

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES DEPARTMENT OF
EARTH SCIENCES



INTEGRATED HYDROGEOLOGICAL INVESTIGATION OF UPPER BILATE
RIVER CATCHMENT: SOUTH WESTERN ESCARPMENT OF
MAIN ETHIOPIAN RIFT

BY: - Sintayehu Legesse Gennoro

*A Thesis Submitted to the School of Graduate Studies of Addis Ababa University
In Partial Fulfillment of the Requirements for the Degree of Master of Science in
Hydrogeology*

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By: - Sintayehu Legesse Gennoro

Advisor: - Tenalem Ayenew (Ph.D)

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By

Sintayehu Legesse

Approved by the Board of Examiners:

Dr. Balemwal Atenafu

(Chairman)

Dr. Tenalem Ayenew

(Advisor)

Dr. Seifu Kebede

(Examiner)

Dr. Mulugeta Alene

(Examiner)

This work is dedicated to my lovely mother

Birtukan Teshome Ashagere

(1953 – 1999)

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ABSTRACT

The study was conducted at Upper Bilate River Catchment 230km, South West of Addis Ababa and East of Hossana to characterize aquifer and assess hydrogeological system of Upper Bilate catchment by giving particular emphasis to groundwater potential investigation, mechanism of recharge and groundwater surface water interaction, in an integrated manner. Data has been collected from the respective institutes and organizations and processed using hydrogeological and GIS and remote sensing software. Integrated approaches of hydrogeological investigations are adopted by paying particular attention to geology, recharge estimation, hydrogeological system and hydrogeochemistry in the assessment of water resources potential of the catchment. Areal depth of precipitation of the area was estimated by categorizing the area in to unimodal and bimodal zones. Potential evapotranspiration (PET) of the area and the water body was estimated using Thornthwaite Mather and Penman Combination methods and Pan Evaporation method respectively. Actual Evapotranspiration (AET) was estimated using Turc and Soil moisture balance methods. Base flow separation and conventional water balance approaches were used to estimate recharge. To characterize the aquifer system of the area pumping test data, well completion reports, well logs and geology of the area were analyzed. Piper plots, Collins bar diagram and Hierarchical cluster Analysis (HCA) were used to classify the water chemistry. Maps, cross-sections and well-logs are used to show groundwater flow system and recharge discharge conditions. The estimated values of PET are 1222.93mm and 842.4mm using Penman and Thorhthwaite method respectively. The results indicate that, the highland which is unimodal rainfall pattern zone receives more precipitation (1284.65mm) than the lowland (1216.6mm). Pan Evaporation method resulted about 2.57mm for the open water evaporation which was insignificant as compared to the area. AET was estimated to be 800.92mm and 1019.8mm using Turc and Soil moisture balance methods respectively. The estimated recharges of the area are 129 and 96.18mm using base flow separation and water balance approaches respectively. The average of the two values is taken as the annual recharge of the area which is 9.2% of the total precipitation. The pumping test analysis results indicate that the hydraulic conductivity of the area ranges from 0.17 – 8.8 m/d and the mean and median were 2.17 m/d and 1.12 m/d respectively. There was variation in water type from Low TDS Na-Ca-HCO₃ to high TDS and EC Na-HCO₃ water types. Accordingly, the western and northern part of the area is recharging zone and the central and southern part is discharge zone while the area just southeast of Boyo plain is categorized under deep groundwater zone due to the damming effect of Ambericho fault. Thus, detailed hydrogeological especially remote sensing and geophysical investigation should be conducted to delineate major water bearing zones, aquifer thickness and aquifer depth in the volcanic and alluvial formation particularly in the northern part of the study area.

Key words: Upper Bilate, western escarpment, recharge estimation, aquifer characterization, hydrochemistry, recharge/discharge zone.

CHAPTER ONE

1 Introduction

1.1 Background and Statement of Problem

Upper Bilate River Catchment is found in Western Escarpment of the Main Ethiopian Rift. The two perennial rivers namely Weira and Guder which feed the main Bilate River emanate from the Silte (Alichu Wiriro Woreda) and Partly from Gurage (Gumer woreda) highlands and around Hossana respectively. There are also some intermittent rivers which emanate from the highlands of the catchment, though they are seasonal they contribute significant amount of water to surface and groundwater. Some part of this river catchment particularly Shashogo woreda suffer frequent flooding from the highlands of neighboring zones during rainy seasons, owing to this critical problem farmers can't farm wide farm lands. However, in this river catchment the former Government had planned to develop a big irrigation project, 'Boyo Irrigation Project', and had tried to implement the proposed project, during the transition period the farmers shattered the structures which were constructed and sprinkled the construction materials. But this river catchment, has still untouched wide agricultural land with its perennial rivers and very good weather conditions for investment.

Population growth and utmost interest to hold wide area, the research area land cover is dramatically decreasing and through time the land is going to be bare. This crisis leads to fertile soil erosion and decreases groundwater recharge by facilitating runoff. Now a days, rivers carry enormous amount of water and fertile soil to downstream. It is also becoming a global issue for environmental Change.

Both ground and surface water are renewable if managed in a responsible and sustainable manner and are non renewable otherwise, which has adverse effect on an area. Therefore, identification of factors accountable for depletion of water resources is useful for policy makers to manage the problem with respect to the rising demand.

This study will provide more detailed results that can readily be used for groundwater development, aquifer and watershed management that will lead to sustainable and environmentally sound water resources utilization practices in the Upper Bilate Catchment

by thorough investigation of the Precipitation, Runoff, topography, geology, land use land cover and aquifer conditions of the area.

1.1.1 Significance of the Study

The result of the proposed research work will have a great importance in filling the science gap, provide detail Hydrogeological information about the area which can be one input for understanding of hydrogeological systems of the river basin, and used as data for further research work.

Moreover, this research work covers portion of four SNNPR zones and one special woreda; Hadiya, Gurage, Silte, Kenbata Tenbaro Zones and Alaba Special Woreda. The findings of this research work used for understanding the natural water budget of the basin, has substantial importance to utilize the resources safely without harming, provide information in order to utilize the water resources of the area properly and keep the existence of the resources sustainable, for economic feasibility, construction, and development of water supply schemes in the area.

1.1.2 Previous Works

Previously the study area had been assessed by governmental and non-governmental organizations for different purpose at different time. Among these The Hydrogeological Map of Ethiopia 1:2,000,000 compiled by Tesfaye Cherent (1993) has been reviewed for the benefit of the intended research. This is a regional scale aquifer classification, standardizing the productivity of aquifer and broad scale potential assessment. According to this study the study area covered with two formations, namely Trachybasalts, trachytes and rhyolites and Ignimbrites and pumices of the Rift floor. The first group includes alkali trachytes and subordinate basalts of the huge mountains at the Rift margin (e.g. the Arsi Mts. and the Guraghe Mts.). This formation covers north western part of the study area including Mugo, Kebule, Wasela, Kebecho, Homagera, Wegila, Bele, Homacho, and Simbate Ridges. These rocks are generally massive and they have a low permeability and productivity except where a few faults cause localized fracturing.

The second formation includes ignimbrites and pumices of the rift floor and subordinate lacustrine deposits which are located south east of the study area. In most cases the

ignimbrites are well jointed while in some cases it is massive and pumiceous. Where it is well jointed, it has a high to moderate permeability, but in the rest a low permeability.

Geological Map of Ethiopia 1:2,000,000 2nd edition compiled by Tefera *et al.* (1996) also has been reviewed. It is a very regional Scale map, showing the outline of major geologic unit. The study area comprises of Tertiary Volcanic, quaternary volcanic and quaternary sediments.

Water Resource Potential Assessment of the two neighboring river basin namely Omo – Gibe and Bilate River Basin which covers 10 Woredas of SNNPR Zones was conducted in regional scale by AG Consult Consulting Hydrogeologists & Engineers Plc.(2007) based on the request of Southern Nation, Nationalities and Peoples Regional State Water Resource Development Bureau. The objective of the study is to ensure a high success for the development of the water resources of the region for economic and social benefits of the people, allocation and apportionment of water, based on comprehensive and integrated plans and optimum allocation principles that incorporate efficiency of use, equity of access, and sustainability of the resources.

According to this study, the study area classified into four basins based on dominantly recharged and dominantly discharge areas, groundwater availability and its burial depth and geomorphologic setting for the purpose of hydrogeological characterization, namely: the watershed areas of Bilate and Gibe drainage basins, upper to middle Bilate drainage basin, Dijo River drainage basin, and Eastern and south eastern Alaba Terminal small basin. From this classification the second drainage basin falls in upper Bilate river catchment. Which is further divided into three sub – basin namely: Lemo-Angacha plateaux and Boyo plain western Sankura-Alaba saddle. It points out the Lemo – Angacha plateaux are covered by acidic to intermediate lava rock unit and pyroclastic deposits such as ignimbrites and subordinate tuff. The groundwater in this region shallow to deep probably was resulting from local geomorphological condition and structural condition. The buried depth of groundwater ranges from 7m to 133ms.

The second subdivision is Boyo plain. This plan is runs approximately N-S and confined from east by Lemo structural ridges and from the west by Ambericho fault that passes close to Doisha town and extends south to Bonosha town. The floor of the plain is mainly covered by lacustrine and alluvial, debris flow or talus deposits. The groundwater in this

region is shallow and abundant .The later subdivision which is the Western Sankura-Alaba saddle receives recharge from scanty rainfall and Bilate River (areas gets closer to this river). This zone is mainly covered by pyroclastic deposits such as tuff, ignimbrites and ash. The buried depth of groundwater in this zone is deep. Generally the depth to major groundwatertable is over 80m. The shallowest watertableever encountered in this zone is 81.95 m and the deepest is 182.6 m.

SOS Sahel/Ethiopia carried out a research on Land cover change and Land Degradation study at Boyo Lake Catchment in November,2008 at large scale. The research investigated land cover changes, extent of land degradation, its causes, and effects in Boyo Lake catchment during 1973-2000. It also explored the pattern of changes in the different land cover units, interactions between them and the effects such interactions have brought to the general environment and the human livelihoods in the study area.

The study combined GIS and Remote Sensing techniques with secondary data, in-field interviews, and focus group discussions in order to understand the complex environment of the catchment and develop action-oriented proposals that would contribute to the reconciliation of human actions and environmental sustainability.

Hydrogeology of The Bilate River Basin, by Girum Lissanu, Geological Survey of Ethiopia, Addis Ababa, 1981 is also previously conducted research work in the study area. This research work discussed the hydrogeological characteristics of the Bilate River Basin. The area of the basin covered during this study extend between $06^{\circ} 44''$ to $08^{\circ} 22'$ North and $37^{\circ}44''$ to $38^{\circ}30'$ East.

It is pointed out in the report that physiographically the Bilate River basin is a tectonic valley with a length of 170 kms and width ranging from 5 to 60 kms. Along much of its length the valley is bounded by fault scarps or steep slopes on either side. The floor of the valley is mostly flat plain and appears to be in part a remnant of the depositions floor of ancient large water basin.

Water quality of Bilate River and its major tributaries such as Bisare, Bidessa, Beshan Guracha, Cherake and Guder have been studied and analysis was made for anions and cations. The TDS generally increased downstream. The increase downstream could be influenced by the corresponding low rainfall, high evaptranspiration, and relatively

sluggish drainage and mineralized thermal springs that join the river downstream. Accordingly the groundwater quality deteriorates to the east and south. The salinity increases with depth to the watertable and it was because of the bicarbonate.

It is also mentioned in the report that water bearing characteristics of the geological formations within Bilate basin has been qualitatively classified as: Alluvium, Pleistocene, Basalt, Ignimbrite, Volcano Sediments and Rhyolitic and Trachytic lava flows which signify excellent aquifer, very good aquifer, good aquifer, and poor aquifer and aquicludes respectively.

1.2 Objective of the study

1.2.1 General Objective

The general objective of this research is to assess hydrogeological system and groundwater potential investigation of Upper Bilate River Catchment.

1.2.2 Specific Objectives

- To show the regional, intermediate and local groundwater flow direction of the catchment,
- To delineate the major water bearing zones & characterize aquifers by zonation of permeability ranges within the catchment & mapping potential groundwater zones,
- To identify the groundwater recharge-discharge condition with their environmental controlling factors,
- To produce geological map of the area,
- To produce hydrogeological map of the area,
- Assess the hydrogeochemistry of the catchments and use the data for hydrogeological system analysis (to delineate recharge and discharge zones, flow systems and aquifer connectivity with adjacent catchments and understand the origin of the different water bodies), and
- To assess water quality from domestic and agricultural point of view.

1.3 Approach and Methodology

To achieve the above objectives different data such as literatures, meteorological, stream flow, maps, pumping test, lithological logs, well and spring inventory, in situ and laboratory chemical test results have been collected from different sources. The data sources are Addis Ababa University, Ministry of Water Resources, Meteorological Agency, EMA, WWDSI, AG Consult, SOS/Sahel, Regional, Zonal and Woreda water Resource development offices and EIGS.

The mean monthly and annual meteorological parameters were analyzed using Microsoft Excel and the estimated values were used to analyze potential (PET) and actual (AET) evapotranspiration and recharge of the area. In assessing the PET Penman combination methods, Thornthwaite and Mather, and Pan Evaporation methods were used. AET was computed using Turc and Thornthwaite Mather Method.

The collected point precipitation data were changed to areal depth of precipitation using Arithmetic mean, Thiessen polygon, and Isohytal contour map methods to represent for the whole area.

The collected stream flow data from the two tributaries; Guder and Weira and the major Bilate River were analyzed to separate surface runoff and base flow of the streams and the estimated values were used to compute groundwater recharge of the area.

To figure out the groundwater recharge of the area two conventional methods used; Long term mean minimum flow of streams and water balance of the area. Pumping test and lithological test analysis data were collected to characterize aquifer and groundwater flow system of the catchment.

70 water chemistry analysis results were collected from secondary and primary sources. Out of which 60 are of secondary sources and 10 are of primary sources. These data used for hydrochemical investigation and water chemistry assesment from domestic and agricultural point of view.

CHAPTER TWO

2 General Overview of the study area

2.1 Location and Accessibility

Upper Bilate River Catchment is found in SNNPRG 230 km. South West of Addis Ababa and 130 Km. North West of the regional town Awassa. This river catchment covers portion of four SNNPRG Zones; Hadiya, Gurage, Silte, and Kenbata Tembaro zones and Alaba Special Woreda. The river catchment starts from the highlands of Gurage and Hadiya Zones to the river gauging station Alaba Special Woreda.

This river catchment encompassing an area of about 2,075 Square kilometers and a perimeter of 295 km. and it is delimited within zone 37⁰, 800000 - 900000 N and 360000 – 420000 E. The elevation ranges from 1750 – 3350 m.a.s.l.

The area can be accessed through two routes, one on the Addis Ababa-Hossana asphalt road and the other on the Addis Ababa-Shashemene-Ariba Minch asphalt road which are 230 Km. and 340 Km. respectively. Some of the roads within the study area are all weather gravel roads and the road networks are poorly developed. During rainy seasons starting from June through October most part of the catchment will be under water which makes the area inaccessible using vehicle except motor bicycle.

2.2 Physiography and Climate

2.2.1 Physiography

The physiographic set up of the study area is the result of volcano- tectonic, rifting and erosion and deposition processes. Owing to these Earth Processes, the area falls within the elevation range of 1,750 - 3,350 m.a.s.l.

The catchment can be divided into three physiographic regions: the rift, the transitional escarpment and highlands. The middle part of the basin which totally covers Shashogo and Ana Lemo Woredas is the rift floor bounded to the west by Mt. Ambericho, Mt. Dato, to the north Mugo Ridge and to the east Ambericho fault line. Most part of Angacha, Danboya, Lemo, woredas are categorized under the transitional escarpment zones with an altitude ranges of 2,000 – 2, 400 m.a.s.l. These areas are characterized by steep faults and

fractures dip towards the rift. The rugged topography which incorporates Misha Woreda to the North West, Meserake and Meerab Azernet Berbere, Muhur Aklil, Gumere, and Alichu Wiriro Woreda to the North and part of Angacha and Danboya woredas to the South West is classified under the highlands. Almost all springs in the study area emanate from the shoulder of these mountainous areas.

The lowest elevation is the level of Bilate gauging station (1,750 m.a.s.l) and the highest is Alichu Wiriro Woreda (3,350 m.a.s.l). There is a large topographic difference between the rift floor and the plateau.

The catchment has a closed surface water drainage system. It is bordered by Omo – Gibe basin to the south west, Ziway – Abijata – Shala Lakes basin to the east and Lower Bilate catchment to the south.

Guder and Weira Rivers are the two perennial rivers which feed the main Bilate River. These rivers emanate from the shoulder of mountain ridges that boarder the area from the west and north respectively. The intermittent Batena and Konkoye rivers from the western and eastern part of area also feed Guder and Weira rivers respectively. There are also intermittent rivers for example Metenchose and Jeto which feed significant amount of water during rainy season since they originate from the steep fault escarpment.

The drainage density is high in the plateau and escarpment area and very low in the rift floor (Ayenew 1998). It is due to intensive faulting and volcanic activities in the area. In many places small stream disappear in the floor, before reaching the major drainage system. The typical example is Metenchose Stream. It originates from Amberichao Fault plain from Wulbarege Woreda and dumps its entire load within the Boyo Plain before reaching Lake Boyo. It has no predefined channel that is why it displaces most of Shashogo Woreda community during rainy season.

The drainage pattern of the area is characterized by dendritic and rectangular pattern.

2.2.2 Climate

The climate of the area is humid to sub – humid in the highlands and semi – arid in the rift valley. The long term mean annual temperature vary widely, it ranges from 16⁰C and below it in the highlands and around 20⁰C in the lowlands. The lowest temperature occurs

during the main rainy season; seasonal temperature variation is not pronounced. The temperature of the area shows strong altitudinal variations but the rainfall is not. The minimum and maximum temperatures of the area are 12.7⁰C and 25.76⁰C respectively.

The study area shows two rainfall pattern zones; the northern and north western unimodal pattern zone and the central and southern bimodal pattern zone. The unimodal pattern zone receives relatively higher precipitation (1284.7mm) than the bimodal rainfall pattern zone (1216.7mm). In general, the long term average mean annual rainfall of the area is estimated to be 1231.65mm. The main rainy season is June through September.

The maximum and minimum relative humidity of the area is estimated as 79.8 % during the month July and 57.5 % during the month February respectively. The long term mean annual wind speed at 2m above the ground level is 1.39 m/s. The potential and actual evapotranspiration of the area are 1222.93 mm and 1019.8mm respectively.

According to the climatic classification for Ethiopia, the study area has three physiographic zones; the Alpine zone with an altitude range of ≥ 3000 m.a.s.l, the plateau zone with an altitude range between 2200 – 3000m.a.s.l, and the medium altitude zone with an altitude range between 1700 – 2200m.a.s.l.

2.3 Settlement and Existing Water supply

The study area is one of the most densely populated regions of the Country; because of the culture to have many children and wide farm land. In addition to this, the weather condition is favorable for living with relatively low death rate. The total population is estimated to about 1,582,219 (CSA 2007).

Water is being used for domestic and agricultural purposes. The distribution of water supply schemes is not evenly distributed throughout the area. The area covered with alluvial and fluvial deposits have better access to water supply. Majorities of the people who live around shallow and deep well infeasible area depend on traditional water supply sources such as unprotected springs, rivers and open dug wells. The existence of high fluoride concentration in groundwater sources makes the problem sound.

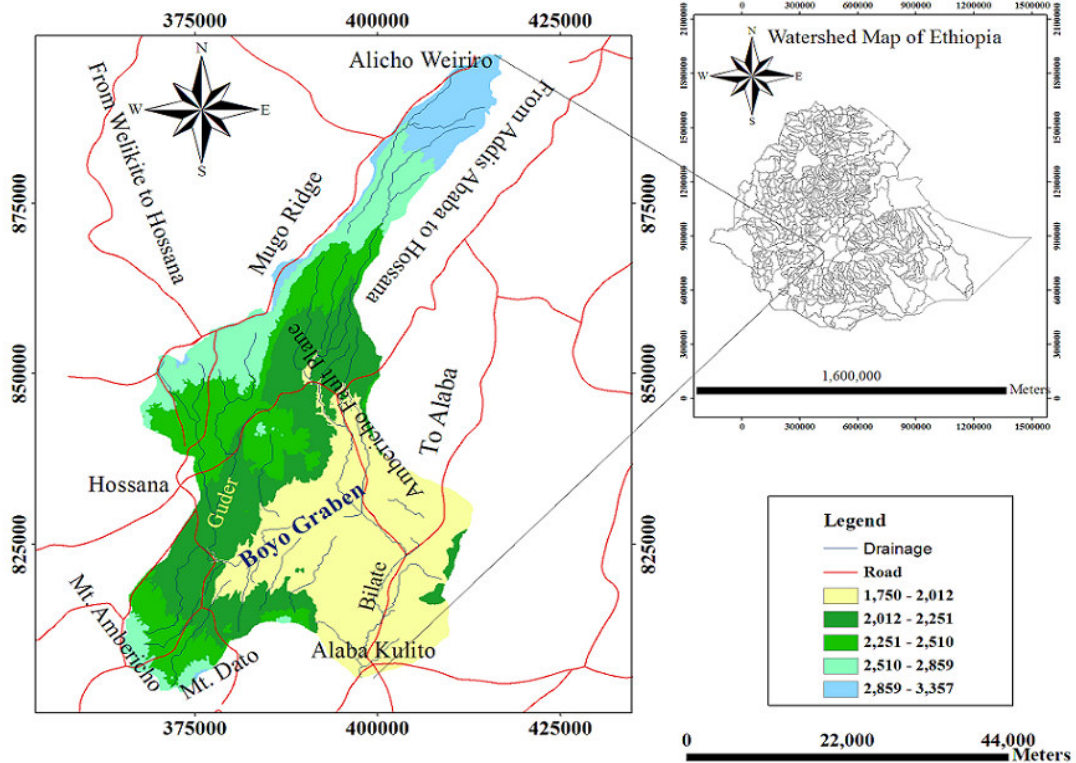


Figure 2. 1 Location Map of the study area.

The study area covers 13 woreda of SNNPRG. The population of each woreda with their respective water coverage is presented in Table 1. The data were collected from AG – Consult Engineers and Hydrogeologists PLC, the respective zonal and woreda water resource development office and CSA.

