8
Sirnka	73.4758 1	69.1016 9	67.8823 5	65.3671 9	57.5483 9	48.4769 2	61.5982 9	68.4322	68.6	66.0153 8	64.4	67.9218 8

Appendix:4 Mean Annual Sunshine Hour of Sirinka, Kobbo, Milla Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sirinka	8.4	10.3	6.4	7.2	7.5	6.1	5.7	5.7	7.3	8	6	7.3
kobbo	8	8.6	9	9.5	9.5	7.6	5.6	6.6	7	9.7	9.5	9
Milla	8.9	9.2	8.6	10.6	8	6.4	5.9	6.8	9.1	9.8	9.8	9.1

Appendix:5 Mean Annual wind Speed of Kobbo, Sirinka Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
kobbo	1.8	2.2	2.2	1.8	1.4	1.9	2	1.4	1	1	1.3	1.3
Sirinka	1.355	1.385	1.35	1.23	1.29	1.490476	1.333333	1.210526	0.990476	0.921739	1.109524	1.55
	1.5775	1.7925	1.775	1.515	1.345	1.695238	1.666667	1.305263	0.995238	0.96087	1.204762	1.425

Appendix:6 Potential Evapotranspiration calculated using Penman-Monteith method (Kobbo)

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo	ETO
	°C	°C	%	km/day	hours	MJ/m ² /day	mm/day	mm/month
January	13.2	26.4	65	2	8	18.7	2.99	89.7
February	14.1	28.1	54	2	8.6	20.9	3.4	95.2
March	16.1	29.4	54	2	9	22.9	3.95	122.45
April	17	30.6	57	2	9	23.4	4.25	127.5
May	16.8	32.4	49	1	9.5	23.8	4.26	132.06
June	18.4	34.2	77	2	7.6	20.6	4.26	127.8
July	18.1	32.1	81	2	5.6	17.7	3.75	116.25
August	16.8	30.5	67	1	6.6	19.5	3.81	118.11
September	15.5	30.2	60	1	7	19.9	3.71	111.3
October	13.6	29.4	58	1	9.7	22.8	3.89	120.59
November	12.3	28.3	55	1	9.5	21	3.33	99.9
December	11.5	26.8	55	1	9	19.5	2.93	90.83
Average	15.3	29.9	61	2	8.3	20.9	3.71	
Annual								1351.69

Appendix:7 Potential Evapotranspiration calculated using Penman-Monteith method (Sirinka)

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo	Eto
	°C	°C	%	km/day	hours	MJ/m ² /day	mm/day	mm/month
January	11.1	23.8	73	2	8.4	19.5	3.08	92.4
February	11.1	25.8	69	1	10.3	23.6	3.83	107.24
March	13	26.1	68	1	6.4	19	3.36	104.16

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April	14.9	27.9	65	2	7.2	20.6	3.77	116.87
May	15.6	29.1	58	1	7.5	20.7	3.78	113.4
June	16.7	31.2	48	1	6.1	18.3	3.44	103.2
July	16.5	29.5	62	1	5.7	17.8	3.5	108.5
August	15.1	27.3	68	1	5.7	18.1	3.47	107.57
September	14.3	27.2	69	1	7.3	20.4	3.76	112.8
October	12.5	26.5	66	2	8	20.5	3.58	110.98
November	12.2	24.6	64	2	6	16.3	2.79	83.7
December	10	23.6	68	1	7.3	17.5	2.75	85.25
Average	13.6	26.9	65	1	7.2	19.4	3.43	
Annual								1246.07

Appendix: 8 Potential Evapotranspiration calculated using Thornthwaite Method for sirinka and kobo station by using the two station mean annual temperature

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Tm (OC)	19.6806	20.4475	21.892	23.3015	23.668	24.986	24.097	23.104	23.012	21.841	20.4	19.67	
N	19.0902	20.0386	21.892	24.0006	24.851	26.485	25.301	24.029	23.473	21.622	19.79	18.883	
Nm	0.97	0.98	1	1.03	1.05	1.06	1.05	1.04	1.02	0.99	0.97	0.96	
im	7.80915	8.27	9.1619	10.0606	10.299	11.171	10.58	9.9332	9.8738	9.1294	8.241	7.8027	
I	112.331	112.33	112.33	112.33	112.33	112.33	112.33	112.33	112.33	112.33	112.3	112.33	
a	2.489	2.489	2.489	2.489	2.489	2.489	2.489	2.489	2.489	2.489	2.489	2.489	
PETm (mm/yr)	62.3542	69.2635	83.717	100.657	106.66	123.16	111.51	99.515	96.638	82.395	68.17	61.629	1065.67