Table 2. 1 Population of each woredas and their water coverage.

No.	Woreda	Water coverage	Population
1	Lemo	18.3 %	148,063
2	Shashogo	22%	123,588
3	Misha	18.7%	163,920
4	Wulbareg	17%	89,967
5	Analemo	19%	89,967
6	Alaba	39.6%	237,372
7	East Azernet	10%	101,874
8	West Azernet	11%	94,287
9	Angacha	11.3%	117,558
10	Gumer	21%	114,259
11	Alichu Wiriro	12%	125,624
12	Doyogena	27%	82,723
13	Danboya	26%	93,017
Total		19.45%	1,582,219

2.4 Land use/Land cover and Soils

2.4.1 Land Use/Land cover

Land use/land cover map of the area is used for the purpose of evapotranspiration estimation (chapter 3). It is prepared based on field observation and satellite imageries. Land cover units are incorporated in the soil – water balance model by way of rooting depth. In terms of areal coverage the important land cover units are cultivated land, grass land, bush/shrub land, wood land, bare land, permanent open water body (Boyo Lake) and swamp. Settlement covers a small area.

The main crops grown in the area are wheat, barley, maize, sorghum and different types of grains and vegetables. A large portion of the land in the rift is covered with grass, bushes and shrubs. Most part of the area is characterized by Eucalyptus tree which has deep rooting depth.

2.4.2 Soil

Soil map of the study area was used to estimate soil water holding capacity in the course of actual evapotranspiration using soil – water balance approach. It shows the influence of soil parent material and the spatial variability in the degree of weathering. Soils are formed on account of the climate, physiographic, geology and other factors responsible for soil formation and development. The central part of weakly developed soils is associated with lacustrine sediments, river alluvium and pumice. Unconsolidated sediments are common below the rift shoulder slopes and at the foot of volcanic mountains. Many areas bordering the rift bear well – developed soils overlying weathered ignimbrite and pumice.

According to FAO textural soil classification (FAO 1997) and the Land use/land cover practice of the area, the soil of the basin is reclassified into four classes.

Class – 1:- This class is dominated by clayey soil. It is the result of hydrolysis and dissolution of silicate minerals due to the aggressive nature of water caused by dissolved CO₂. When CO₂ charged waters that are low in dissolved solids encounter silicate minerals, such as Plagioclases, olivine and pyroxene will leached and leaving an aluminosilicate residue (clay) with increased Al/Si ratio. It has a well developed soil profile except in a few areas of the rift, floor and in hill slopes and volcanic ridges where the soil cover is typically thin.

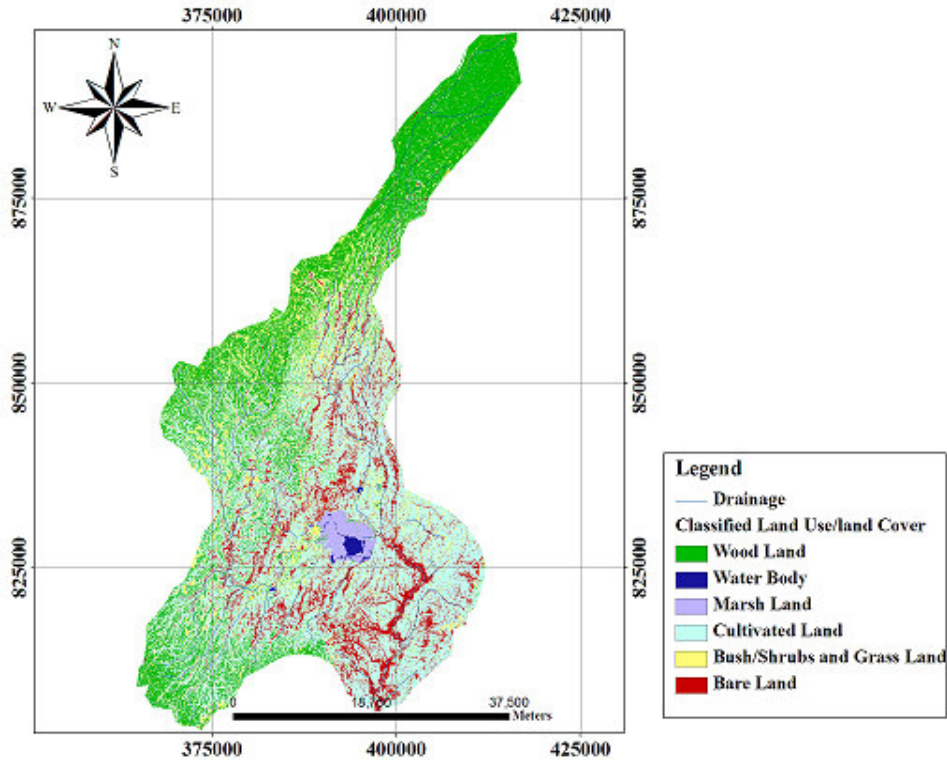


Figure 2. 2 Classified land use/land cover of the area

The area classified under this class is extensively cultivated and moderately deep rooted crops such as corn and cereals are grown. It covers the highland and escarpment of the rift.

Class – 2:- The floor of the rift is covered with this class soil. It is conquered by fine sandy loam soil with moderately deep rooted crops dominantly corn. In the central and southern part of Shashogo and Alaba Special Woreda the shallow rooted paper can also grow. As compared to class – 1 it is not extensively cultivated. The change in colour and texture from place to place, are derived from a variety of volcanic materials and are associated with fine textured volcano – clastic and alluvial deposits (Ayenew 1998). The weathering product of volcanic ash and pyroclastic deposits is also the major source of this class soil.

Class – 3:- texturally these soils are the same as class – 1, but the degree of cultivation and vegetation practice differ. Due to the presence of wood the degree of cultivation is less than that of class one. These soils occupy higher altitude around Gumer and Danboya woredas.

Class – 4:- These are predominantly silt loam texture soils. The soils have fine – grained unconsolidated parent materials and have thin surficial material and alluvial deposits. Their topographic position and low coherence of matrix materials make these soils sensitive to

erosion. Bare land and gully are common south east of the study area due to this incoherence behavior of the soil. In this part of the area deep rooted crops such as postural grass and shrubs are commonly grown.

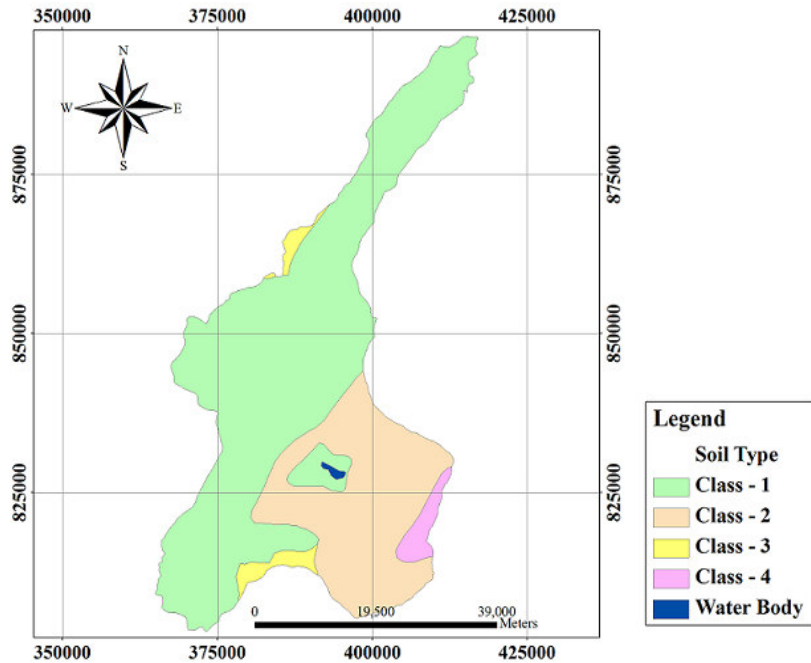


Figure 2. 3 Reclassified FAO (1975), Soil map of the area.

2.5 Geology

2.5.1 Regional Geology

Bilate basin lies within the Main Ethiopian Rift, which forms part of the 5000 km. long down faulted trough. The rift floor and escarpments are highly faulted. The faults in the MER are parallel and sub-parallel to the NE–SW trending rift axis (Woldegebriel *et al.* 1990). The Rift floor is affected by several faults that form smaller horst and graben structures. The NNE-SSW and N-S trending faults are the dominant faults, while the E-W and N-S faults control stream courses in the southern and southwestern part of the catchment.

Except patchy Precambrian rocks, the rift is covered with Cenozoic volcanics and Tertiary and quaternary sediments (Mohr 1967; Woldegebriel *et al.* 1990). The volcanic rocks are dominantly fissural basaltic lava flows, rhyolites and ignimbrites associated with volcanoclastic tuff and ash deposits (Ayenew *et al.* 2008).

Older volcanic units (Pre-Pliocene) outcrop on the rift escarpment or margin and the recent volcanics cover the entire rift (Kazmin *et al.* 1980). The Main Ethiopian Rift Valley (MER) contains abundant acidic lavas and ignimbrites and they are associated with central volcanoes containing wide calderas. The axial rift is covered by Quaternary central volcanic products. On the MER, peralkaline silicic ignimbrites, unwelded pyroclastics and minor lavas related to fissural eruptions of regional extent are the most abundant volcanic rocks.

The general stratigraphy of Bilate Basin which has been investigated by Ethiopian Geological Survey comprises volcanic and sedimentary units. The stratigraphy summary of the river basin from the oldest to the youngest is as follows;

- A. Pre – Rift Basaltic succession with minor silicic members (Jima volcanic – Tertiary volcanic) are well exposed on the plateau and escarpments adjoining the Bilate River Valley which rests unconformably on the Precambrian basement. The basalt flows form an unbroken succession and several hundred meters thick in some places. They are intensely jointed, hydrothermally altered and spheroidally weathered basalts outcrop in the western escarpment of Lake Abaya graben. Tertiary volcanic succession has been down faulted into rift floor which in part is covered by rift valley lakes including Abaya and Boyo.
- B. Upper - Miocene (9 – 5 my) succession (Nazereth – Series). According to Meyer *et al.* (1978) cited in Tefera *et al.* (1996) the name Nazereth Series was given to a thick succession of welded ignimbrites with fiamme, pumice, ash and rhyolite flows and domes with rare intercalations of basalt flows which occur in the MER, rift margins and adjacent plateaus. This formation includes what was mapped by Di Paola *et al.* (1972) as basalts and ignimbrites of the plateau Trap Series. The Nazereth Group volcanic products are exposed over the surrounding areas along the rift margins and escarpments. The ignimbrite of the Nazereth series is considered to be products of eruptions mainly from marginal centers in the rift (Morbedelli *et al.* 1973). An age range of 9 – 3 Ma has been given to the Nazereth Series (Tefera *et al.* 1996).
- C. Mursi and Bofa Basalt – Late Pliocene (4 – 1.6 Ma) flood basalt volcanism is widespread in MER rift and other related rifts (Mengesha *et al.* 1996). According to Kazmin *et al.* (1981) cited in Tefera *et al.* (1996), the Bofa basalts are well developed in the northern and central part of the MER forming a wedge between Nazereth Series and Dino formation

and a lower age limit of 3.5 Ma. In the rift floor, the Nazereth Group is overlain by succession of flood basalt of Pliocene age.

- D. Dino Formation – in this river basin the Bofa Basalt and Nazereth Series are in most places overlain by green and gray ignimbrites with well developed fiamme and associated unwelded pyroclastic and waterlain pyroclastic with occasional intercalated lacustrine beds and aphyric basalts. The pyroclastics of the Dino Formation may have sources from axial felsic volcanic eruptions complexes. The felsic lava of the Dino formation are peralkaline in composition and the ignimbrite members are not confined only to the rift floor but extensively developed on the escarpments.
- E. Quaternary Ignimbrite – this formation overlay Bofa Basalt of Pliocene age. It comprises of Quaternary bimodal transitional basalt/peralkaline felsic volcanic products of Wonji Group. The volcanic products of Wonji Group (including those from axial volcanic centres) are intimately associated with lacustrine sediments related to ancestral lakes in the rift floor (in the fluvial periods of Pleistocene).

With the formation of Wonji Fault Belt during the Upper – Miocene – Quaternary times tectonic movement and volcanic activity occurred in the MER, which produced steep – like structures and related volcanic activity, represented mainly by basaltic lava fields together with aligned scoria and spatter cones. The fault zone is frequently marked by central volcanoes, which erupts significant amount of felsic products.

- F. Quaternary Pumacious Pyroclastic – They are grey and yellowish coloured, poorly sorted and consist of accidental fragments of rhyolites and basalt. This pumacious pyroclastic belong to the explosive episode of the older rhyolitic volcanic centres.
- G. Abaya Rhyolite (Rhyolitic Volcanic Complexes) – The Quaternary central volcanic complexes which are situated along the axial zones of MER (Wonji - Fault Belt) (Tefera *et al.* 1996). They are strongly banded in situ with alignment of fine vesicles and brittle thinly banded layers of few centimetres. They are exposed on the flanks and caldera rim of Obitchaka and Donga (Simbura) area.
- H. Alkaline Olivine Basalt (Tena Bilate) – Pleistocene to Holocene fissural basaltic volcanism in the MER are mainly concentrated along the WFB. The basalts are clearly controlled by extensional fractures with chains of scoria cones aligned along fractures and generally displaying fresh surfaces (Tefera *et al.* 1996). The NNE trending fault along the axis of the rift floor has been a conduit for basaltic eruptions with lines of scoria cones making fault traces. They are interstratified with the earlier succession of lake sediments. They are

- exposed over a broad area between Lake Abaya and Dugna – Fango and all along Bilate river bed and banks with adjoining rift floor being covered by the overlying intensely denuded lacustrine sediments.
- I. Dugna – Fango Rhyolite – These outcrop mainly at the base of Dugna – Fango volcano. Exposures are concentrated along the N – E to S - W trending, intensely tectonized stripe of land in the central part of the Wonji - Fault belt axis upon which the mountain building activities of Dugna – Fango took place.
 - J. Recent Basalt – The younger episode of basaltic eruption outcrops along an axial zone of more recent volcano – tectonic activity of the Sawla – Dore – Hako and North West Abaya hydrothermal field.

The next sedimentary sequences are:

- K. Pleistocene Volcano – Sediments:- they are essentially lacustrine sediments of mainly volcanic origin and were related to the existence of large lakes during Pleistocene time (Mohr 1967). They are generally yellowish – grey colored, horizontally bedded and poorly sorted with fragments of rhyolites, obsidian and basalt in a matrix of ash and silty clay.
- L. Holocene Lake Beds – they outcropped in localities surrounding Lake Abaya and Boyo. Lithologically they are mainly constituted by poorly compacted, well sorted and friable and fairly reworked yellowish clay and silt material.
- M. Recent Alluvial and Fluvial deposits – the lower course of Bilate River covered with fluvial deposits along its gentler slope. There are also lacustrine deltas on the northern part of Lake Abaya which are a few kilometers wide. Colluvial and outwash debris is found widespread in the area particularly along the foothills of the major fault scarps. Recent deposits in the area include soils and alluvial sand deposits. The soils are mainly residual weathering deposits, whose composition is controlled more by the physical condition of formations than by the type of rock from which they were derived. On the older basaltic area dark brown cotton soil is common while the soil outcrop of the ignimbrites is red lateritic.

2.5.2 Local Geologic Set Up

Local geologic set – up of the study area mapped using field observations of river cuts, quarry sites, exposed mountain cliffs, bore holes and shallow well logs, vegetation and

drainage network patterns. These all are supported by interpretation and analysis of topographic maps (1:50,000), satellite image (1:100,000), DEM (1:100,000), and GPS.

Upper Bilate River Catchment is mainly covered with Cenozoic volcanics and Tertiary and quaternary sediments. The major formations which cover the area are; the Nazereth group (Upper – Miocene to Pliocene), Dino Formation, Pleistocene Volcano – Sediments, and Recent Alluvial and Fluvial deposits.

Accordingly, the lithologic description of each unit from the oldest to the youngest is presented below.

- a. Pre – Rift Basaltic succession with minor silic members (Jima volcanic – Tertiary volcanic). They are basalts with ash, tuff and rhyolites; often covered by ash and tuff. This formation is rarely exposed surficially in the study area, however it is reported in geological logs of bore holes that were drilled around the western highlands such as Hossana town water supply deep well #5, Kalisha Kebele deep well and Lera town water supply deep well.
- b. Upper - Miocene (9 – 5 my) succession (Nazerethe – group) – this formation include ash flow, tuffs, pantelritic ignimbrites and unwelded tuff. The Nathereth formation widely covered the northern and some part of western part of the study area including Alichu Weriro, Gumer, Merab and Meserake Azernet Berbere, Ana Lemo, woreda and the Westsern part of the study area including Angacha, Doyogena and Lemo woredas. The ignimbrite which exposed along the river cut and quarry sites at Lemo Woreda (Hise kebele), at Meserak Azernet Berbere Woreda (north of Kilito town) quarry sites, and at East of Doyogena Woreda quarry sites are black welded ignimbrite with fiamme. The thickness of the ignimbrite is ranging from 20 m at lower elevation and more than 60m at the peak places. In most places the upper part is altered and weathered due to exposure and the layer underneath is slightly jointed with very close joint separation and wide joint spacing. The intermediate lava flow varieties of these outcrops are weathered to kaolinite and it is reported from Lemo woreda that kaolinite is being mined in the area has been transported to Awassa where it is further processed at Awassa Tabor Ceramics Factory as an input for ceramics production.



Figure 2. 4 Showing the Nazreth series (Ignimbrite) which is the parent rocks for alteration products, like kaolinite.

The alteration product of the ignimbrite, ash flow and pumacious pyroclastics exposed at quarry sites Lafto Lenqa and Achamo have been used as selected construction materials for road construction.

Trachytic and rhyolitic lava flows are reported at the boreholes drilled around Lisana kebele along the border of Lemo and Shashogo Woreda (along Disahamo, Ajacho and Lisan ridge) and slightly exposed at foot of Mugo ridge around Moshoshe and Sheshera springs (which are going to be the sources of Hossana town water supply).

- c. Dino – Formation - Nazereth Series are overlain by green and gray ignimbrites with well developed fiamme and associated unwelded pyroclastics mainly tuff, ignimbrite, pumice and waterlain pyroclastics with occasional intercalated lacustrine beds. This formation is widely exposed at quarry sites and at Bilate river bed of Shashogo and Alaba Special woreda. It is also exposed at quarry sites of east of Angacha and Danboya woreda and at Lemo and Ana Lemo woreda. The gray ignimbrite with associated unwelded pyroclastics is well exposed on the road from Worabe to Alichu Wiriro and the peak around Wulbarege and East Azernet Berebere are pumacious and unwelded pyroclastics. These peaks ranging in height from 50 – 100m from the ground level. Pyroclastic agglomerate is noted along Doisha Ambericho fault scarp.



Figure 2. 5 Showing tuff and Pyroclastic agglomerate

(Note: Highly fractured tuff and well developed crystals)

The peralkaline silicious undifferentiated composition of this formation observed at west of Angacha, Danboya towns and north of Alaba town at Tiliku Tuka ridge.

- d. Quaternary Ignimbrite - formation overlay Nazerezth and Dino Formation. It comprises of Quaternary ignimbrite and bimodal transitional basalt/peralkaline felsic volcanic products of Wonji Group. The rugged topography which surrounding Misha and part of west Azerent Berbere Woreda formed from this ignimbrite formation. It is also exposed along the river Jeto, at quarry site in Morsito town. The upper most part of this formation is moderately fractured and filled with secondary clay minerals. The spring which serve Morsito town and the spring 'Chaka – Minch' emanate from fractures of this formation.
- e. Rhyolitic Volcanic Complexes – This formation is equivalent to Abaya rhyolites. It is outcropped at south central part of Misa woreda and which overlies quaternary ignimbrite. The color of this formation is pinkish to reddish. The joints observed at GPS location 371392 E and 846924 N follows the MER trend which is NNE – SSW with vertical orientation and also has the same trend as which is observed at Bilate River Bed in ignimbrite around Alaba.

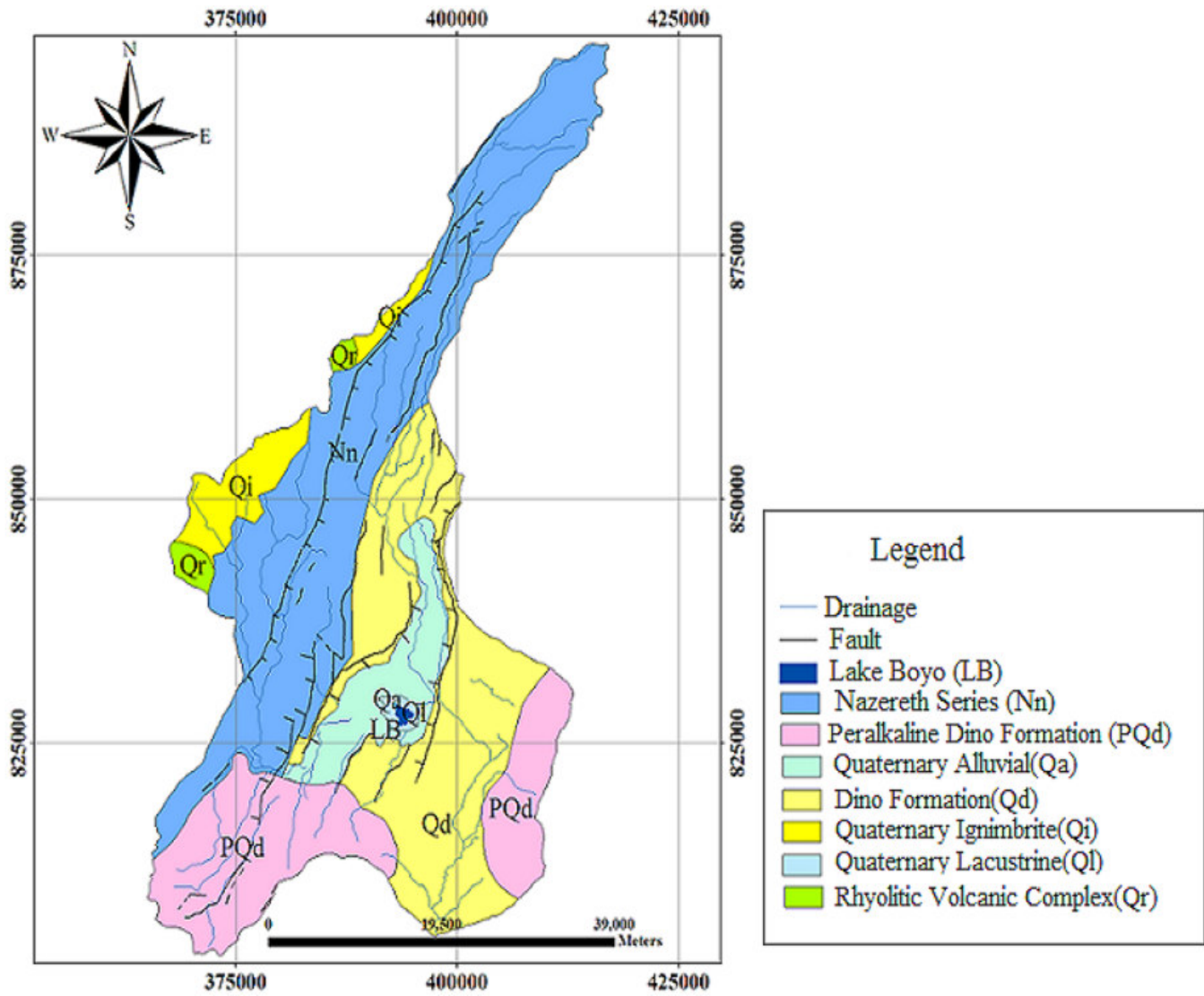


Figure 2. 6 Geological Map of the area.

- f. Holocene Lake Beds – This formation covers small area surrounding Boyo Lake/Swamp with a maximum area of 6sq.km. They are mainly constituted by poorly compacted, well sorted, and friable and fairly reworked yellowish clay and silt material.
- g. Recent Alluvial and Fluvial deposits – This formation covers most part of Shashogo Woreda especially at Boyo flood plain starting from Achamo kebele to Bidika kebele. The sources of this alluvial deposit are mainly Weira, Guder, and Metenchose rivers. Colluvial and outwash debris is found widespread in the area particularly along the foothills of the major fault scarps such as at the foot of Doisha Ambericho fault scarp, Mt. Dato and Mt. Ambercho. Recent deposits in the area include soils and alluvial sand deposits particularly around Doisha kebele at Metenchose river banks and Boyo flood plain. The soils are mainly residual weathering deposits, whose composition is controlled more by the physical condition of formations than by the type of rock form which they were derived. On the older basaltic area dark brown cotton soil is common while the soil outcrop of the ignimbrites is red lateritic.

2.5.3 Structural Set Up

Upper Bilate River Catchment is located in the south western escarpment of MER. This part of Ethiopian Rift, which has an average width of 80 km, is a complex trench trending North – North East and separating the Ethiopia plateau on the west and the Somalia Plateau on the east.

The basin is rift controlled basin and the rift floor along this drainage system is blanketed by welded tuff, lacustrine strata, and fissural basalt and maars (Zanettin *et al.* 1978). The drainage system of Bilate River is controlled by the NNE – NNW trending normal fault and E – W trending Bonga transverse fault system.

The central sector of the MER is a symmetrical rift, mostly characterized by well defined synthetic rift margins having variable throws along the strike of the boundary faults. These margins are marked by high angle normal faults with large throws that comprise several steps – faulted blocks. The faulted margins show right – angled spurs and re – entrants similar to those documented in the broad rift zone of south west Ethiopia (Moore and Davidsons. 1978; Davidson *et al.* 1983). These steps – faulted blocks form a ladder like structures in the northern tip of the area. In most places of this part erosion makes gentle slope towards the western escarpment.

At Gurage section, more than 1.5km thick flood basalt is exposed by several major step faults that strike north northeast and in turn, cut by northwest to north northwest oriented fault blocks topographically down from, and east of the main Gurage escarpment by these transverse faults has resulted in the blocks having a pattern of serrated edges and re-entrants (Woldegebriel *et al.* 1990). The rift within a rift formation within the central part of the study area forms horst and graben structures. The Graben which is presently occupied by Boyo Plain is the result of rift within a rift structure. This structure in association with the Ambericho fault scarp makes the whole Shashogo and Ana Lemo woredas Natural Reservoir.

The subdued and eroded rift margin of poorly welded tuff between the Wagebeta caldera complex and the Gurage escarpment shows a right angle spur where intersected by the transversely oriented Bonga lineaments (marked by its three aligned Wagebeta Calderas) (Woldegebriel *et al.* 1990). These transversely oriented Bonga lineaments used as a conduit for groundwater flow from the western highland towards the floor of the rift. The typical example is the emergence of most springs along the northern part of the surface water divide is the result of Bonga Lineaments.

In general, the northern and western part of the area is highly affected by tectonic activity and rifting. The lineaments in the study area are oriented dominantly in the, E-W, N-S, NE-SW, and NW-SE direction. Despite the overall NE - SW trend of the MER, the WFB is characterized by active NNE SSW trending extension fractures and normal faults. These are often set in an en-echelon arrangement and area associated with volcanic activity (Abebe *et al.* 2007). These type of faults are found at Ambericho fault plain north of Doisha town.



Figure 2. 7 Ambericho Normal fault with very steep deep angle, N – S orientation, and 80m displacement to west

CHAPTER THREE

3 Hydrometeorology

Meteorological data are used as a basis for the study of rainfall, runoff, evapotranspiration, and hence are among the crucial tools for water resources investigation.

3.1 Precipitation

The spatial and temporal variation of rainfall in Ethiopia is controlled by the movement of the position of the Inter Tropical Convergence Zone (ITCZ). According to rainfall distribution analysis and its temporal variability which was done based on rainfall data obtained in and nearer the catchment metrological stations (1971 – 2007) of EMA (Annex 3.1), the study area is characterized by two rainfall pattern zones.

The Northwestern part which covers Gurage and Silte highlands is characterized by Unimodal (single peak) rainfall pattern. The main rainy season in this part from June to September is controlled by ITCZ which lies to north of Ethiopia during these months .So, Southwest winds bring rains from the Atlantic Ocean.

The south and southwestern part of the study area which covers Boyo plain , Lemo and Kenbata highlands is characterized by Bi – Modal (double peak) rainfall pattern. The main rainy season in this part is from July to October is also controlled by ITCZ by the same reason.

The second wet season occurring from March to April, during this period the ITCZ will be located to south of Ethiopia moving northwards. When it positioned southward low pressure will be developed in Sudan and Arabia while high pressure develop over Gulf of Aden and Indian Ocean. The high pressure generates South East winds which brings the small moisture from Indian Ocean.

The dry period, from October to February is when the ITCZ lies to the south of the country. In these months, the north easterly trade wind traversing Arabia dominates the region and therefore, produces very little or no rainfall in the study area.

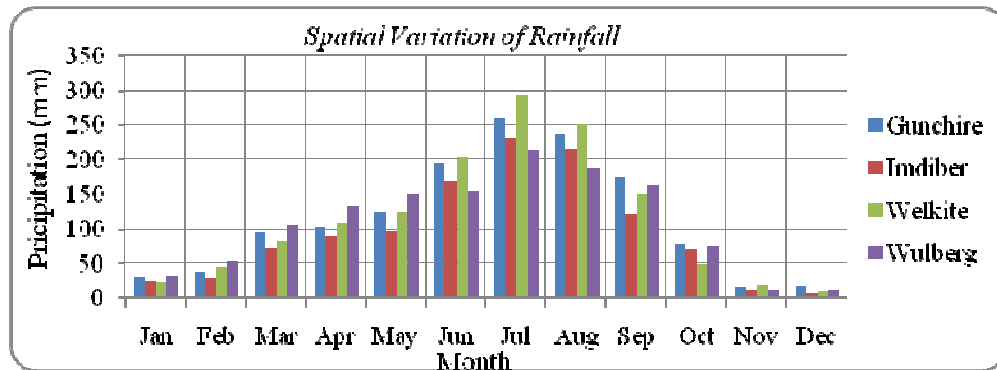


Figure 3. 1 Mean monthly precipitation trend of Northwestern part of the study area from 1971 to 2007 (Unimoda Rainfall Pattern Zone)

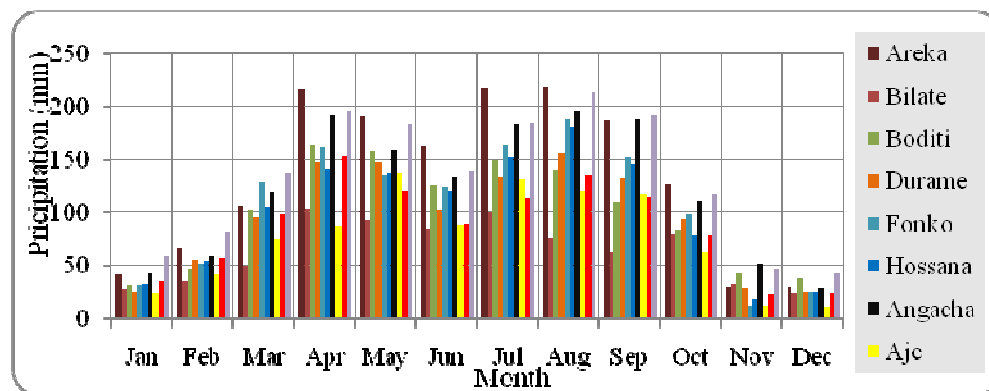


Figure 3. 2 Mean monthly precipitation trend of South and Southwestern part of the study Area from 1971 - 2007 (Bimodal Rainfall Pattern zone).

There are many physical factors controlling the depth and distribution of precipitation in a given catchment. Surface elevation is one of the powerful factors affecting the depth of precipitation in a given area which positively affects the depth of precipitation. However, in this river catchment instead of surface elevation (Correlation coefficient between rainfall and altitude is 0.083 i.e. poorly correlated) the rainfall is greatly affected by local rain shadow, the position to rain bearing winds (with lee and windward orientation), and Orographic effect.

During the main rainy season which is July/October when the ITCZ lies north of the country, southwest wind brings rain from Atlantic Ocean. This wind will be blocked by Mt. Ambericho and Mt. Dato., as a result the influence of Orographic effect creates a greater

rainfall depth at Areka (1595.06mm) and Shone (1585.61mm) stations than Hossana (1191.67mm) and Fonko (1275.87mm) stations. While at the second wet season the south east wind brings rain from Indian Ocean and this wind will also be blocked by Lisana and Mugo Ridges this effect produces rain shadow to Hossana station than Angach (1463.9mm) and Fonko stations. Owing to the above factors, Hossana have lower rainfall than the surrounding stations though it has greater elevation (2200 m.a.s.l.).

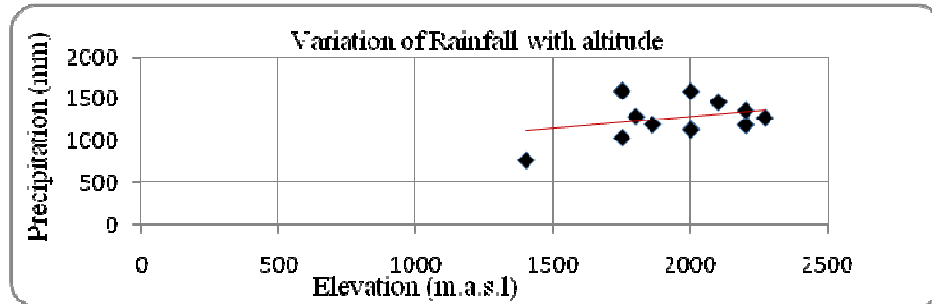


Figure 3. 3. Variation of rainfall with altitude.

3.1.1 Annual Effective 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 Isohyetal Contour Map methods. All these used for comparison of one from the other according to the Orographic effect and areal distribution of the stations.

3.1.1.1 Arithmetic mean – it is computed as the arithmetic mean of the amounts measured by the gauges within the area.

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

Accordingly, the areal depth of precipitation of the area estimated using this method is therefore 1236.05 mm Annex 3.1.

3.1.1.2 Thiessen Polygons method – this method assumed that the recorded rainfall in a gauge is representative for the area halfway to the adjacent gauges. Thiessen polygons are formed around each precipitation station by drawing the perpendicular bisectors of the lines joining adjacent stations. Using this method the weighted average of each precipitation stations based on the following relation.

$$P_A = \frac{\sum_{i=1}^n p_i a_i}{A_t} \text{ where } p_i \text{ is observed precipitation, } a_i \text{ is area where the station found,}$$

and A_t is the total area under investigation.

The area of each station and the total area under investigation were calculated using Arc GIS software 9.2. Accordingly the estimated average areal depth of precipitation is 1234.59 mm.

3.1.1.3 Isohyetal Contour Map method - it consists of drawing lines of equal rainfall depth (Isohytes) by interpolation between observed rainfall depths at observed points. The average depth of precipitation is given by:

$$P_A = \frac{p_{1,2} * a_{1,2} + p_{2,3} * a_{2,3} + \dots + p_{n-1,n} * a_{n-1,n}}{A_t}$$

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 estimated depth of precipitation using Isohyetal contour map method is 1231.65mm.

All the above methods are used to calculate areal depth of precipitation from point measurement. However, depending on distribution of gauging stations and the effect of topography validity of Arithmetic mean and Thiessen Polygon methods is less. Thiessen polygon method for determining areal rainfall is sound and objective, but it is dependent on a good network of representative gauges (Shaw 1988). In the study area the network of gauges is poor. Arithmetic mean is also unreliable in the study area because the area is found at the escarpment of MER it is highly affected by steep faults and the stations are widely spaced.

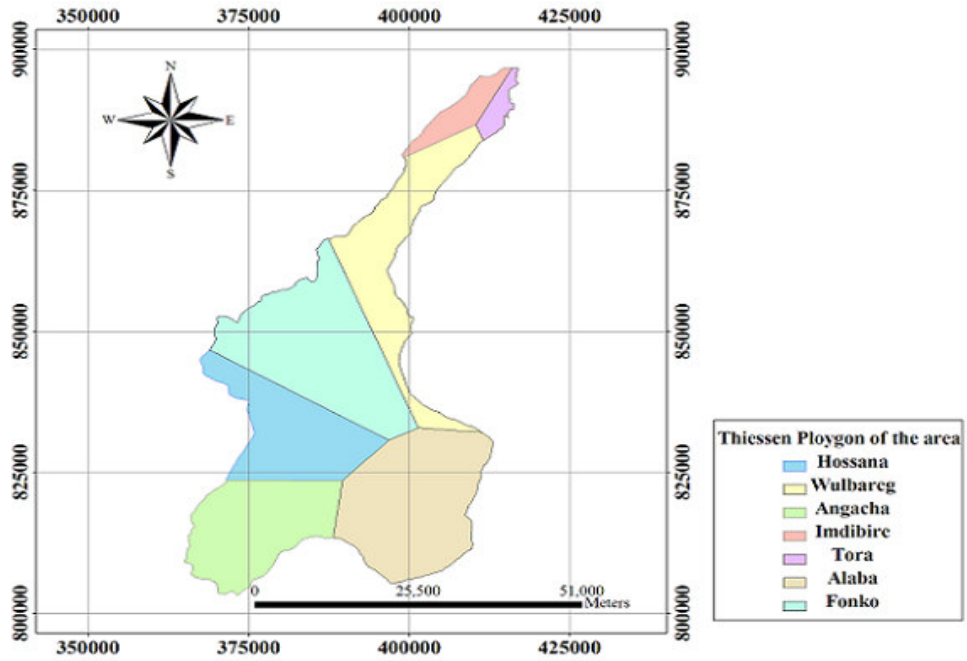


Figure 3. 4 Thiesson Polygon of the area.

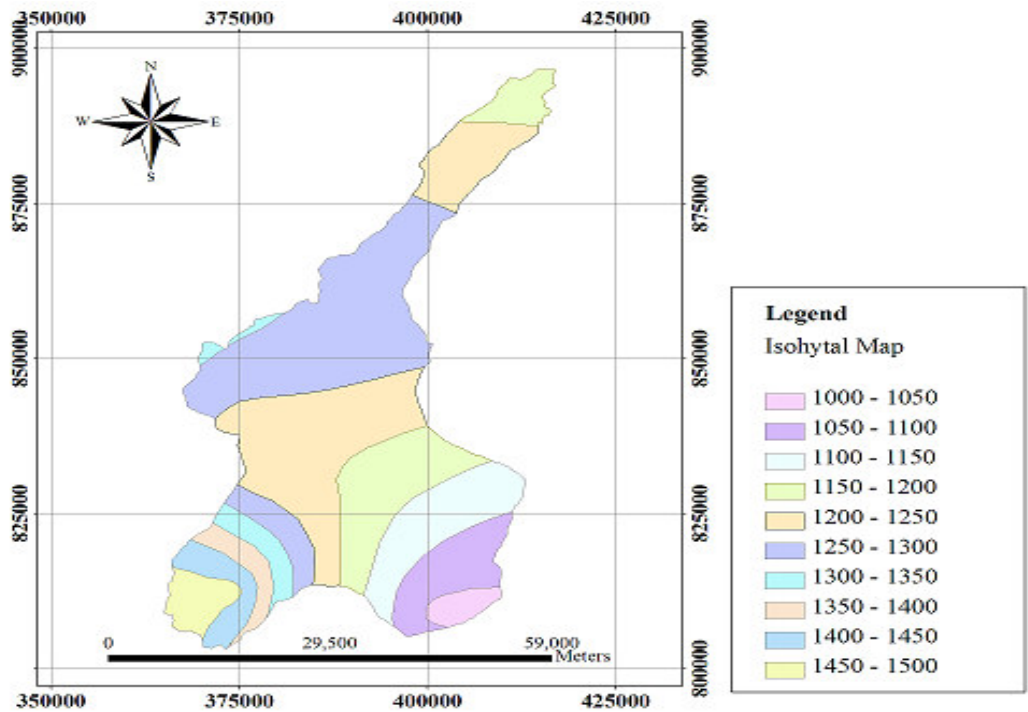


Figure 3. 5 Isohytal Contour Map of the Study area

While Isohytal contour map method is the most appropriate method of estimation of areal depth of precipitation for the area. Because the rainfall stations are unevenly distributed over the area due to orographic effect. Therefore the areal depth of precipitation of the area is 1231.65mm.

Table 3. 1 Long term average annual Temperature ($^{\circ}\text{C}$)

Station	Annual Mean Temperature ($^{\circ}\text{C}$) of the Study Area	
	Duration	MAT
Hossana	1978 – 2007	16.64
Alaba	1991 – 2005	19.49
Imdibir	1980 – 2007	18.74
Angacha	1991 – 2005	18.64
Wulbareg	1991 – 2005	17.4
Bodity	1981 – 2007	18.17
Bilate agricl.	1972 – 2004	22.81
Areka	1988 – 2003	19.82
Aje	1978 – 1989	19.59
Long-term average annual		19.03

3.2 Temperature

One of the factors affecting evaporation is temperature of the evaporating surface. The rate of evaporation is dependent on the temperature at the evaporating surface and that of atmospheric air. The amount of water vapour in the atmosphere is directly related to the temperature (Shaw 1988). At a given temperature air can hold a maximum amount of moisture: saturation humidity. This is directly proportional to the temperature of air. Mean annual temperature of the study area ranges from 16.64°C at Hossana to 22.81°C at Bilate agricultural station. Mean annual minimum temperature of the study is 12.7°C and Mean annual maximum temperature of the study area is 25.76°C . The mean monthly temperature of the study area ranges from 17.51 in August to 20.55°C in February/March.

3.3 Relative Humidity

It is the relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature. It indirectly governs the rate of evaporation; higher values indicate that the air is nearer to saturation point, and lower values that the air consists fewer water vapour in the atmosphere. As relative humidity approaches 100%

evaporation ceases. It is estimated from the Meteorological stations in and nearer to the area.

Table 3. 2 Long term Mean Monthly Values of A/ Temperature ($^{\circ}\text{C}$), B/ Relative Humidity (%) and, C/ Wind speed above ground level (m/s) and D/ sunshine hour (hour/day)

Station	A/ Monthly Mean Temperature ($^{\circ}\text{C}$)												
	Jan	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Areka	20.7	21.4	21.4	20.6	19.7	18.8	17.9	18.3	19.2	19.6	19.9	20.3	19.8
Bilate	23.9	24.5	24.6	23.8	22.6	22.2	21.1	21.5	22.3	22.4	22.4	22.9	22.8
Hossana	16.8	17.8	17.8	17.6	16.9	16.1	15.4	15.5	15.9	16.5	16.8	16.4	16.6
Indibir	18.8	19.5	19.5	19.5	19.1	18.6	18.2	17.8	18.2	18.3	18.8	18.9	18.7
Bodity	18.8	19.7	19.7	19.1	18.5	17.3	16.3	14.5	17.5	17.9	18.2	18.4	18.2
Mean	19.8	20.6	20.6	20.1	19.4	18.6	17.8	17.5	18.6	18.9	19.2	19.4	19.2
B/ Mean Monthly Relative Humidity (%)													
Bilate	50.4	52.8	60.5	69.4	71.3	72.4	73.5	70.6	71	67	57.1	51.8	63.9
Hossana	70.2	62.2	67.9	71.6	75.7	82.9	86	86.7	84.1	77.07	69.2	67.5	75.1
Mean	60.3	57.5	64.2	70.5	73.5	77.6	79.8	78.6	77.5	72.1	63.2	60	69.5
C/ Mean Monthly Wind Speed (U) 2m above ground level (m/s)													
Bilate	1.5	1.7	1.4	1.2	1.3	1.3	1.1	1	0.9	0.8	0.9	1.5	1.2
Hossansa	1.6	1.7	1.6	1.7	1.4	1.5	1.6	1.4	1	1.7	1.8	1.8	1.6
Mean	1.6	1.7	1.5	1.4	1.4	1.4	1.3	1.2	1	1.2	1.4	1.6	1.4
D/ Mean Monthly Sunshine Hour (hour/day)													
Hossana	8.4	8.1	8	7	7.4	5.7	3.9	4.1	5.8	8.5	9.5	9.6	7.2
Bilate	7.8	8.4	7.8	6.4	7.6	6.1	4.8	5.4	6.3	7	8.8	8.5	7.1
Mean	8.1	8.2	7.9	6.7	7.5	5.9	4.4	4.7	6.1	7.7	9.2	9	7.2

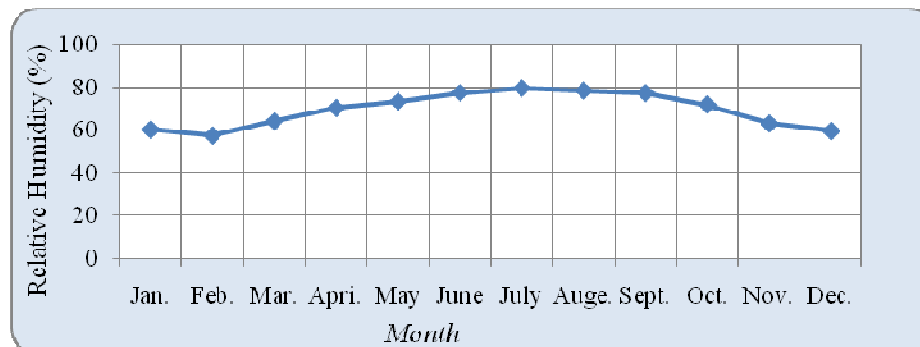


Figure 3. 6 Seasonal variation

3.4 Wind Speed

While evaporation proceed, the air above the evaporating surface gradually becomes more and more saturated and, if it is unable to take up any more evaporation ceases. The replacement of saturated air by drier air would enable evaporation to continue. Thus, this movement of air and moisture transfer is directly proportional to wind speed and turbulence. Though wind speed is an important factor in controlling the rate of evaporation, in the study area there is shortage of data. The wind speed is analyzed from the nearby stations Hossana and Bilate.