Well ID	UTM N	UTM E	Elvation	Type of Aquifer	T from con.rate pumping((m2/d)	Specific Capacity (M3/day/m)	K (t/d)m/d	Screen Length (m)	S
sw-32	1305814	625457	836	Alluvial deposit	593.96	289.21	14.44	54	56
sw-29	1310054	628107	830	Alluvial and pyroclastic deposits	326.76	100.17	4.34	84	4
sw-9	1305426	628526	821	Basalt scoria and alluvial deposit	7,115	5,040	89	82	44
sw-12	1305966	629577	818	Basalt scoria and alluvial deposit	676.00	204.74	11	60	4
sw-14	1306444	630152	815	Basalt scoria and alluvial deposit	517	467.75	8	72	39
sw-26	1310062	628683	830	Alluvial, pyroclastic deposits & rhyolite	692	365.15	6	84	4
sw-30	1310427	627350	833	Fractured rhyolite	144	85.89	2	72	49
sw-31	1306386	625342	841	Basalt scoria and alluvial deposit	464	272.95	6	64	
sw-33	1305231	625561	842	Alluvial deposit	652	1,016.47	12	54	5
sw-34	1304650	628685	821	Alluvial deposit	1027	455.61	20	52	52
sw-35	1304050	625813	833	Basalt and alluvial deposit	1030	396.27	16	70	55
sw-36	1304650	625085	835	Basalt and alluvial deposit	485	175.53	8	60	56
sw-28	1310644	627950	825	Fractured rhyolite	5533.56	391.2	53.69	78	47
sw-27	1310651	628564	823	Fractured rhyolite	1722.71	788.4	39.66	72	42
sw-18	1306974	628801	824	Basalt scoria and alluvial deposit	1736	978.64	42.32	75	4
sw-13	1306516	629481	819	Basalt scoria and alluvial deposit	1210.24	1225.81	21.63	69.6	42
sw-7	1305200	629196	819	Basalt scoria and alluvial deposit	3,637	1,455.16	77	64	41
sw-8	1304940	628350	822	Basalt scoria and alluvial deposit	17,106	2,169	228	75	4
sw-10	1306098	628394	827	Basalt scoria and alluvial deposit	5,389	1,468	69	78	46
sw-11	1305775	629142	824	Basalt scoria and alluvial deposit	820	470.31	10	82	43