Accordingly, the average wind speed 2m above the surface of the earth of the study area is 1.4m/s.

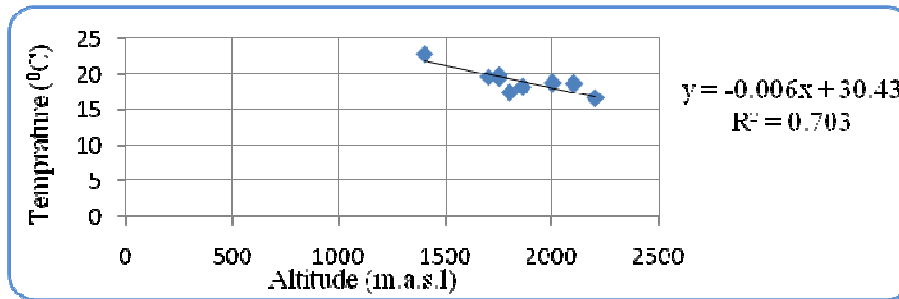


Figure 3. 7 Temperature versus altitude

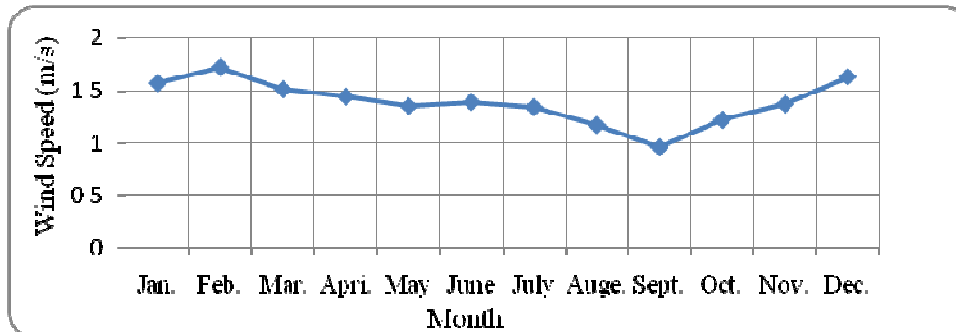


Figure 3. 8 Temporal variation of wind speed in the area

Table 3.3 Mean monthly precipitation computed for both rainfall pattern zones

Station	Mean Monthly Rainfall (mm) South and Southwestern part of the study area (Bi – modal Pattern)													
	Duration	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Areka	1988 - 2003	42.19	67.02	105.85	216.31	190.6	162.89	217.22	218.77	186.93	126.23	30.99	30.06	1595.06
Bilate	1971 - 2004	28.52	34.88	49.95	104.18	92.46	84.74	99.3	75.39	62.72	78.89	32.4	23.43	766.86
Boditi	1976 - 2007	32.09	47.98	103.37	164.33	158.33	125.16	149.69	139.95	109.79	83.92	43.42	38.06	1196.09
Durame	1978 - 2007	26.54	55.23	95.47	146.8	146.8	102.63	132.97	155.24	132.39	93.97	29.43	25.76	1143.23
Fonko	1986 - 2007	31.57	52.08	129.44	162.22	135.07	124.44	164.05	188.2	152	98.26	12.16	26.38	1275.87
Hossana	1978 - 2007	32.47	53.8	104.74	141.84	136.56	121.41	151.25	181.38	145.46	77.91	18.45	26.4	1191.67
Angacha	1987 - 2005	42.5	59.2	119.2	191.5	159.8	133.1	183.6	195.7	187.5	110.9	51.7	29.2	1463.9
Aje	1972 - 1991	23.6	42.2	74.1	86.9	137.4	88.5	131.5	119.7	116.8	62.4	12.3	11	906.4
Alaba	1985 - 2007	35.3	56.21	98.36	152.16	120.17	89.17	112.73	135	114.61	77.96	22.37	23.3	1037.34
Shone	1978 - 2007	58.28	81.71	136.64	196.1	182.96	138.63	184.65	212.31	191.59	116.56	46.99	43.19	1589.61
MMR		35.31	55.03	101.71	156.234	146.02	117.07	152.7	162.16	140	92.7	30.02	27.68	1216.60
Mean Monthly Rainfall (mm) Northwestern part of the study area(Mono - modal pattern)														
Gunchire	1988 - 2007	29.52	38.14	95.06	101.93	124.78	194.38	258.84	236.62	172.52	78.07	14.89	18.11	1362.86
Imdiber	1980 - 2007	25.01	27.53	71.99	89.16	96.22	167.79	230.23	214.5	118.98	71.87	12.28	7.87	1133.43
Welkite	1978 - 2007	22.9	44.29	80.74	107.29	124.49	201.98	291.64	251.81	149.39	49.33	18.6	10.4	1352.86
Wulberg	1978 - 2007	30.35	53.82	104.89	133.52	149.93	154.39	212.32	187.81	163.05	74.56	12.02	12.8	1289.46
MMR		26.95	40.95	88.17	107.96	123.86	179.64	248.26	222.69	150.99	68.46	14.45	12.3	1284.65

3.5 Sunshine Hours

Evaporation take place almost without interruption during both day and night, however the process is almost active under direct radiation from the sun. Like wind speed data is unavailable in the study area. Here also the sunshine hour was analyzed from the nearby stations Hossana and Bilate.

3.6 Evapotranspiration

Evapotranspiration is the water lost to the atmosphere by two processes-evaporation and transpiration. Evaporation is the loss from open water body, such as lakes and reservoirs, wetlands, bare soil, and snow cover; transpiration is the loss from living-plant surfaces. The most important factors include solar radiation, surface area of open bodies of water, Relative humidity, wind speed, density and type of vegetative cover, availability of soil moisture, root depth, reflective land-surface characteristics, and season of year.

3.7 Potential Evapotranspiration

Potential evapotranspiration or PET is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration assuming no control on water supply.

Although there are various methods used to estimate potential evapotranspiration; two methods, Penman combination approach and Thornthwaite approach are used in this study based on the available input data.

3.7.1 Penman combination method

Penman use standard climatological records of sunshine, temperature, humidity and wind speed to calculate evapotranspiration. The physical principle used by Penman combines the mass transfer (or aerodynamic) method and the energy budget method. The method gives good estimates of PET because it takes into account many metrological variables.

The basic equation for calculating PET from vegetated surface is:-

$$PET = \frac{\left(\frac{\Delta}{\gamma}\right)H_T + E_{at}}{\frac{\Delta}{\gamma} + 1}$$

In order to make arranged, the explanation of the symbols in the formula and the calculated PET values with all the parameters is tabulated in Table 3.4.

3.7.2 Thornthwaite and Mather (1948)

PET can also be calculated using Thornthwaite formula which is based on temperature with an adjustment being made for the number of daylight hours (Shaw 1988).The equation for calculating PET on monthly base is given by:-

$$PET_m = 16N_m \left(\frac{10\bar{T}_m}{I}\right)^a mm$$

Where m is the month 1, 2, 3...12, and N_m is the monthly adjustment factor related to hours of daylight, \bar{T}_m is the monthly mean temperature $^{\circ}C$,

$a = 6.7 \times 10^{-7} I^3 - 7.7 \times 10^{-5} I^2 + 1.8 \times 10^{-2} I + 0.49$, and I is heat index for the year, given by

$$I = \sum i_m = \sum \left(\frac{T_m}{5}\right)^{1.5} \text{ for } m=1.....12$$

The PET value estimated using Thornthwaite (1948) method is 842.4mm Annex 3.2.

This method has been used widely throughout the world, but as compared with the estimates from the Penman formula, Thornthwaite values tend to exaggerate the potential evaporation (Shaw 1988). Contrary to this, in our case in the opposite,

Parameter		Description																	
H _T		The available Heat, calculated from incoming (R _i) & outgoing (R _o) radiation determined from sunshine records, temperature and humidity using the formula:- $H_T = R_i(1-r) - R_o; \quad R_i(1-r) = 0.75R_a f_a \left(\frac{n}{N}\right)$																	
		R _a – Solar radiation (fixed by latitude and season and is constant for a given latitude and season, obtained from standard meteorological tables); - r the reflective coefficient for incident radiation or albedo of the vegetation covers of the catchment that depends on the nature of the surface. - $f_a \left(\frac{n}{N}\right)$ takes several forms based on latitude and for the study area latitudes south of 54 ½ °N is taken as $f_a \left(\frac{n}{N}\right) = \left(0.16 + 0.62 \frac{n}{N}\right)$ (Shaw, 1988) n- monthly mean sunshine hrs (from Meteorological record); N – Daylight factor (Fixed by latitude & season & is constant for a given latitude & season) - $R_o = \sigma T^4 (0.47 - 0.075\sqrt{e_d})(0.17 + 0.83n/N)$; σT^4 – the theoretical blackbody radiation at the temperature of the air (T in Kelvin scale); σ (Stefan – Boltzmann constant) = 5.67 x 10 ⁻⁸ Wm ⁻² k ⁻⁴ , e _d – the saturated mean vapor pressure at dew point(mm of mercury), e _d = e _a (RH/100) e _a – the saturated vapor pressure at air temperature(T _a), RH– Relative Humidity in % - obtained from meteorological record																	
E _{at}		The Energy for evaporation based on the air humidity and air temperature, the subscript <i>t</i> signifies inclusion of transpiration effects. $E_{at} = 0.35 \left(1 + \frac{u_2}{100}\right) (e_a - e_d);$ e _a -e _d is saturation deficit, U ₂ – Mean wind speed (miles/day) at 2m above the surface (from Meteorological record)																	
Δ		The slope of the curve of saturated vapor pressure against temperature corresponding to the air temperature (e _a at T _a against T _a). $\Delta = (e_a - e_d)/(T_a - T_d)$																	
γ		The reflective coefficient for incident radiations or the Albedo of the basin that depends on the nature of the surface. The dominant land cover of the study area are mature forest, bushes and shrubs, grasses and cultivated crops; and therefore albedo of 0.24 is taken for the catchment.																	
Month	Temp(°c)	e _a (mm/d)	RH (%)	e _d (mm/d)	U ₂ (mile/d)	T (Kelvin)	n (hr/d)	N (hr/d)	n/N	R _a (mm/d)	F _a (n/N)	RI(1-r) (mm/d)	σT ⁴ (mm/d)	R _o (mm/d)	H _T	E _{at} (mm/d)	Δ/γ	PET (mm/d)	PET (mm/month)
January	19.85	17.13	60.3	10.33	84.31	292.85	8.09	11.6	0.7	12.8	0.59	5.66	14.75	2.54	3.12	4.39	2.17	3.52	109.12
Februa.	20.55	18.16	57.52	10.45	92.36	293.55	8.24	11.8	0.7	13.9	0.59	6.15	14.9	2.55	3.6	5.19	2.32	4.08	114.24
March	20.55	18.16	64.18	11.65	81.08	293.55	7.89	12	0.66	14.8	0.57	6.33	14.9	2.89	3.44	4.13	2.32	3.65	113.15
April	20.1	17.54	70.49	12.36	77.38	293.1	6.74	12.3	0.55	15.2	0.5	5.7	14.81	1.91	3.79	3.22	2.23	3.61	108.3
May	19.37	16.75	71.31	11.94	72.49	292.37	7.51	12.6	0.6	15	0.53	5.96	14.66	2.07	3.89	2.9	2.15	3.58	110.98
Jun	18.58	16.04	77.66	12.97	74.64	291.58	5.88	12.7	0.46	14.8	0.45	4.99	14.54	1.65	3.34	2.19	2.04	2.96	88.8
July	17.75	15.27	79.8	13.07	71.95	290.75	4.36	12.6	0.35	14.9	0.38	4.25	14.38	1.38	2.87	1.85	1.96	2.53	78.43
August	17.51	15	78.64	13.14	62.83	290.51	4.74	12.4	0.38	15	0.4	4.5	14.35	1.48	3.02	1.82	1.95	2.61	80.91
Sept	18.62	16.08	77.53	13.15	51.55	291.62	6.05	12.1	0.5	14.8	0.47	5.22	14.55	1.75	3.47	1.91	2.04	2.96	88.8
Oct	18.91	16.36	72.02	11.90	65.51	291.91	7.73	11.8	0.66	14.2	0.57	6.07	14.61	2.23	3.84	2.65	2.1	3.46	107.26
Nov	19.23	16.7	63.15	11.10	73.51	292.23	9.15	11.6	0.79	13.1	0.65	6.38	14.65	2.74	3.64	3.73	2.14	3.67	110.1
Dec	19.38	16.75	59.65	9.99	87.53	292.38	9.04	11.5	0.79	12.5	0.65	6.09	14.68	2.82	3.27	4.44	2.15	3.64	112.84
Annual PET (mm/year) of the area																			1222.93

Table 3. 4 Potential Evapotranspiration calculated using Penman Combination method

it underestimates the PET value of the area. Penman Combination method is more appropriate than Thornthwaite method as a result of using more meteorological parameters. So, the value obtained by Penman Combination method (1222.9mm) taken as the annual PET of the area.

3.8 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.

Actual evapotranspiration or 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.

3.8.1 Turc Empirical Formula

It is a widely used formula to estimate annual AET of a catchment area and it can represent the entire different climate including Africa (Shaw 1988). The formula takes into consideration mean annual precipitation and mean annual temperature of the catchment area.

$$AET = \frac{P}{\sqrt{0.9 + \left(\frac{P}{L}\right)^2}} \text{ (mm / y)}$$

Where p is the mean annual precipitation (mm),

$L = 300 + 25T + 0.05T^3$ (mm) and T is mean air temperature ($^{\circ}\text{C}$). Accordingly, $L = 1120.33$ mm/y and AET of the river catchment is 800.9 mm.

3.8.2 Soil Moisture Deficit

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), viz 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 (mm) that can be extracted from a soil without difficulty by give vegetation (Shaw 1988). 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 2.4.1. and reclassified FAO (1975) soil classification Section 2.4.2. the estimated precipitation and potential evapotranspiration of the area, the actual evapotranspiration has been calculated using Thornthwaite and Mather standard soil water balance model.

In the model all the units are described in mm and the explanation to the symbols are listed below.

P – is monthly mean precipitation in mm, PET is estimated potential evapotranspiration of the area.

P-PET – difference between rainfall and potential evapotranspiration, positive values indicate wet season and negative values indicate dry season. Positive values are representing additions of moisture to the soil while the negative values are showing the monthly demand of moisture by the vegetation which is not satisfied by the monthly rainfall.

Table 3. 5 Thornthwaite Soil Moisture Balance model for the area classified under cultivated land, moderately deep rooted crops (corn and cereals) and fine sandy loam texture.

Parameter	AET for cultivated land, Moderately deep rooted crops (corn and cereals) and fine sandy loam texture, Water capacity root zone of 150mm												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	32.92	51	97.84	142.45	139.68	134.94	180	179.45	143.12	85.77	25.57	23.28	1236.02
PET	109.12	114.24	113.15	108.3	110.98	88.8	78.43	80.91	88.8	107.26	110.1	112.84	1222.93
P – PET	-76.2	-63.24	-15.31	34.15	28.7	46.14	101.57	98.54	54.32	-21.49	-84.53	-89.56	13.09
APWL	-272	-335	-350							-21.49	-106	-196	
S _m	25	16	15	49.15	77.85	123.99	150	150	150	130	74	40	
ΔS _M	-20	-9	-1	34	29	46	26	0	0	-20	-60	-34	
AET	48	60	98.84	108.3	110.98	88.8	78.43	80.91	88.8	105.77	81.57	67	1017
SMD	61.12	54.24	14.31	0	0	0	0	0	0	1.49	28.53	45.84	205.53
S	0	0	0	0	0	0	75.56	98.54	54.32	0	0	0	228.42
TARO	7.6	3.8	1.9	1	0.5	0	75.56	136	122	61	30.5	15.25	
RO	3.8	1.9	0.95	0.5	0.25	0	37.78	68	61	30.5	15.25	7.6	
D	3.8	1.9	0.95	0.5	0.25	0	37.78	68	61	30.5	15.25	7.6	

Accumulated potential water loss (APWL), which indicates the severity of water shortage, is obtained by cumulating of the negative values of the differences between monthly precipitation and potential evapotranspiration for dry season only; and the summation begins with the first month of dry season.

S_m – soil moisture.

During dry month soil moisture can be calculated using the following formula.

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

Thornthwaite water balance user's manual.

Where, L_{am} accumulated water loss at the month m, and W available water capacity of the root zone,

While during wet season Soil moisture values for each wet month are 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 is actual evapotranspiration of the month. To quantify AET of the month there are two cases; if P_m > PET_m, then PET = AET and if P_m ≤ PET_m, then AET_m = P_m + S_{m-1} – S_m, where S_{m-1} and S_m are soil moisture during the month m-1 and m respectively.

SMD – Soil moisture deficit (PET_m - AET_m)

S – Soil moisture surplus.

TARO – total available for runoff

RO - river discharged

D – Detention.

Since the area is classified into four different classes of soil and vegetation: clay soil with moderately deep rooted crops (corn, cereals), fine sandy loam with moderately deep rooted crops (corn, cereals), clay soil with woodland, and silt loam soil texture with deep rooted crops (pasture grass and shrubs), four models have been analyzed. The Thornthwaite & Mather soil water balance model of fine sandy loam soil texture with moderately deep rooted crops vegetated land is presented above and the rest three models are annexed. According to this model the annual mean AET of the study area is estimated as 1019.8mm.

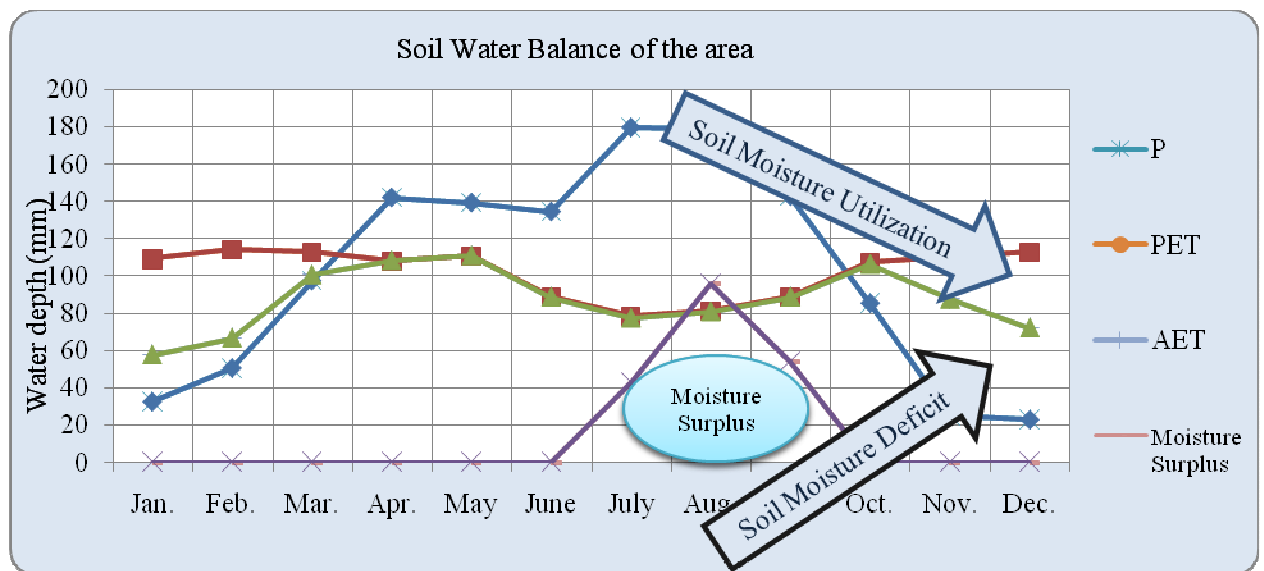


Figure 3. 9 Thornthwaite Soil Water Balance of the area

AET estimated by Turc (1954 and 1955) Empirical Formula is 800.92mm and by soil moisture balance method is 1019.8mm. Turc used monthly mean temperature and monthly mean precipitation of the area, while Thornthwaite soil water balance in addition to the factors which considered by Turc, it considers more meteorological parameters such as temperature,

humidity, sunshine hours and wind speed and soil texture and vegetation cover. So, the result estimated by Thornthwaite water balance model (1019.8mm) is taken as AET of the area.