Appendix: 9 Pumping test result of the sunnuta well field

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Field No	X	Y	Na+	K+	Ca2+	Mg2+	CO2-3	HCO3-	Cl-	F-	SO2-4	NO-3	SiO2	pH
BH-6	577559	1301584	42	3.4	97.2	62.3	_	308.5	36.2	0.29	30.2	1.9	_	7.2
BH-11	573530	1305612	36	2.99	104.6	49.8	_	300.4	19.8	0.44	29.7	1.18	_	7.5
BH-9	628793	1306943	128.3	3.68	28.8	14.8	_	256.2	99.3	0.98	158.57	2.66	48.79	8.22
SBH-12	600307	1291395	37.1	1.78	65.6	21.6	_	335.5	46.08	0.93	31.71	6.2	50.07	7.66
SBH-13	629097	1289381	123.1	0.77	13.7	5.4	_	81	184.34	0.5	96	0.89	35.52	7.67
SBH-14	623055	1289262	103.5	3.36	33.4	21.9	_	366	59.91	0.92	47.48	2.22	60.78	7.93
sw-15	630126	1306437	17	2.48	24.5	7.6	_	152	18.43	1	9.79	4	22.68	7.07
sw-16	629348	1307106	120	4.8	36	34.08	_	268.4	52.79	0.66	222.28	25.48	44.48	7.56
sw-20	628952	1308892	120	4.2	40	17.76	_	214.72	60.07	0.5	170.53	7.59	53.04	7.66
sw-21	628276	1309272	111	6.1	47.12	24.17	_	305	46.41	0.56	144.88	27.9	45.51	7.21
sw-22	628484	1308652	118	4.8	73.72	40.58	_	341.6	82.82	0.58	212.33	49.67	55.13	7.21
sw-25	628808	1309507	126	3.4	83.2		_	331.84	101.02	0.55	275.24	46.19	43.42	7.23
sw-19	629083	1308282	51	6.5	44.8	25.92	_	300.12	14.56	0.52	82.22	0.78	58.55	7.33
sw-43	625789	1310859	124	3.5	70.4	48.96	_	341.6	82.82	0.54	256.28	47.31	58.28	7.27
sw-49	621658	1309341	140	4.1	40	21.12	_	258.64	72.81	0.52	127.97	5.99	43.76	7.71
sw-53	622113	1307069	140	4.2	58.4	31.2	_	309.88	69.17	0.68	162.88	23.67	35.24	7.63
sw-54	621527	1307094	126	3.4	48	15.36	_	219.6	58.25	0.61	183.37	5.11	38.26	7.75
sw-50	621785	1308754	148	5.4	37.6	15.36	_	219.6	70.8	2.45	201.1	3.96	40.75	7.72
sw-44	625733	1311473	140	3.8	63.2	24.96	_	248.88	79.18	0.66	253.73	4.35	50.11	7.51
sw-45	625678	1312073	140	5.3	37.6	23.04	_	224.48	72.81	0.71	155.67	8.14	44.36	7.87
sw-40	624910	1308219	136	4	72	29.76	_	312.32	81	0.66	216.61	20.06	33.69	6.93
sw-41	625022	1307597	118	4	81.6	46.08	_	292.8	92.83	0.6	236	31.13	34.79	7.33
sw-47	625609	1313272	123	3.9	42	16.13	_	183	59.63	0.64	241.11	5.21	_	7.53
sw-48	625077	1311448	129	3.51	75.6	26.21	_	219.6	81.39	0.68	328.8	6.18	_	7.22
sw-36	625085	1304650	140	4.4	50.4	22.68	_	244	62.46	0.66	276.64	6.35	_	7.58
sw-09	628526	1305462	120	4.1	88.22	52.92	_	102 329.4	100.32	0.66	344.32	6.37	_	7.29

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sw-30	627350	1310427	101	3.9	104.88	5.93	_	305	60.07	0.64	208.53	11.08	_	7.22
sw-31	625350	1306415	130	11.3	67.64	9.58	_	344.04	46.41	0.91	176.28	3.79	_	7.03
sw-33	625561	1305231	124	1.8	96	34.56	_	348.92	93.74	0.62	181.32	15.37	_	6.86
sw-34	625685	1304650	136	1.8	46.4	22.08	_	280.6	71.3	0.68	210.52	5.05	_	7.99
sw-35	625813	1304050	126	2.2	56	15.84	_	263.52	52.79	0.68	226.03	3.32	_	7.79
swh-1	608595	1318046	113	5.4	28	21.6	_	217.2	51	0.5	194.5	3.1	_	8.15
sw-2	595744	1303667	115	5.5	54.4	23	_	256.2	57.3	0.6	222.7	4.2	_	7.76
sw-3	630714	1305659	136	2.73	3.87	3.38	_	341.7	9.58	0.4	25.52	_	_	7.48
sw-4	607675	1310980	110	4.71	3.68	11.78	_	353.9	33.36	1.42	96.14	_	_	7.6
sw-5	599389	1307238	120	2.66	3.86	2.54	_	414.9	32.08	0.06	119.92	_	_	7.69
sw-6	599359	1307385	172	5.5	72	12.48	_	427.1	48.84	2.66	136.9	_	_	7.87
sw-7	591319	1300065	140	2.99	3.68	10.21	_	414.9	67.54	2.35	135.93	_	_	7.93

Appendix: 10 Water chemistry of the study area.

DECLARATION

I hereby declare that the thesis entitled “**AQUIFER CHARACTERIZATION AND WATER QUALITY ANALYSIS OF SUNNUTA WELL FIELD, AFAR REGION, ETHIOPIA.**” has been carried out by me under supervision of Dessa Nedaw (PhD), department of Geology, Addis Ababa University during the year 2015 as partial fulfillment of MSc Degree program in Hydrogeology. I further declare that this work has not been submitted to any other university or institution for the award of any degree or diploma, and also that all sources of materials used during the thesis work have been properly acknowledge.

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Kinfe Atsbha (candidate)

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Date