Table 3. 6 AET estimated using Soil Moisture Balance

Class	Soil	Vegetation cover	AWCRZ	RD	Area	AET
1	Clay	Moderately deep	150	0.5	1373.442	1017
2	Fine	Moderately deep	150	1	600	1017
3	Clay Soil	Woodland	350	1.17	52.085	1094
4	Silt Loam	Deep rooted	250	1.25	45.174	1057
Total					2,070.701	1019.8

3.9 Pan Evaporation

According to Grismer *et al.* 2000 cited in Slaviša *et al.* (2004), Class A pans are used worldwide for estimation of PET because of the simplicity of the method and the straightforward data interpretation. For estimation of AET of open water body (Boyo Lake/swap) pan evaporation of Bilate is used. This should be calibrated using pan coefficient of the area. Pan coefficient of the area is selected based on ground cover of the pan station and its surroundings and general wind and humidity conditions (FAO 1997).

3.9.1 FAO – 24 Pan Method

Potential Evapotranspiration obtained by the application of this method from the following equation:

$$PET = K_p \cdot E_{pan}$$

Where, *PET* is Potential evapotranspiration (mm month⁻¹), *K_p* = pan coefficient, *E_{pan}* = pan evaporation from (mm month⁻¹).

To implement this method, the following parameters are required: evaporation from the Class A pan (Section 3.6.3.1), mean relative humidity (%), wind speed at 2 m height in Km/d. Evaporation from Class A pan presented in Table 3.6, mean relative humidity of the area is 69.54 Table 3.2 and wind speed at 2 m above the ground is 1200.96 km/d. According to this the pan coefficient is determined to be 0.6 (FAO 1977).

Table 3. 7 PET of Boyo Lake/swamp from Pan Evaporation

Station	PET of Open Water Body from Pan coefficient of 0.6												
	Jan.	Feb.	Mar.	Apri.	May	June	July	Auge.	Sept.	Oct.	Nov.	Dec.	Annual
Bilate	232.1	196.2	192.1	152.9	150.1	168	156	155.1	133.6	152.6	182.9	187.7	2059.1
PET	139.3	117.7	115.2	91.7	90	100	94	93	80.2	91.5	109.7	112.6	1235.5
WAPETWB	0.29	0.24	0.24	0.19	0.18	0.2	0.19	0.19	0.17	0.19	0.22	0.23	2.57

WAPETWB is waited average potential evapotranspiration of water body.

3.10 Stream flow analysis

The hydrograph of discharge against time has two components, surface runoff (which is produced by a volume of water derived from the storm event), and the broad band near the time axis, representing base flow contributed from the groundwater. The base flow component separated from a hydrograph of a gauged river in a single hydrologic year represents the total recharge over the catchment upstream of the gauging site, assuming that there is no groundwater inflow and outflow into and out of the basin.

In the river catchment there are three river gauging station; Bilate gauging station near Alaba kulito, Weira gauging station near Fonko town and Guder gauging station near Hossan (Table 3.8).

Table 3. 8 Base flow and Run off of gauging stations

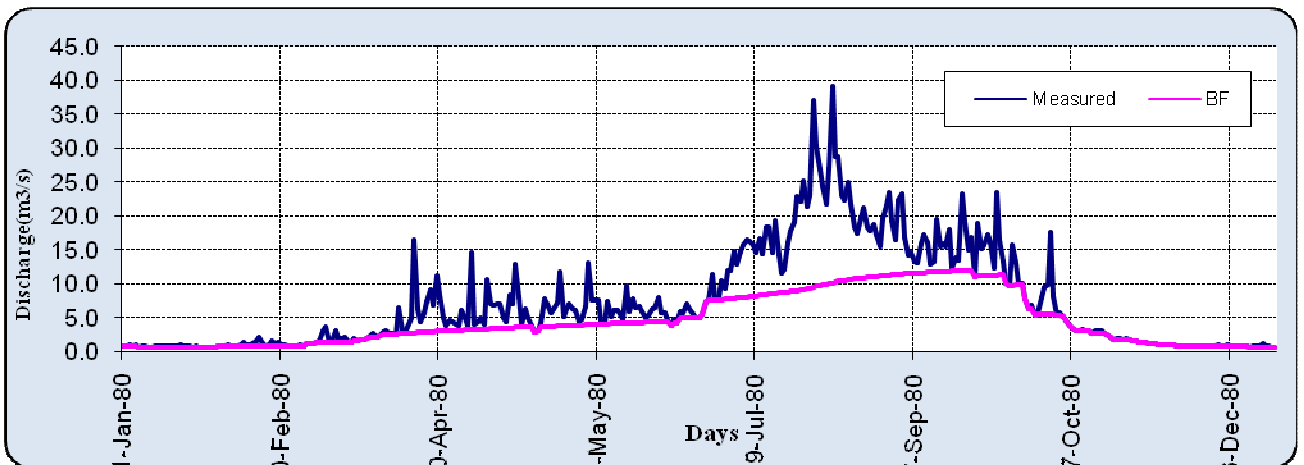
Gauging Station	Location		Duration	Area (sq.km)	Base Flow (mm/year)	Surface runoff (mm/year)	Recharge estimated from base flow (mm/year)
	Easting	Northing					
Bilate	397562	805236	1971 – 2004	2075	129	51.26	129
Weira	390676	848873	1987 – 2007	491.8	317.06	181.34	317.06
Guder	380218	838064	1990 - 2006	106.6	211.24	139.93	211.24
Annual Recharge of the area is							129

The Separation of surface runoff and base flow has been made using a computer code (Time Plot) developed by Gabriel Parodi. This computer code uses daily flow values and an

attenuation coefficient which ranges from 0.9 to 0.995 based on slope and land use and land cover conditions the bigger the attenuation coefficient the bigger the surface runoff the lesser the base flow.

According to this separation method, Weira River has high recharge to the ground than the other two. Guder is the second recharging river Annex 3.6, 3.7, 3.8, and 3.9. As discussed in the later chapters, Weira river catchment is highly structurally affected and most of its catchment covered with alluvial and lacustrine sediments. Guder river emanates north of Hossana town is also structurally affected with moderately fractured pyroclastic and volcanic rocks.

While at Bilate gauging station the recharge and runoff of the river are very small as compared to the other two. This is due to the damping effect Guder River to Boyo lake/swamp and the infiltration of Weira River at Boyo plain which is covered with alluvial and lacustrine deposits north of Bilate Gauging station. However, the recharge and runoff of the area is computed from Bilate gauging station because it reflects the hydrological behavior of the catchment. The estimated recharge of the catchment is 129mm. From the precipitated 1231.6mm only 10.5% is contribute to groundwater recharge and 4.5% leave the area as surface runoff. The rest 85% turn back to the atmosphere as AET and groundwater abstraction.



Note: The time written in the graph is not the exact time; instead the time is 34 years average.

Figure 3. 10 Hydrograph of Bilate River near Alaba Kulito

Table 3. 9 Analysis result of time plot at Bilate Gauging station.

Year	Measured	Average flow in the month (m ³ /s)												Average
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
34Years Average	Total Flow	1.16	1.44	5.68	7.19	8.5	14.97	27.79	30.46	19.24	17.76	6.18	1.93	11.86
	BF	1.01	1.08	4.4	6.43	7.8	11.3	13.37	15.89	16.9	15.78	6.09	1.79	8.4871
	RO	0.15	0.36	1.25	0.76	0.73	3.67	14.41	14.57	2.35	1.98	0.09	0.151	3.3726

3.11 Groundwater Recharge

Groundwater recharge may be defined in a general sense as the downward flow of water reaching the water table, forming an addition to the groundwater reservoir. Recharge may occur naturally from precipitation, rivers, canals, lakes, as man induced phenomena; irrigation, urban recharge.. The groundwater recharge varies in a wide range governed by the rainfall distribution, topography, land use and geology. The major recharge to the aquifer comes from precipitation and river channel losses. Direct recharge take place in all areas except where at the steep slope (at the escarpment of the fault) and in areas where there is wide coverage of clay around northern eastern and southern part of the area and where the volcanic rocks are fresh around Misha, Lemo, Angacha and Gumer Woreda.

In the study area three types of recharges are identified; the first is direct recharge from precipitation which widely vary with the position of wind ward and lee ward, indirect recharge into the watertable from the surface water sources such as Bilate, Weira, Gudre rivers and Boyo lake/swamp and some other tributary which drain to Bilate and the last is localized recharge which comes from the highlands of the catchment without well – defined channels.

Quantification of groundwater recharge is full of problems of varying magnitude and hence substantial uncertainties. The theoretically simple processes of direct groundwater recharge are thus by no means easy to quantify in nature. Therefore to reduce uncertainty, it is desirable to apply and compare a number of independent approaches, as allowed by available data.

The recharge estimation methods adopted in this research work are long term mean minimum flow of streams and conventional water balance approaches.

3.11.1 Recharge estimation from long term mean minimum flow

Partitioning the river discharge into direct runoff contribution from the precipitation and base flow contribution from groundwater, then the average of a 12 month total base flow and total direct runoff over a multi – year period will be the annual groundwater recharge and annual direct runoff respectively.

According to stream flow analysis of the study area, the annual base flow of the catchment is calculated to be 129mm which is 10.5% of the total precipitation.

3.11.2 Water Balance of the river catchment

Water balance is an accounting of the inputs and outputs of water. The water balance of a place, wheather it is an agricultural field or watershed, can be determined by calculating the input, output, and storage changes of water at the Earth's surface. The major input of water is from precipitation and output is evapotranspiration.

The water balance represents the hydrological gains and losses of a given system (reservoir, column of soil, aquifer, river basin, etc) over a specific period. The water balance is sometimes referred as water budget. Hydrologic budget is a quantitative evaluation of the total water gained or lost from a given hydrological system during a specific period of time.

The following assumptions were made for the catchment:

- The surface water divide and groundwater divide coincides,
- The catchment is bounded by both surface and groundwater divide, except at the mouth of the River where groundwater escapes as base flow,
- There is no groundwater inflow,
- There is no abstraction and diversion ,
- No groundwater flow across the boundary, and
- The water balance is on annual basis, which means change in storage assumed to be zero.

Based on the assumptions made the water balance equation representing the catchment is:

$$\text{Inflow} = \text{Out flow} \pm \Delta S \text{ where, } \Delta S \text{ is change in storage.}$$

In annual base change in storage is zero or steady – state. Which means inflow is equal to outflow. It means the flow is under natural condition. The application of the steady – state hydrologic – budget equation provides only a crude approximation of the hydrologic regime in a watershed. In the first place it is a lumped – parameter approach (rather than a distributed – parameter approach), which does not take into account the areal variations in (Freeze 1979).

The general water balance equation is;

$P = AET + E_o + RO + \Delta G + W$ where, P is Precipitation, E_o is Open water evaporation, RO is runoff, ΔG is groundwater recharge and W is abstraction by groundwater pumping.

The general water balance equation set for the catchment in annual bases is as follows;

$$P = AET + E_o + RO + \Delta G, \text{ where the system is under natural condition.}$$

When the inflow exceeds the outflow the total water storage in the basin ΔG increases and when inflow less than the outflow results in decreased storage.

Thus, $P = 1231.6\text{mm}$, $AET = 1019.8\text{mm}$, $E_o = 2.57\text{mm}$, $RO = 112.56\text{mm}$ and substituting all these parameters we get $\Delta G = +96.7\text{mm}$. This result contradicts the assumption made at the beginning; since it is conducted in annual bases the change in storage should be zero.

From this result the following justification can be made for the situation.

The surface water divide may not coincide with groundwater divide. In this case in northern part of the study area just below the water divideline there are springs which discharge more than 40 l/s. For example Spring Moshoshe, Sheshera, Kereso and Adiyoy which emanates from the shoulder of Mugo Ridge discharge 47 l/s, 52 l/s, 40 l/s and 12 l/s respectively. The springs

are fracture springs this indicates that there is inter aquifer connectivity between adjacent basin (Omo – Gibe Basin) due to Bonga transverse fault system.

CHAPTER FOUR

4 HYDROGEOLOGY

4.1 Introduction

The hydrogeological system comprises many components: the quantity of groundwater stored in the aquifer system and its quality, watertable(phreatic) levels and their fluctuations over time indicating changes in the amount of water stored in the aquifer, groundwater head (piezometric level) fluctuations of confined or semi-confined aquifers indicating the changes over time of the hydraulic pressure in the aquifer, recharge and discharge sources and the time-dependent rates of discharge and recharge from each source (hydraulic stress), groundwater budget, and chemical composition (UNESCO 2004).

The principal hydrologic properties of rocks are porosity, effective porosity or specific yield and permeability. Porosity is the percentage of a gross volume of soil or rock that is filled by air or water; the soil or rock containing such pores is called a porous medium. When the pores have their origin in the genesis of the rock, the rock is said to have primary porosity (sedimentary deposits, weathered hard rocks). When their origin is from events that occurred during a later stage (jointing, faulting, and dissolution) the porosity is said to be secondary. This properties control the entrance of water in the water – bearing formations or rock, their capacity to hold, transmit and deliver water, and confinement and concentration of percolation to the direction of maximum ease of movement. The occurrence of water in rocks of any region is therefore determined by the character, distribution, and structural setting of the rock it contains.

Total porosity of volcanic formations is generally high, due to voids created by exsolved gases and to the frequent scoriaceous and brecciated parts, as well as to their often clastic nature. But compact lavas and dykes have less than 5 percent total porosity. In some rocks most of this porosity is closed and isolated voids through which water cannot readily flow unless the rock becomes weathered and fractured (UNESCO 2004). The result is that the porosity available for groundwater flow is often much less than total porosity, especially in fresh

(young) volcanics. Specific yield (drainable porosity) is small for fine-grained pyroclastic formations, ashes and weathered rocks.

The distribution of permeability and porosity is related to the characteristics of the rocks. This is important when explaining the hydraulic properties and when choosing sites for drilling wells to exploit groundwater resources. In this research work, in order to identify different hydrogeological units the available data (geological information, meteorological, bore hole, pumping test, remote sensing data, etc) are interpreted and the area is classified into different hydrogeological units.

4.2 Hydrogeological Units and Aquifer System

Groundwater occurs in many types of geological formations; those known as aquifers are of the most important. An aquifer may be defined as a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs (Todd 2004). Hydrogeological field observations such as the distribution and magnitude of spring discharges, the degree of fracturing of the rock units, the thickness of the formations, the grain size rounding and sorting, the clay proportions, the type and degree of cementation, and the extent of weathering are some of the significant field observations which provided indirect evidence as to whether a rock unit is likely to be an aquifer of low, moderate or high productivity. (Chernet1993). In addition to direct hydrogeological investigation pumping test data analysis was employed in order to reinforce the classification.

Accordingly the following hydrogeological units are incorporated in the study area; Basaltic Aquifer (Jima – Volcanics), Volcanic Aquifers (Nazereth Series, Dino Formation and Quaternary Ignimbrite), Lacustrine Deposits and Alluvial Sediments.

4.2.1 Basaltic aquifers (Jima – Volcanics)

In the study area this formation is rarely outcropped surficially, however it is reported in geological logs of deep wells which were drilled in western highlands. They are mainly confined and leaky types. Pumping test analysis results shows that the hydraulic conductivity ranges from 1 – 3 m/d and they provide a discharge of 5 – 8.8 l/s with not pronounced

drawdown. The formation shows a low to moderate, but an overall moderate permeability and productivity.

4.2.2 Volcanic Aquifers

About 80% of the study area is covered with volcanic rocks of different episode. These include the Nazereth Series of Upper – Miocen epochs, Dino formation of Quaternary period and Quaternary Ignimbrite. Generally the volcanics can be divided into trap series volcanics (Early Tertiary) dominantly localized in the highlands and Late Tertiary volcanic (Rift Series) mostly confined within the rift floor (Demile *et al.* 2008). All this are subjected to varying degrees of secondary activities such as weathering, fracturing, and jointing. The volcanic rocks are dominantly rhyolites and ignimbrites associated with volcano-clastic tuff, pumice and ash deposits. The rift is characterized by fractured basaltic and ignimbritic aquifers.

The most important aquifers are localized in the fractured and weathered volcanic. The rift floor and escarpments are highly faulted. The faults in the MER are parallel and sub-parallel to the NE–SW trending rift axis (Woldegebriel *et al.* 1990). Structural discontinuities in the rift and escarpments are known to provide the best aquifers (Chernet 1993). In the area structural discontinuity plays an important role to make the formations aquifers and also around northern part it reduces storage of aquifers by facilitating fast circulation.

The Ignimbrite of Nazereth Series which covers northern and western part of the area is highly faulted and fractured in association with rifting. The geological map of the area and field observations show that, the northern and western part of the area is densely faulted due to tectonic activity. Despite the occurrence of permeable rocks and high recharge rates in some highlands adjacent to steep escarpments, the groundwater reserve is low due to the fast release of the recharged water to the rift plains through large open faults (Demile *et al.* 2008). It is hard to get deep and shallow wells in Misha, Meserake Azernet Berbere, Alichu Wiriro and east of Meerab Azernet Berbere Woredas due to the above reason. However, there are many hand dug wells from the upper overburden soil parts and there are also many springs with high discharge rate such as Hage, Doyido, Lenchicho, Siko, Adiyo, Kereso, Moshoshe and Sheshera springs. The emergence of these springs is from adjacent catchments following deep sited fault system. The chemical analysis result of these springs suggests that the source of

water for these springs is rain with young age and short water rock interaction time. In general, this part of the area is classified as low productive aquifer.

The western highlands including Lisana, Hayisse, Danboya, Doyogena, and Angacha woreda have relatively high precipitation. Due to the same reason as the northern part, the groundwater reserve is low. In spite of the fact that this area has low relief than the northern part, it has better groundwater reserve than the northern part. The rural and urban community water supply sources are hot and cold springs which emanate from the shoulder of mountains. Streams in this area follow weak zones that are faults and contacts between different lithologic units. The productive aquifers are also aligned following streams and at the lower plain land. In recent days, governmental and nongovernmental organizations drilled deep and shallow wells in this area. In general, this part of the area is categorized as moderately productive aquifer.

The Dino – Formation which forms horst just immediately next to Boyo graben is less affected by faulting and fracturing. The upper most part is covered with weathered tuff and in some places such as Alaba and Sankura area with thick ash fall deposits. Depth to the groundwater is deeper than the rest of the area (≥ 200 m). The chemical analysis test result discussed in Chapter five suggests that the water in this area has long water rock interaction time and highly mineralized. In addition to all these, the pumping test analysis result reveals also that the hydraulic conductivity decreases towards Alaba. Moreover, the precipitation of the area is minimal as compared to the west and northern part of the area; this means direct recharge to the groundwater is very low. Therefore, from aquifer classification point of view, the area is categorized as low productive aquifer zone.

4.2.3 Lacustrine Deposits and Alluvial Sediments

The rift and intermountain graben in the northwestern highlands are filled with alluvial, colluvial and lacustrine sediments (Demile *et al.*, 2008). Most of the lacustrine sediments are located around existing lakes because they were deposited when these lakes were much larger during the pluvial times (Chernet 1993). In this river catchment this deposit is outcropped surrounding Lake Boyo. The lacustrine sediments is consisting of volcanic sands and waterlain sands and the permeability is very high. From personal experience, I had been

supervised some shallow wells which were drilled surrounding this area. Though there is no pumping test data conducted in these wells, it is estimated from compressor yield during well development that almost all of the wells provide more than 7 l/s for a small drawdown. The lacustrine sediments may be taken to have a moderate or high permeability and productivity and the permeability is of intergranular type (Chernet 1993). The lacustrine sediments with small amount of volcanic ash and silt intercalation which were reported from shallow wells at Boyo Plain have very high permeability and productivity with small drawdown.

The problem in this formation is the presence of high salinity and high fluoride content especially wells developed in Urbecha, Golicho Boyo, Suta, Biramora Kemo, Shemo Boyo, and western part of Alage Gimbichu kebele. Fluoride content is more pronounced in hand dug wells.

Two types of alluvial sediments are recognized: (1) those spread out in alluvial plains, and (2) those which occur as thin strips along streams. The alluvial plains are filled up graben and large stretches of flat land in the Rift Valley and along the whole length of the western border of the country. These are troughs in the lowlands where during the pluvial streams deposited large amounts of sediments carried down from the highlands. The thin strips of alluvium along streams occur in most places both in the highlands and the lowlands (Chernet 1993). The Boyo graben/plain filled up with alluvial sediments of coarse to medium grained. This plain stretched from North West of Wulbareg Woreda through Shashogo Woreda upto rift ward side of Angacha and Danboya Woredas.

Thin strips of alluvial sediments occur along the major tributaries Weira and Guder. The line running from the foot of Kebul and Mugo Ridges passing through the border between Lemo and Ana Lemo Woreda is filled with thin strips of this formation. From well completion reports following this line reveal that all the aquifers are of silt, medium to coarse grained sand and gravel with slight to highly weathered tuff overlain it. The depth to water level varies from 1.5m to more than 50m depending on the geomorphological condition of the area and also it provides a discharge of more than 9 l/s. Their permeability and productivity vary from place to place depending on their grain size and sorting and on their thicknesses. In general, this formation is taken to have moderate to high permeability.

4.3 Types of Aquifer

Calculating hydraulic characteristics would be relatively easy if the aquifer system (i.e. aquifer plus well) were precisely known (Kruseman *et al.* 1990). Identification of the type of aquifer system is crucial to choose theoretical model. It has been the major problem in interpreting pumping test data in the area, which miss lead into improper well design.

Identification of the aquifer system of the area was performed using three integrated approaches;

- By carefully observing the lithological log of the wells,
- By construction of diagnostic plots (log – log plots) and specialized plots (semi – log plot) of drawdown vs time and,
- By observing the static water level with respect to the position of water bearing formation.

A geologic log is constructed from sampling and examination of well cuttings collected at frequent intervals during drilling a well or test hole. Such logs furnish a description of the geological character and thickness of each stratum encountered as a function of depth, thereby enabling aquifers to be delineated (Todd 2004). It is the most important way of knowing the aquifer system than the others but preparation need careful follow up. If it constructed well, the aquifer system could precisely known.

Construction of diagnostic plots (log – log) and specialized plot (semi – log) enables to identify the aquifer system of the area. Specialized plots are specific to a given flow system and a diagnostic plots are used to identify the dominant flow regime; these yield straight lines on specialized plots. The characteristic shapes of the curves can help in selecting the appropriate model (Kruseman *et al.* 1990). Most of the plots are not exactly compared with the theoretical model, rather it needs experience. Microsoft Excel is used to plot the graphs.

The last method which is not more commonly used method but give strength for the above methods is observing the static water level/piezometric or potentiometric surface of the well. In confined aquifer, the piezometric surface will lie above the top of the aquifer while in unconfined aquifer the static water level (SWL) doesn't lie above the top of the aquifer.

Taking the static water level measurement just after well construction has vital use. Owing to shortage of deep meter and awareness, most of the wells have neither SWL measurement, nor observation well to take SWL during inventory period.

Figure 4. 1 A, B and C are diagnostic plots and A', B' and C' are specialized plots of Lera, Kalisha and Hule Gutanch Deep Wells respectively

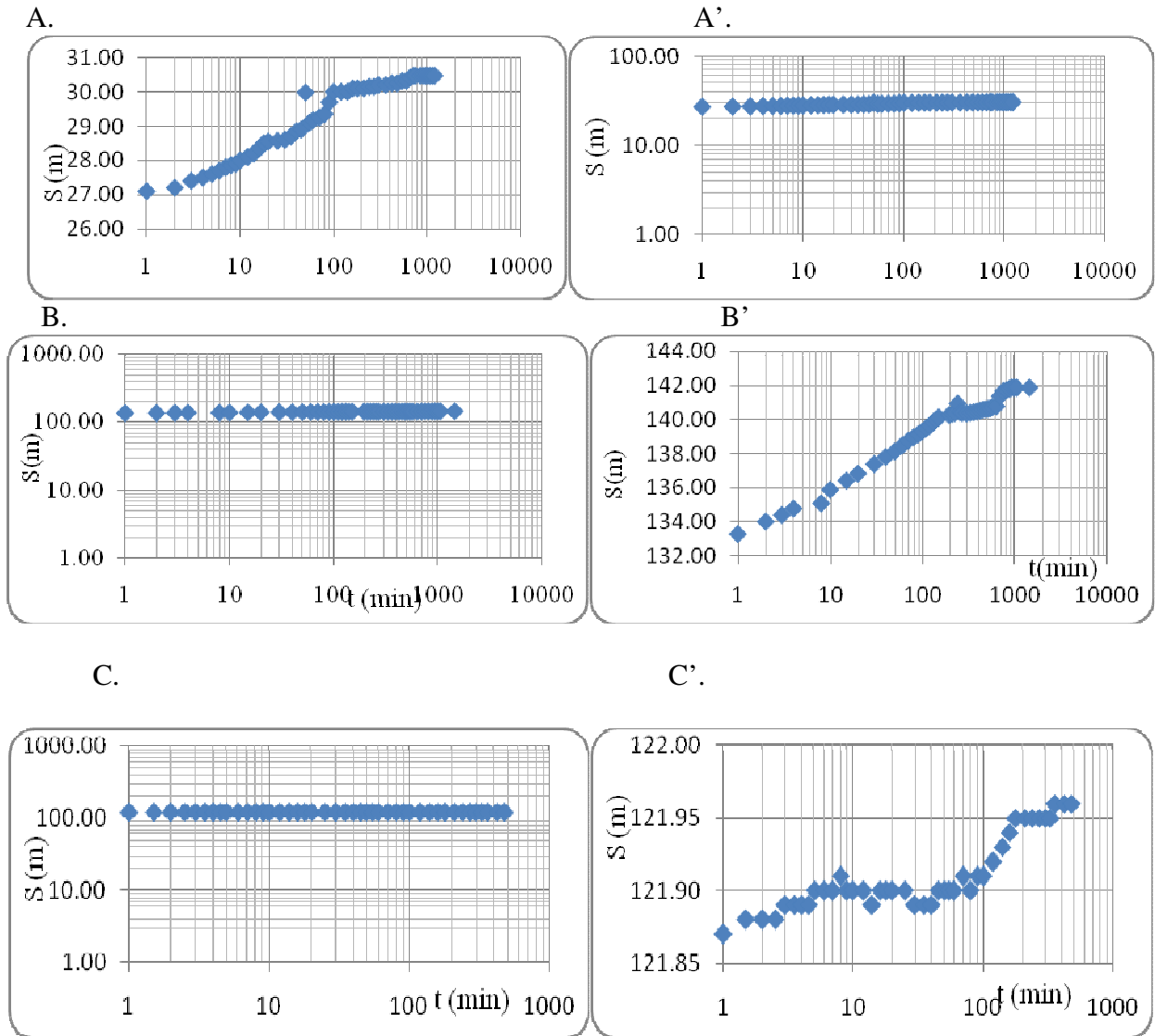


Table 4. 1 Transmissivity, Hydraulic conductivity, Aquifer type and test methods

N o.	Site Name	Location			Depth (m)	SWL (m)	Q (l/s)	Aquifer type	Test Method	T (m ² /d)	K (m/d)	Aquifer Thickness (m)
		X	Y	z								
1	Bonosha T/W/S	397949	829286	1904	86	18	4	Unconfined	Neuman (1975)	7.49	0.42	22
2	Hossana #5	380313	837958	2280	200	132.5	8.8	Confined	Theis (1935)	240.1	4.9	42
3	Lisana	381014	831845	2164	157	89.21	6	Confined (fract.)	Theis (1935)	242.8	8.8	27.5
4	Kalisha	375411	836136	2269	189	130.8	8.8	Unconfined	Neuman (1975)	48.72	1.35	36
5	Bedene	420171	828642	1805	220.9	124.3	9.8	Unconfined	Neuman (1975)	42.5	1.02	41.78
6	Lemo Belela	392282	849451	2010	63	19.19	1.01	Confined	Theis (1935)	2.5	0.17	15
7	L/Hongolame	374090	838472	2297	51	24.2	0.81	Leaky	Hantush (1955)	7.4	0.62	12
8	Alaba Feleka	410787	802987	1883	362	267.9	2.2	Confined	Theis (1935)	10.8	0.26	39.61
9	Lemo Duna	393198	847668	2043	72	45.7	0.861	Confined	Theis (1935)	9.1	0.6	15
10	Around Alaba	405856	863711	1793	262	196.5	3	Confined	Theis (1935)	44.8	1.1	40
11	Shurmo	377288	845381	2389	139	110	5	Confined	Theis (1935)	72.1	3.2	22
12	Lera T/W/S	379554	854853	2609	120	26.1	5	Unconfined	Neuman (1975)	60.65	2.4	25
13	Hule Gutancho	405281	831914	2000	158	118.2	6.25	Confined	Theis (1935)	147.74	4.9	30
14	Bonosha Kore	403664	827808	1908	236	155.7	4.5	Confined	Theis (1935)	13.82	0.3	34.86
15	Alaba Cherko				183.5	104.2	6	Leaky	Hantush (1955)	81.47	2.0	40.08
16	Kidigisa	373907	842115	2340	91.9	41.1	6	Confined	Theis (1935)	100.2	4.3	23
17	Lemo Harbucho	377863	843078	2351	63	42.08	0.56	Unconfined	Neuman (1975)	7.4	0.6	12

4.4 Hydraulic Characteristics of Aquifer

Owing to shortage of surface water and springs around central and southern part of the study area, there are many deep and shallow wells which were drilled and equipped with submersible and hand pumps respectively. Among these almost all deep wells and around 10 shallow wells possess pumping test data but not in well organized manner. During inventory period about 29 pumping test reports were collected; 19 deep wells and 10 shallow wells out of which only 17 reports are evaluated in the analysis due to the later reasons. The reports were compiled by different governmental and nongovernmental organizations such as JICA, Yadot Engineering, Ethio Drilling, Hydro Construction and South Water Works and Construction Enterprise.

The available pumping test data in the area are obtained by testing with low capacity pumps that cannot create enough drawdown for the well to estimate the hydraulic properties that would nearly represent the aquifer. In some wells tests are conducted by installing small capacity pump at shallower depth than drilled and using small diameter casings which lead to small capacity pumps. All these underestimate the actual potential of the aquifer and the well. As an example Alemtena deep well was drilled by Water Well Drilling Enterprise in Alemtena Kebele. The static water level of the well before the start of pumping test was 75.1 m below the ground level. Pumping test was commenced with 3.5 l/s discharge rate. The test proceeded up to 720 minute without drawdown. Secondly, Bonosha Town Water Supply deep well was drilled in June, 2007 by aiming to serve Bonosha town community. The well site is an ideal place with respect to quality and quantity but the casing which installed is 5', this lead to using 4' pump with only 3.5 liter per second discharge rate. So, the well has been fall to satisfy the intended target.

Thus, all these pumping test data cannot be representative of the aquifer under consideration.

4.4.1 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 *et al.* 1990). It determines the ease by which water can move

through aquifers. It therefore, determines the productivity of the aquifer. The hydraulic conductivity of fractured rocks depends largely on the density of fractures and the width of their apertures. Fractures are not evenly distributed spatially because rocks of different properties respond differently to applied stresses.

Fracturing is common at the escarpment and central part of the area because of rifting and active tectonic activity. Generally, the hydraulic conductivity and yield of wells increases from the highlands to the rift due to faulting (Demile *et al.* 2008). In northern and north western part of the catchment area due to the absence of deep and shallow wells the degree of fracturing cannot be easily identified except at quarry sites north and south of Kילו town and on the way to Alichو wiriro.

4.4.2 Transmissivity (TD or T)

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 *et al.* 1990).

The data which are collected and believed to be representative of the whole catchment are analyzed for constant (main) test. Constant test is performed by pumping the well for a significant length of time with a constant discharge rate.

The analysis result of pumping test data is presented in Table 4.1. The hydraulic conductivity value ranges from 0.17 – 8.8 m/d and the mean and median are 2.17 m/d and 1.12 m/d respectively. In addition to these, the transmissivity ranges from 2.5 – 242.8m²/d. Using large capacity pump is crucial to know the actual potential of the aquifer. The least hydraulic conductivity result is obtained from shallow wells which were drilled in Lemo Woreda and Bonosha town water supply deep well and Feleka deep well around Alaba. The maximum and the minimum pumping rate to the shallow wells are 1.01l/s and 0.56l/s respectively. The result indicates that the actual potential of wells is much higher than the estimated value.

Table 4. 2 Wells without or with small drawdown

Well Site	Location			Q (l/s)	Total Drawdown (m)
Lemo (Danfa)	393752	848772	2040	0.23	1.14
Lemo (Dekaye)	376000	844016	2345	0.2	0.59
Alaba alemtena				3.5	0
Elo Leka	397150	818125	1812	3	0
Feleka Alaba	410787	802987	1883	2.2	9.88
Around Alaba	405856	863711	1793	3	5.02

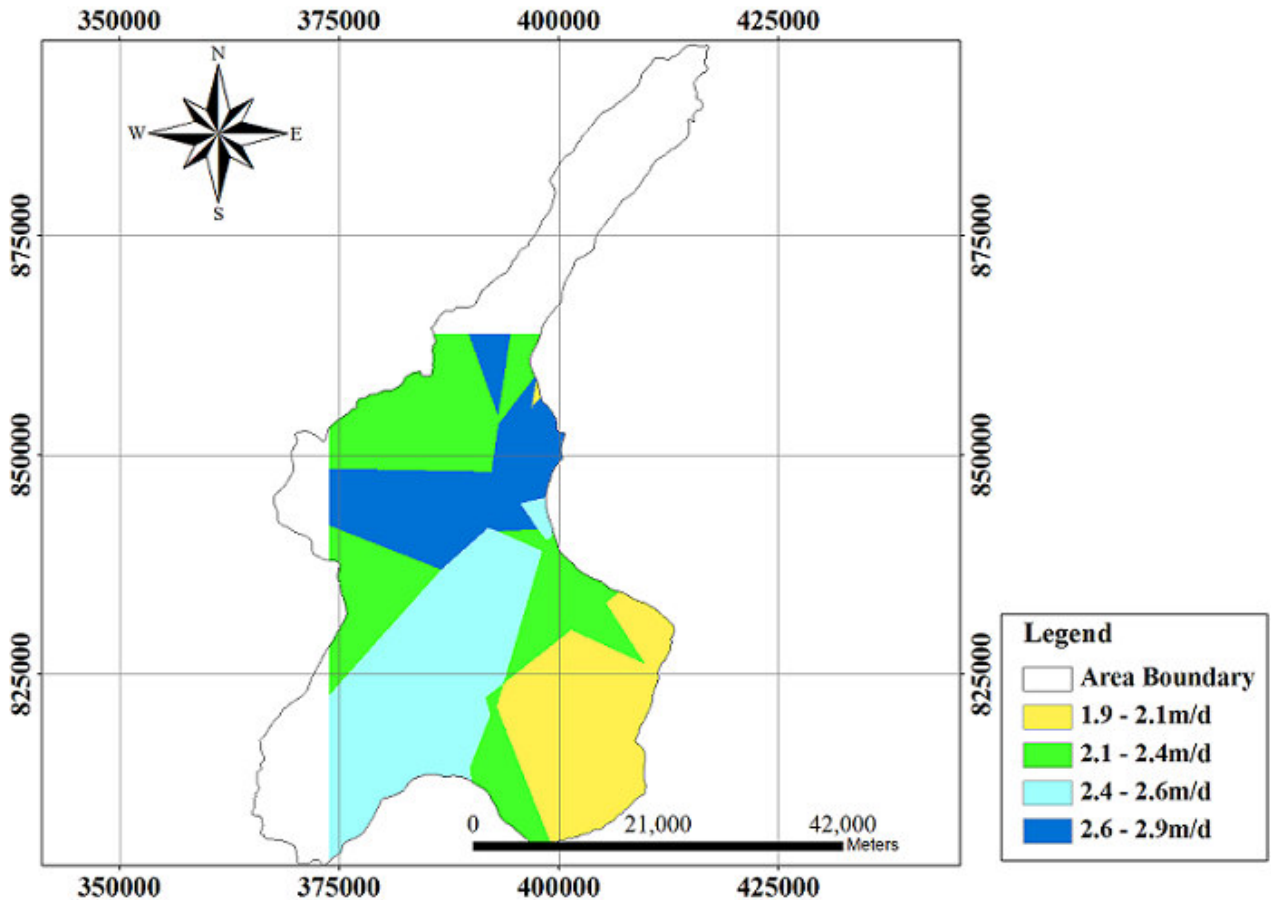


Figure 4. 2 Hydraulic Conductivity Map of the area

It is also seen from the pumping test analysis that, basaltic aquifers have relatively high hydraulic conductivity values ranges from 3.28 – 8.81 m/d which is above the mean value such as Kalish, Shurmo, Haisse and Hossana town #5 deep wells. These types aquifer are reported only from western part of the study area. The fine grained sand and pyroclastic deposit aquifer of the shallow wells in Lemo, Ana Lemo and Angacha Woreda have low hydraulic conductivity value which may also associated with shallow groundwater circulation system, local groundwater recharge and the infilling of secondary weathering products of geologic formation.

Pumice, medium size gravel, fine to coarse sand and transported river materials of different origin aquifers which are reported from deep wells around south and south eastern part of the area have medium hydraulic conductivity value this strictly associated with the low capacity pumps.

4.5 Recharge, Discharge Conditions and Groundwater Flow System

Recharge areas are usually in topographic high places; discharge areas are located in topographic lows. In recharge area, there is often a rather deep unsaturated zone between the watertable and the land surface. Conversely, the watertable is found either close to or at the land surface in discharge area (Fetter 2001). However, using only topographic setup of the area could not be enough to classify the area as recharge and discharge zones. Close evaluation of Hydrochemical trend, land use/land cover and Piezometric patterns are equally important in classification of the area into recharge and discharge zones.

The topography of the area vary widely, it ranges from 1,750 - 3,350 m.a.s.l around Bilate Gauging station and around the northern tip of the area respectively. The highland area gets relatively higher precipitation (1284.65mm) than the lowland Table 3.3. This part receives higher recharge because of high rainfall and deeply weathered and fractured volcanics which are associated with tectonic activity and ultimately flow to the floor of the rift forming high discharge springs at the escarpment aligned NNE – SSW. Mololicho, Moshoshe, Adancho, and Sheshera Springs area the typical examples. Concerning the hydrochemical trend discussed in Chapter 5, very low value of TDS, EC and PH and very high value of HCO_3^- ,

Ca^{2+} and Mg^{2+} estimated from laboratory chemical analysis results in this part of the area and these values are getting increase and decrease towards the floor of the rift respectively.

Flow lines on a flow net tend to diverge from recharge areas and converge towards discharge areas. A Water - table contour map can often be used to locate groundwater recharge and discharge areas (Fetter 1994). The groundwater contour map Figure 4.7 of the area was constructed using the field inventory data that have static water level and elevation above sea level. It clearly shows zone of convergence and zone of divergence. The diverging groundwater flow lines from the highland towards the rift suggesting that the northern and western part of the area are recharging zones while the lowland situated at the foot of the highlands is discharging zones.

The groundwater flow lines or stream lines diverge to Boyo Plain making it discharge zone. The discharge areas are manifested as swamp-filling depressions, river base flows, and cold and hot springs (Demile *et al.* 2008). Several hot and cold springs exist in different parts of the catchment, with the hot springs being aligned along major regional faults. These springs, and many wells, supply water to the urban and rural communities.

If the surface topography has well – defined local relief, a series of local groundwater flow systems can form, because the topographic relief cause undulations in the watertable (Fetter 1994). There are many local discharging zones due to topographic effect. The typical example is the line along the western boundary starting from North of Kilto town towards Lisan Kebele passing through Belesa kebel. The artesian well which was drilled by China Road Construction Company is the manifestation of local groundwater discharge zone.

The topographic undulation of the catchment creates local and intermediate flow system in the area. Local flow systems are shallower, with short flow paths. The water has short contact time with the rocks and is potentially mineralized to a lesser degree than that of intermediate and regional (Fetter 1994). The emergence of Kereso, Moshoshe and Ajacho Springs with small degree of mineralization, low PH and low temperature suggests that the flow system is rapid circulation system and the recharge is closely related with precipitation in this part of the area. It is clearly shown in the conceptual groundwater flow model Figure 4.5. Of the area that the groundwater getting mineralized towards Alaba.

East of Ambericho fault the piezometric surface getting deeper and deeper towards Aje. There are many deep, shallow and hand dug wells which were drilled by different organization at and surrounding Boyo Plain. In this plain the piezometric surface is very shallow (< 25m an average) and the water is relatively fresh. It is highly associated with the daming effect of the NNE – SSW running Ambericho Fault. In this part of the area the rift within a rift structure forms horest and graben. The graben currently occupied by Boyo Lake/Swamp is filled by Alluvial Fluvial sediments while the horst or the uplift is composed of massive Dino formation ignimbrite with scoracious basalt composition dyke. This dyke is exposed only on the road from Doisha to Bonosh town. From the deep bore hole logs Figure 4.8 such as from the two deep wells which were drilled at Alage Gimbichu kebele, and from Deneba Kebele deep well in Shashogo Woreda that were drilled along the fault line reveal that the ignimbrite underneath the surface is massive and slightly weathered upto 150m and below. At regional scale the groundwater movement is discontinuous due to barrier marginal faults, which direct groundwater flow in different directions; in places against the topographic slope (Demile *et al.* 2008). Fault plains have positive and negative effect in groundwater movement. In this case it has negative effect for the area east of it.

The groundwater flow system conceptual model Figure 4.5., the water chemical analysis result discussed in Chapter 5, and the groundwater contour map Figure 4.7. give strength to the above idea. So, the groundwater flow system around Alaba and Sankura area dominated by intermediate flow system or even regional flow system.

4.5.1 Springs

A spring is a concentrated discharge of groundwater appearing at the ground surface as a current of flowing water. During the field excursion about 50 springs inventoried in the study area and very close to the study area. The discharge of the springs ranges from 0.1 l/s to greater than 65 l/s. All these springs are divided into two categories; those resulting from non gravitational forces and those resulting from gravitational forces. Springs categorized under the former category include volcanic springs associated with volcanic rocks and fissure springs resulting from fractures extending to great depths in the earth's crust. Such springs are usually

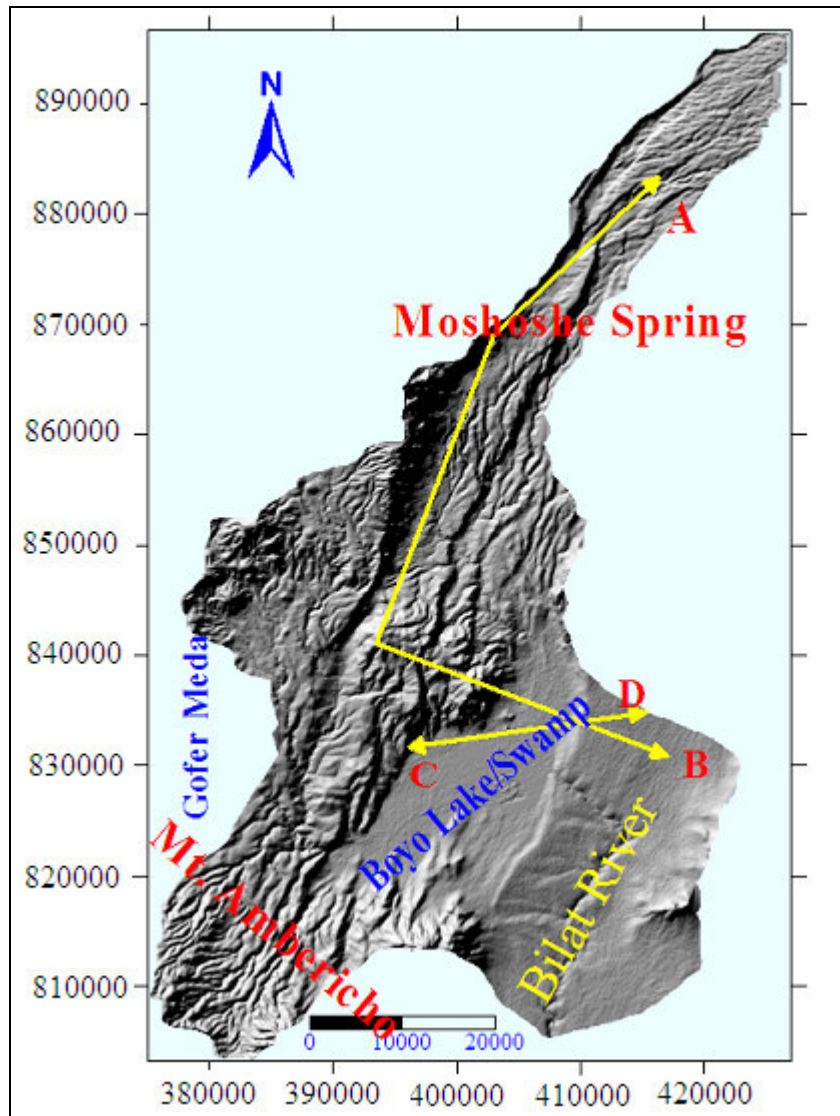


Figure 4. 3 Hill Shade map of the area

thermal. These springs are situated and aligned almost parallel to MER, such as Artuo thermal spring which is found at Alaba Special Woreda and Mololicho spring which emanate from the shoulder of Dishamo Ridge of Shashogo woreda. These springs come to the surface following fractures formed from tectonic activity and rifting.

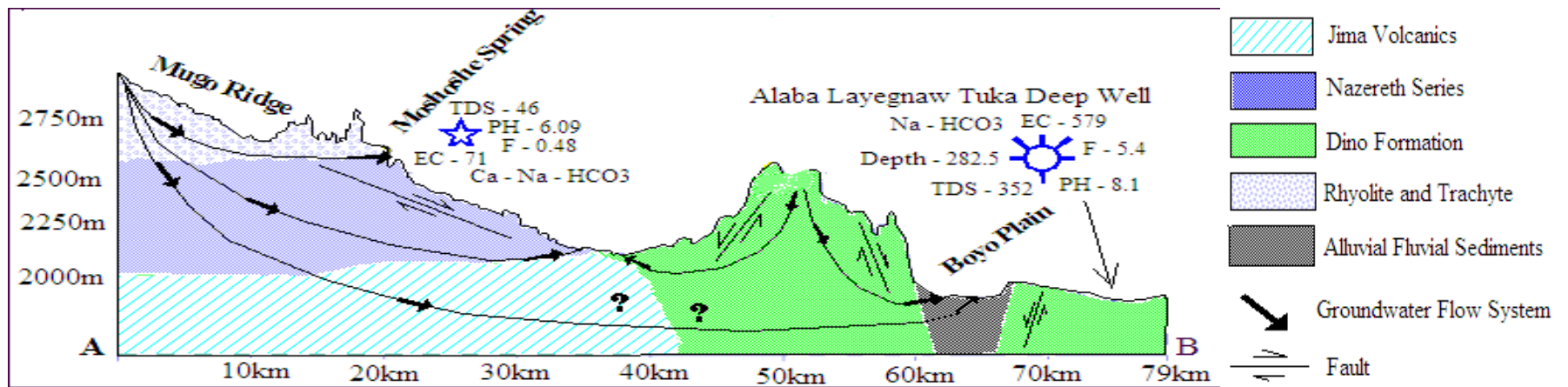


Figure 4. 4 Cross – section showing groundwater flow system

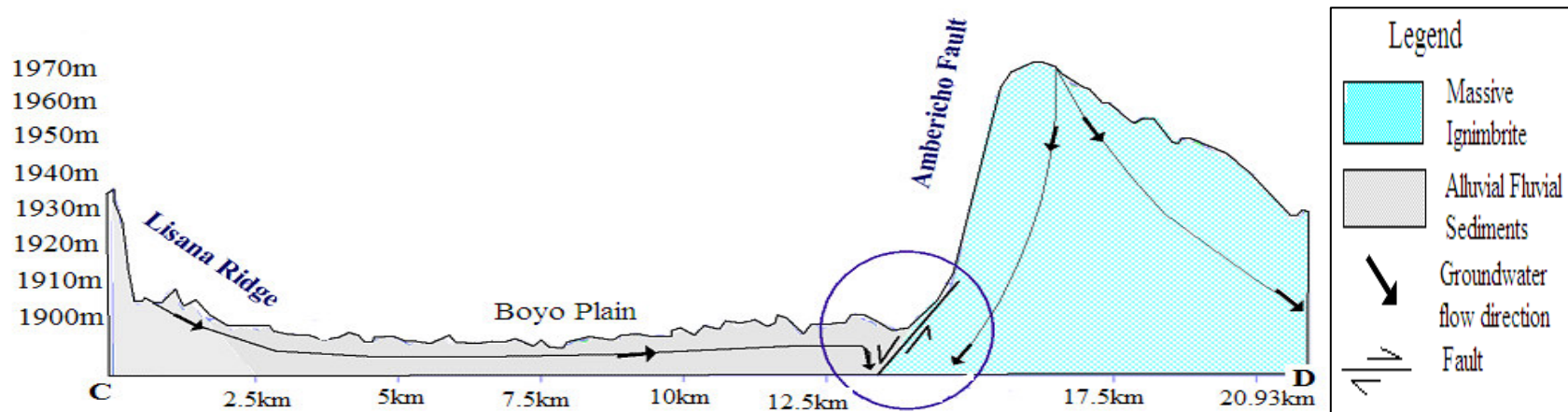


Figure 4. 5 Showing the effect of Ambericho Fault Plain for the deep piezometric level around Alaba.

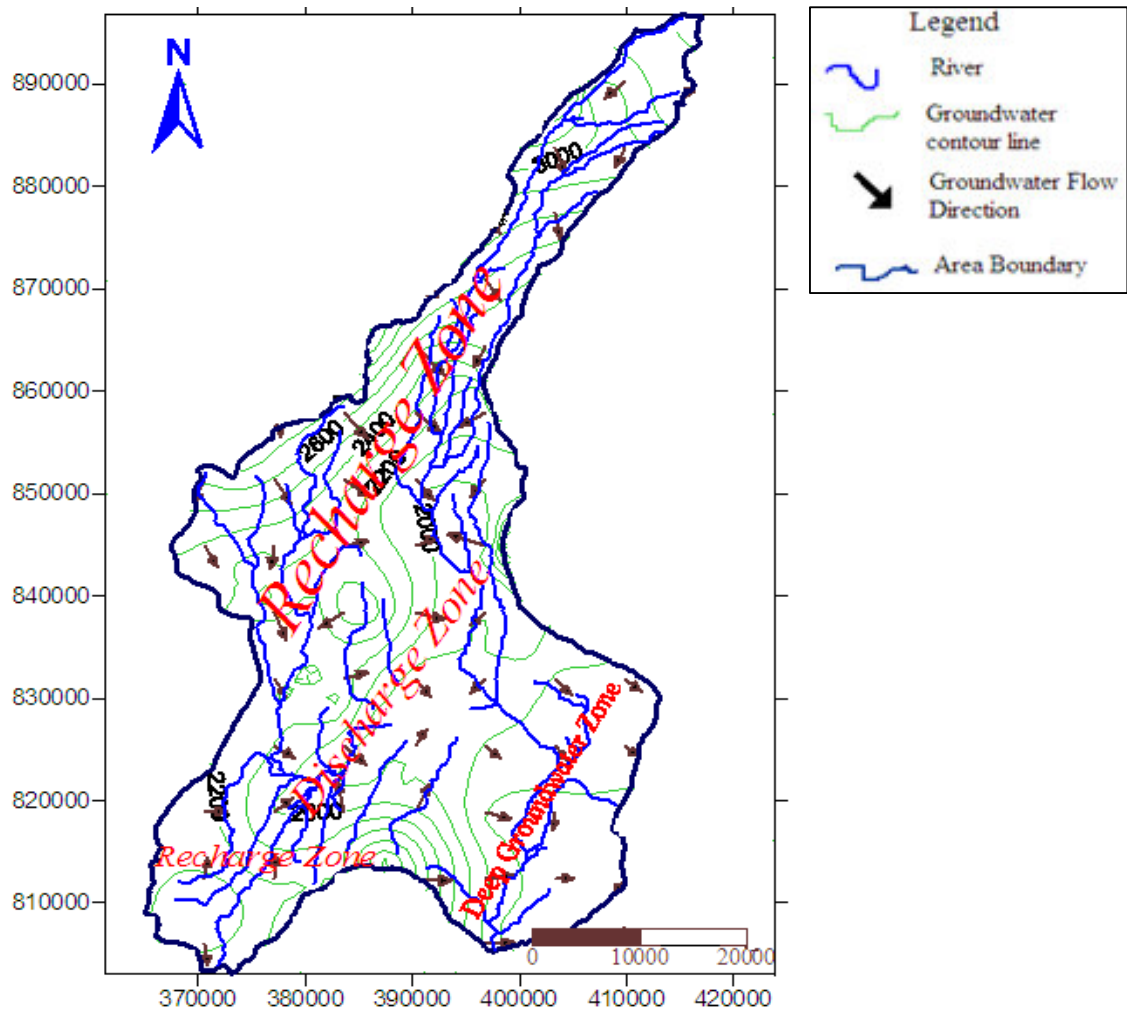


Figure 4. 6 Groundwater flow system

The second category which dominantly found at higher elevation of the study area is gravitational springs. These springs flow under the control of hydrostatic pressure. Under this category there are three general types of springs which are recognized in the study area.

1. Depression spring – formed where the ground surface intersects the watertable. For example Shiro, Madbet Amba, Hage, and Lenchicho springs of Misha woreda, Wagebeta Heba and Bekafa springs of Doyogena woreda, Gede Genet of Angancha woreda.
2. Contact springs – which are created by a permeable water bearing formation overlying a less permeable formation that intersects the ground surface. Abezana, Edo, and Wiro

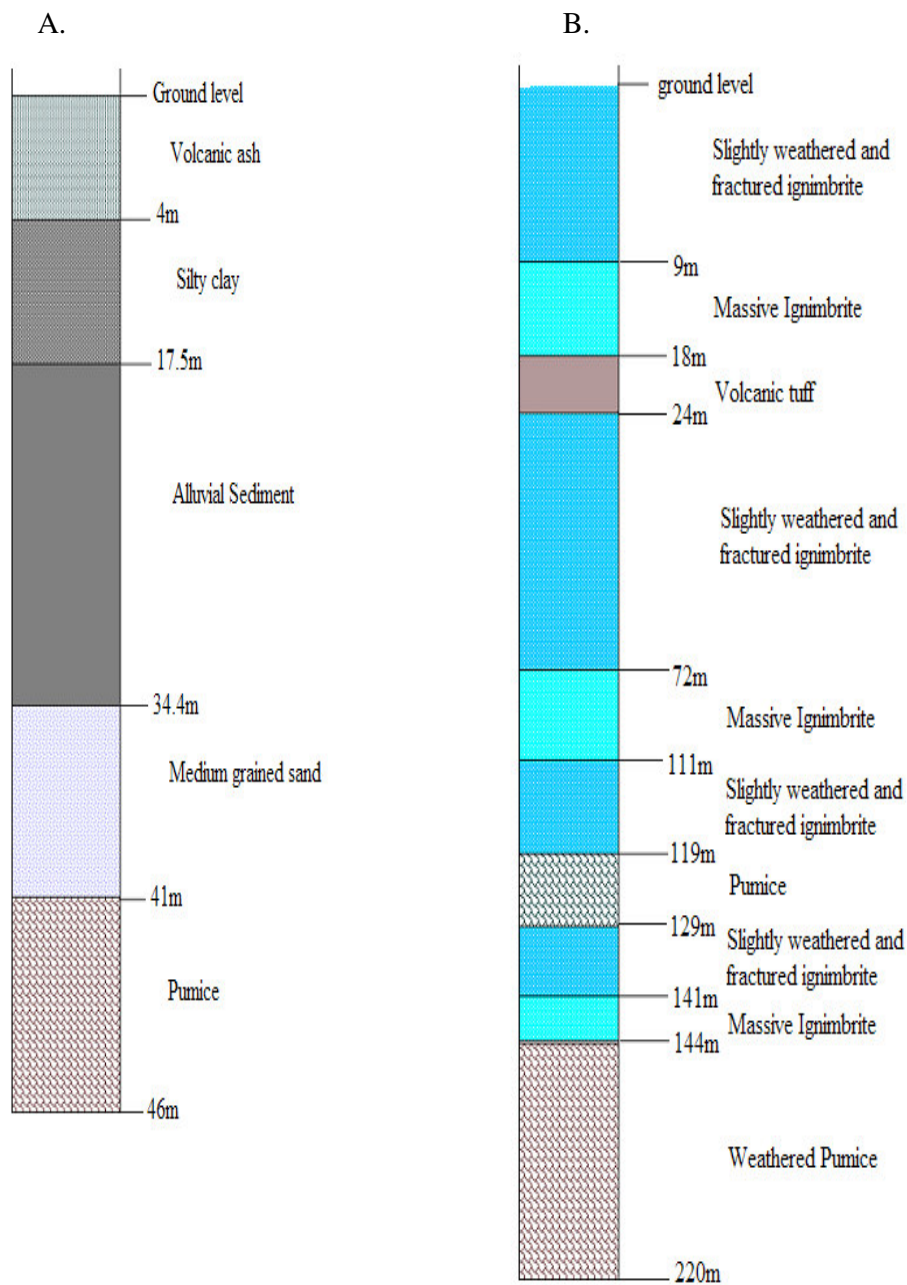


Figure 4. 7 A. geological log of Shemisa Gimbiichu Shallow Well and B. Geological log of Alage Gimbiichu Deep Well at Shashogo Woreda

spring of Alichu Wiriro woreda and Jeto spring which serve Shurmo kebele, Angacha town springs, Kuya'a Sigazamo, Kuya'a Fiso are of among the contact springs in the study area.

3. Fracture springs – these type springs are formed when rocks are fractured along the line of a geologic fault, it may result in a spring supplied from an aquifer in contact with the fault.

Depending on the topography of the land surface there could be a line of springs related to fault. Most of the spring found in the study area fall under this category. Since the study area is found within tectonically active zone, the rock formations are subjected to faulting, fracturing and jointing. These phenomena results in the emergence of springs like Ajacho which is found west of Shashogo woreda, Moshoshe, Small and Large Sheshera, Kereso and Adiyio springs which emanate from the foot of Kebul/Mugo ridge following Bonga transverse fault system.

The discharge of these springs by far greater than those discussed above. For example, the discharge of Moshoshe spring is about 47 l/s, the discharge of Sheshera spring is about 51 l/s, the discharge of Keresu spring is about 46 l/s and the discharge of Adancho spring is greater than 65 l/s. currently, Moshoshe and Sheshera spring are under construction for Hossana town water supply and Keresu spring is also under construction for Worabe town water supply. Adancho Ebala spring is diverted for irrigation activity.

4.6 Groundwater – Surface Water Interaction

The interaction between surface and groundwater is very important for water resource management. They are not isolated components of the hydrologic system. They interact in a variety of ways. Whatever the thing that occur in one system such as pollution and exploitation can affect the other system in one or the other ways.

Though it is essential, there are no monitored data of groundwater level changes, lake level changes and stream level changes. Interaction between stream and groundwater in the area needs detail assessment of the entire catchment.

To have the general overview of the area, some locations were assessed during inventory period. The two major tributaries of Bilate River, Guder (including Batena) and Weira Rivers gain water from the ground aquifer at their upstream as a form of springs, seepage and at their bed. Along these tributaries upstream there are high discharge springs and there are also seasonal seepages from the overburden clay and weathered tuff. The discharge of these rivers increases down a stream. Things start to change dramatically just before they join and named Bilate. The discharge of Bilate River starts to decline just the two tributaries join south of Lake Boyo.

Weira River losses its loads immediately it inters the rift valley at South of Kilty town and North West of Wulbarege town. When it reaches to Boyo Plain since the topography is flat and the graben filled by unconsolidated alluvial sediments it loses its water more than 75%. The same is true for Guder River. Guder dumps its load to Lake Boyo.

From stream hydrograph analysis result it can be seen that the runoff at the mouth of the catchment, at Bilate Gauging Station, is much less than that of Weira and Guder gauging stations. It implies that Bilate River losses it water to the ground upstream of the gauging station around Shashogo Woreda.

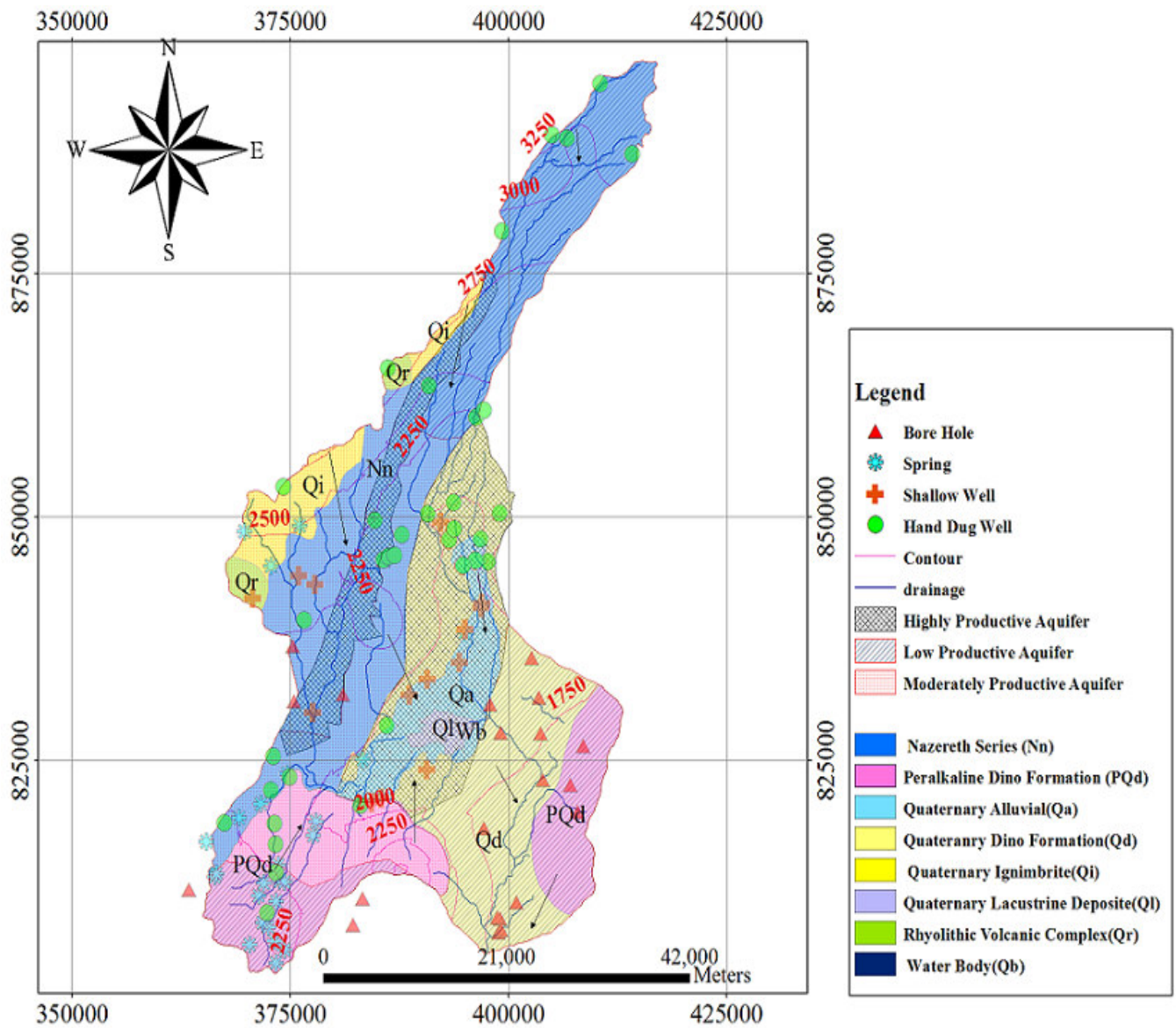


Figure 4. 8 Hydrogeological Map of the area

CHAPTER FIVE

HYDROGEOCHEMISTRY

Hydrogeochemistry deals with geological and hydrological controls in groundwater chemistry. It is an outstanding scientific approach in the field of hydrogeological study.

5.1 PH, TDS, and Electrical Conductance

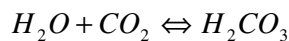
5.1.1 Hydrogen-Ion Activity (pH)

The hydrogen-ion activity in an aqueous solution is controlled by interrelated chemical reactions that produce or consume hydrogen ions. The dissociation equilibrium for water is always applicable to any aqueous solution, but many other equilibrium and many non equilibrium reactions that occur in natural water among solute, solid and gaseous, or other liquid species also involve hydrogen ions. The pH of natural water is a useful index of the status of equilibrium reactions in which the water participates (Hem 1985).

Table 5. 1 Comparison of in situ testing and laboratory analysis results

Station	Location		Field Measurement			Laboratory Result		
	Easting	Nothing	PH	EC(μ s/cm)	TDS(mg/l)	PH	EC(μ s/cm)	TDS(mg/l)
M.Shiro	371565	853089	6.76	46.9	30.8	7.1	49	29
L. Lenka	387682	848028	7.1	219	291	7.33	245	248
A. Wiriro	411099	884906	7	95	57.9	6.7	101	48
Moshoshe	393469	869183	6	73	43.6	6.09	71	46
L. Sheshera			6.03	74	50	6.15	73	48
S. Sheshera			5.92	68	51	6.1	70	46
Bonosha T	397949	829286	6.5	470	297.3	6.93	498	320
Weira Riv.	396810	839450	7.3	143	112	7.57	149	92
Guder Riv.	379411	822112	7	59	63	6.95	68	48

Field PH values generally are higher or lower than laboratory PH values by as much as ± 1 PH unit or more (Pyne *et al.* 1995). Field values are commonly lower than laboratory values because collection, transport, or storage causes a release of dissolved carbon dioxide from the water into the head space of the sample and a release to the atmosphere when the sample is opened.



We can see from Table 5.1. that except a sample which was taken from Alichu Weriro and Guder River, all in situ tests results have lower value than laboratory. The case of Alichu and Guder River is due to the release of CO₂ during sampling, transport and storage which consume hydrogen ion. However, sometimes lower laboratory PH values than field values can result from the natural oxidation or dissolved ferrous ion to ferric iron forming hydroxide precipitates that can adsorb other metals. Oxidation typically lowers the PH through the formation and precipitation of hydroxides, thereby releasing hydronium ion into the water. Sample collected from Alichu Wiriro shows lower laboratory value than in situ test due to the above reason.

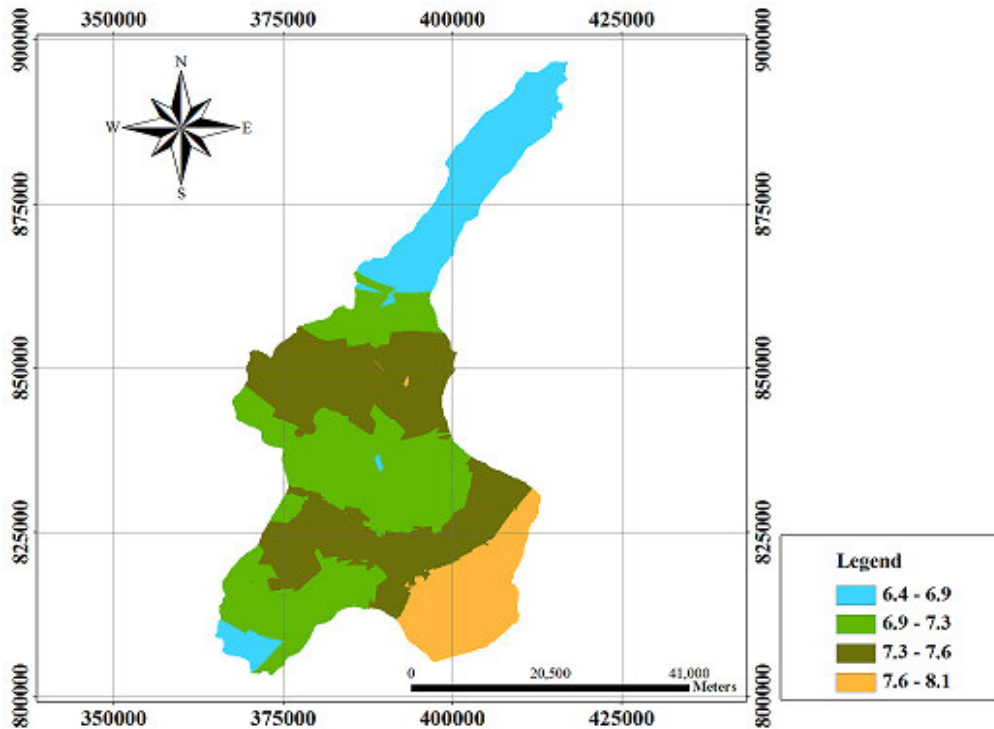
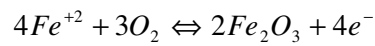


Figure 5. 1 Spatial variation of PH value within the area

As we can see from the diagram the peak points at Mt.Ambericho and Alichu Wiriro Woreda the PH value is much less than the value estimated around Alaba. It is related to the depth to groundwater, dissolution of aluminosilicate mineral, and groundwater interaction time with the media. As the depth to groundwater increases the water subjected to change from shallow oxidation zone to deep reducing zone. The incongruent dissolution of aluminosilicate mineral that take place due to the aggressive nature of CO₂ charged water consumes H⁺ ion (Freez and Cherry 1979).

5.1.2 Electrical Conductivity (EC)

Specific electrical conductance is the conductance of a body of unit length and unit cross section at a specified temperature (Hem 1995). The presence of charged ionic species in solution makes the solution conductive. As ion concentrations increase, conductance of the solution increases; therefore, the conductance measurement provides an indication of ion concentration.

Specific conductance values measured in field and in the laboratory should agree within approximately 5 to 10% unless there has been a chemical reaction following the collection of the water sample and prior to its analysis (Pyne *et al.* 1995). Accordingly, except sample collected from Misha woreda shiro kebele all samples agree with in the range. Laboratory EC value of Shiro kebele spring is greater than in situ test. This is due to the dissolution of residue from a sample container.

On land surface, in the soil zone, and in groundwater zone to depths of many hundreds or thousands of meters, aluminosilicate minerals such as feldspar and mica are thermodynamically unstable and tend to dissolve when in contact with water. The dissolution processes cause the water to acquire dissolved constituents and the rock to become altered mineralogically (Freez and Cherry 1979). It could be seen from the EC map of the area that the water acquires more TDS towards the lowland. It indicates that the groundwater in the plateau is from shallow aquifer zone and the time is short or the water is not traveled long way.

5.1.3 Total Dissolved Solid (TDS)

Total Dissolved Solids concentration is approximately equal to the sum of the concentrations of all dissolved ions. The TDS should be both measured and calculated, and the difference should be within approximately 5%. The measured value is typically larger for surface water, which commonly contains suspended organic and inorganic matter for example water collected from Weira and Guder Rivers show higher in situ value than laboratory results. This is due to the presence of suspended organic and inorganic compounds within the water.

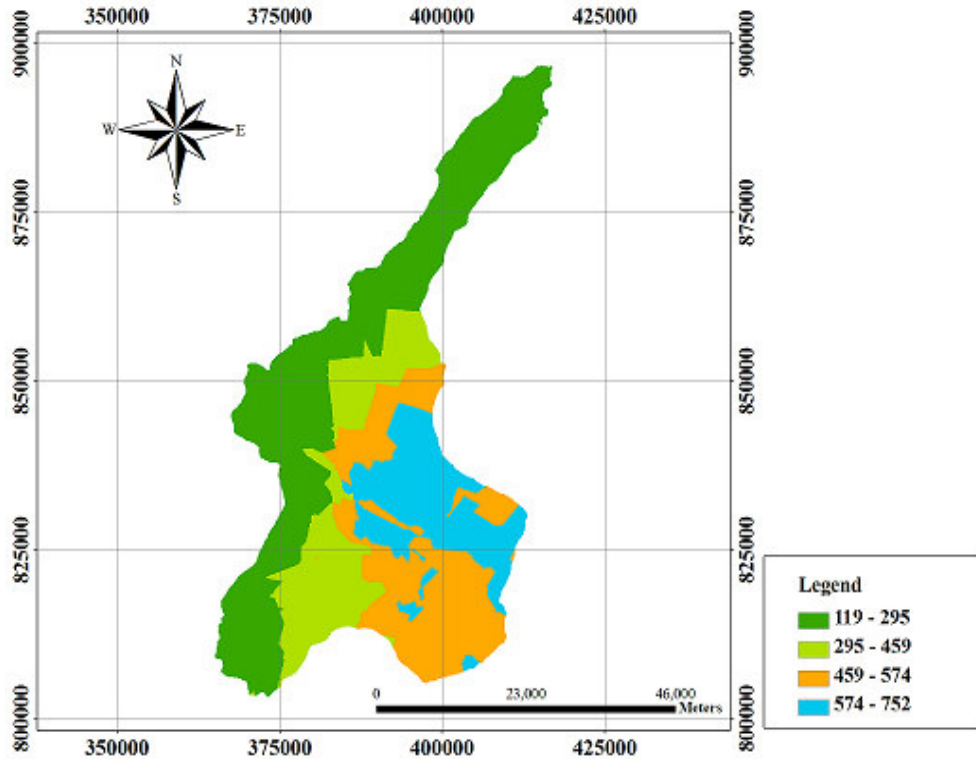


Figure 5. 2 Electrical Conductivity (EC) Map of the area

The more salts are dissolved in water; the higher is the value of electric conductivity. Therefore, TDS and electrical conductivity are in a close connection. Spatially the distribution of TDS value is quite different. The northern and western part of the area has relatively lower value than south and south eastern part of the area. 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 northern and western part of the area is recharge zone and south and south eastern part of the area is discharge zone. While the foot of Ambericho fault and the alluvial fluvial Boyo plain are extremely discharge zone.

5.1.4 Mass Balance between Cations and Anions

The mass balance can be calculated for both the cations (positively charged ions) and the anions (negatively charged ions) in units of mill equivalents per liter (meq/L). This unit of measurement takes into account both the differences in gram atomic weight (molar) units

of each ion and the valence or charge units for each ion. The meq/L difference should be compared using the following equation:

$$Error\% = \left[\frac{C - A}{\frac{C + A}{2}} \right] * 100 \text{ Where A is cation sum meq/L and B is anion sum meq/L.}$$

The error should be within 5% for a high quality analysis. A 10% error is allowed if TDS is less than approximately 100 or more than 5000 mg/l. In this research work about 60 water chemistry data were collected from the respective organizations and 10 primary data from laboratory. From these data only 88.6% (62) pass quality assurance check using mass balance method. 83.3% of the water chemistry data which pass quality assurance check have an error less than 5% and the remaining 16.7% have error equal to or less than 10% and TDS value less than 100.

5.2 Evaluation of graphical and multivariate statistical Analysis (HCA) of hydrochemical data

5.2.1 Graphical Methods

According to Hem (1998) cited in Cuneys *et al.* (2002), most of the graphical methods are designed to simultaneously represent the total dissolved solid concentration and the relative proportions of certain major ionic species. In addition to this the spatial variability observed in the composition of the major ions (as natural tracers) can provide insight into aquifer heterogeneity and connectivity as well as the physical and chemical processes controlling water chemistry. Generally the approach is to divide the samples into hydrochemical groups (facies or clusters), that is group of samples with similar chemical characteristics that can then be correlated with location. Verification that systematic variations along the flow path are related to reactions between groundwater and the aquifer provides the hydrochemical evolution trend for the study area. This information provides the context for interpreting the spatial variations in water chemistry and defining groundwater flow paths and characterization of the hydrologic system.

All the graphical methods use a limited number of parameters, usually a subset of the available data, unlike the statistical methods that can utilize all the available parameters (Cuneys *et al.* 2002). The use of graphical techniques proved to have limitations compared

with the multivariate methods for large data sets. In this section Piper, Collins bar diagram, and Schoeller plots are presented.

5.2.1.1 Piper Diagram

The Piper diagram is the most widely used graphical form of data presentation. The diagram displays the relative concentrations of the major cations and anions on two separate trilinear plots, together with a central diamond plot where the points from the two trilinear plots are projected. The central diamond-shaped field (quadrilateral field) is used to show overall chemical character of the water.

Piper plot of the area clusters the water sample into different water types; Na – Ca – HCO₃, Na – Ca – Mg – HCO₃, Na – HCO₃, Ca – Na – HCO₃, Ca – Na – Mg – HCO₃, Ca – Mg – HCO₃, and Ca – Na – HCO₃ – CO₃. From these Na – Ca – HCO₃ is the dominant water type. This diagram provides little information that allows us to discriminate between separate clusters (groups) of samples. The unusual springs which are circled in the piper diagram are from thermal sources and have insignificant amount of Ca and Mg. It also indicates that the concentration of F⁻ is much higher in thermal springs due to the precipitation of Ca²⁺.

5.3.1.2 Collins Bar diagram

The Collins bar diagram (Collins 1923) is easy to construct and present relative major ion composition in percent milli equivalents per liter (Cuneyt *et al.* 2002). The Collins bar diagram distinctly shows Ca and Mg are very small in class 3 (Artu thermal spring) water samples instead it is reach in Na and K. Ca and Mg are a product of oxidizing zone and Na and K are from deep reducing zone. Due to cation exchange Ca and Mg precipitates as calcite and the concentrations of Ca and Mg getting low and low towards the discharge zone (towards class - 2, 1, 4 and 3). Sodium and potassium are increase towards the discharging zone (from north and west to south and south west) as they are more soluble than Mg and Ca. Collins bar diagram also shows that sulfate ion concentration is also increase towards the floor of the rift.

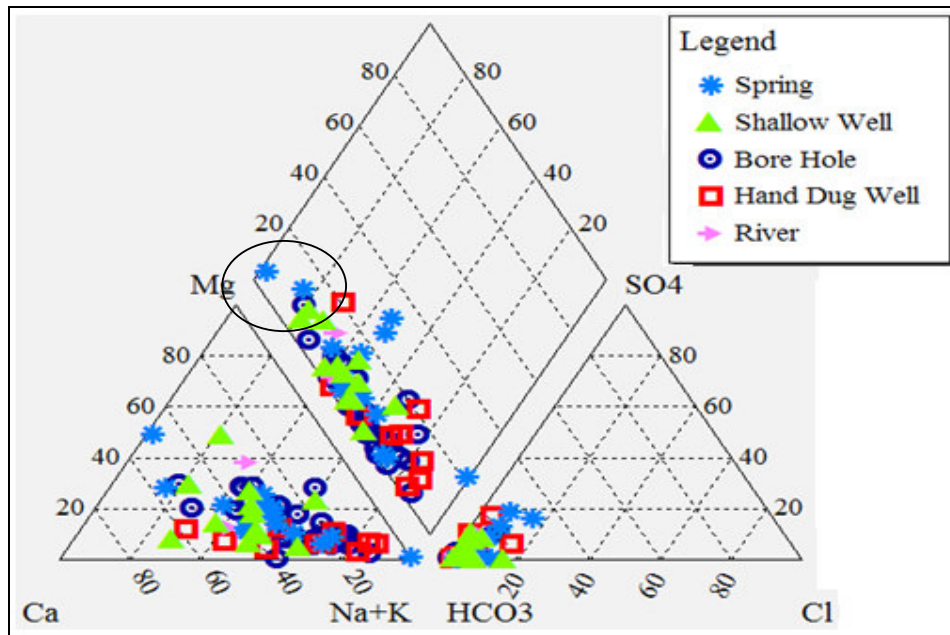


Figure 5. 3 Piper Diagram of the water samples

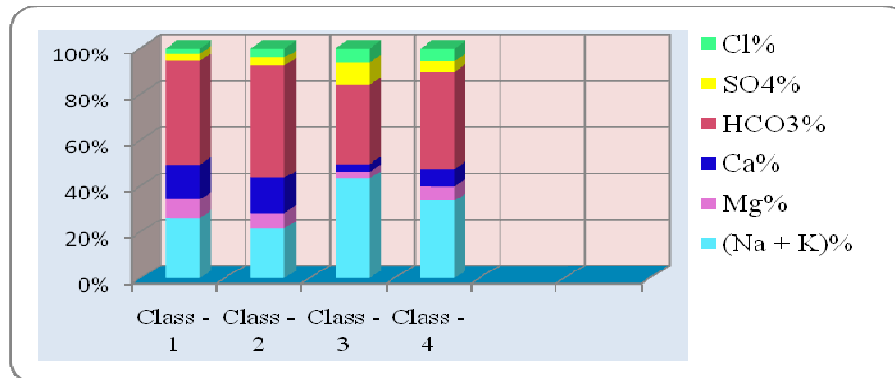


Figure 5. 4 Collins bar diagram

5.3.1.3 Scholler Semi – Logarithmic Diagram

The Schoeller semi-logarithmic diagram (Schoeller 1955, 1962) allows the major ions of many samples to be represented on a single graph, in which samples with similar patterns can be easily discriminated. The Schoeller diagram shows the total concentration of major ions in log-scale.

5.3.2 Multivariate Statistical Technique

Statistical techniques, such as cluster analysis, can provide a powerful tool for analyzing water-chemistry data. These methods can be used to test water quality data and determine if samples can be grouped into distinct populations (hydrochemical groups) that may be significant in the geologic context, as well as from a statistical point of view.

The classification of samples according to their parameters is termed Q-mode classification. This approach is commonly applied to water chemistry investigations in order to define groups of samples that have similar chemical and physical characteristics because rarely is a single parameter sufficient to distinguish between different water types.

In this research work, only hierarchical cluster analysis (HCA) was used to classify the samples into distinct hydrochemical groups based on their similarity.

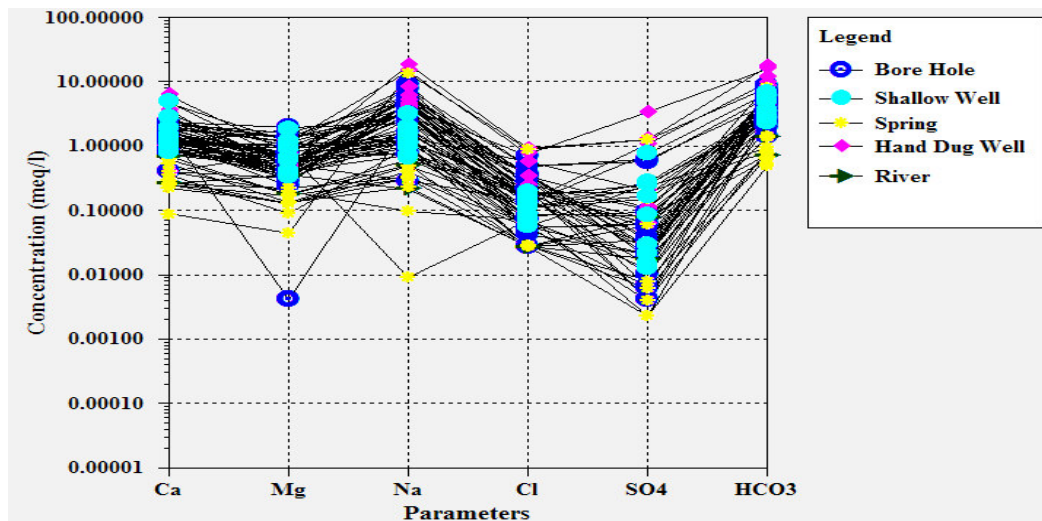


Figure 5. 5 Scholler diagram of data presentation.

It enables to make comparison between multiple parameters from different samples and to group the water samples according to their similarity. XLSTAT 2009 was used to perform this.

Using HCA classification method the collected water samples are categorized into four distinct classes that clearly correlate with the geological and hydrogeological set up of the

area. The low TDS, EC and PH waters are grouped to Class – 1 and the high PH, Conductivity, TDS and low Hardness water samples are categorized under Class – 3. Having very high TDS and very low Hardness value is the behavior of deep thermal water. The thermal springs which are associated with the active MER and aligned parallel to it have very high TDS and highly mineralized. The typical examples are Artu thermal spring which is very close to the southern boundary, Mololicho thermal spring, Eloleka deep bore hole, Hirko shallow well and Alage Gimbichu deep bore hole.

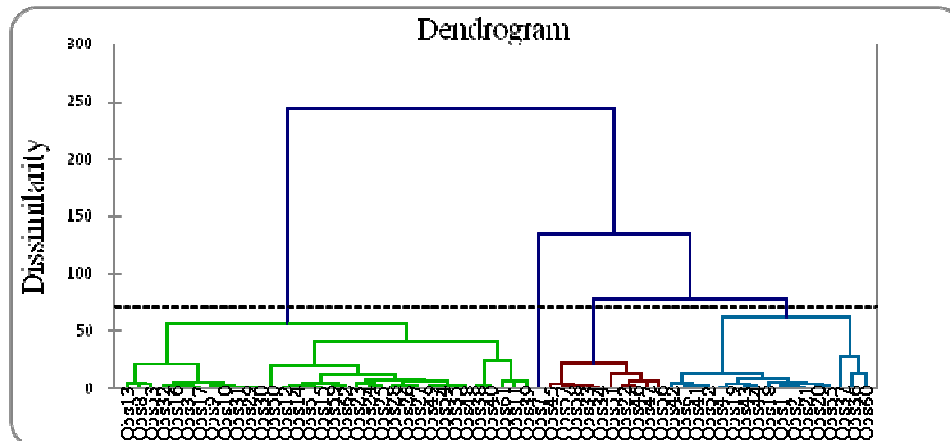


Figure 5. 6 HCA classification of water samples using Xlstat.

The water samples which fall under class – 2 have very low TDS, EC, and PH. Without exception all the samples are distributed along the north and West part of the study area. Springs which emanate from the shoulder of these highlands such as Moshoshe, Sheshera and Kefo springs have very low PH, TDS and EC this indicates that the waters are very young and from shallow groundwater circulating system and these areas are the recharge zone. Class – 1 and class – 4 water samples are relatively with high TDS next to class – 3. Spatially these classes are separated each other. The relatively highly mineralized class – 4 water samples were collected from Alaba Special woreda. These water samples are from deep bore holes with an average depth of 190 m. This clearly suggests that the water is older and the area is discharging zone.

The transitional class – 1 water are from the central and south east part of the area. The water samples which were collected from Boyo plain and western part of Wulbarga Woreda (Achamo Kebele) are grouped in this class. The class of each water sample is presented at 5.1.

Table 5. 2 Different class of water samples

1	7.51	637.69	138	357	Na – Ca – HCO ₃
					Na – HCO ₃
2	7.02	225.63	85.46	153.1	Na – Ca – Mg - HCO ₃
					Ca – Na – HCO ₃
3	9.13	1287	6.6	860	Na – HCO ₃
4	7.98	521	154	313.3	Na – Ca – HCO ₃ – CO ₃
					Na – HCO ₃ – CO ₃

5.4 Hydrochemical Processes and Evolution of water chemistry

Water flowing into the ground system undergoes major changes in ionic composition and PH due to several processes. The evolution involves Hydrolysis of Silicate minerals, cation exchange such as between dissolved calcium and dissolved sodium, oxidation in which organic material is oxidized to carbon dioxide and water, chemical weathering (diagenesis), dissolution and leaching of inorganics from soil and sediment particles creating a relatively stable mineralogy compatible with the water chemistry. In general, the evolution of water chemistry in a groundwater basin proceeds from the near surface oxidizing conditions typically producing calcium bicarbonate water chemistry to deep reducing conditions producing sodium chloride water chemistry.

Water group classified as class – 2 with the dominant water types; Na – Ca – Mg - HCO₃, Ca – Na – HCO₃ and low TDS (153.1 mg/l) are the result of hydrolysis and dissolution of silicate minerals due to the aggressive nature of water caused by dissolved CO₂. When CO₂ charged waters that are low in dissolved solids encounter silicate minerals, such as Plagioclases, olivine and pyroxene will leached and leaving an aluminosilicate residue (clay) with increased Al/Si ratio. The cations released to the water are normally Na⁺, Ca²⁺, K⁺ and Mg²⁺. Hydrolysis is a chemical reaction of water with rock in which the (OH) in water (HOH) becomes part of the new formed substance often silicate minerals will weather this way to form clays. Hydrolysis of these silicate minerals enriches the water in the highlands by Ca, Mg, and Na cations. The rock formations that cover this area are volcanic rocks such as rhyolites, ignimbrites, tuff, trachytes and the thick overburden which is the result of hydrolysis. According to Kebede *et al.* (2005) cited in Demile *et al.* (2008) water of this types represent groundwaters which are either in recharge area at the

early stages of geochemical evolution or rapidly circulating groundwaters which have not under-gone significant water rock interactions.

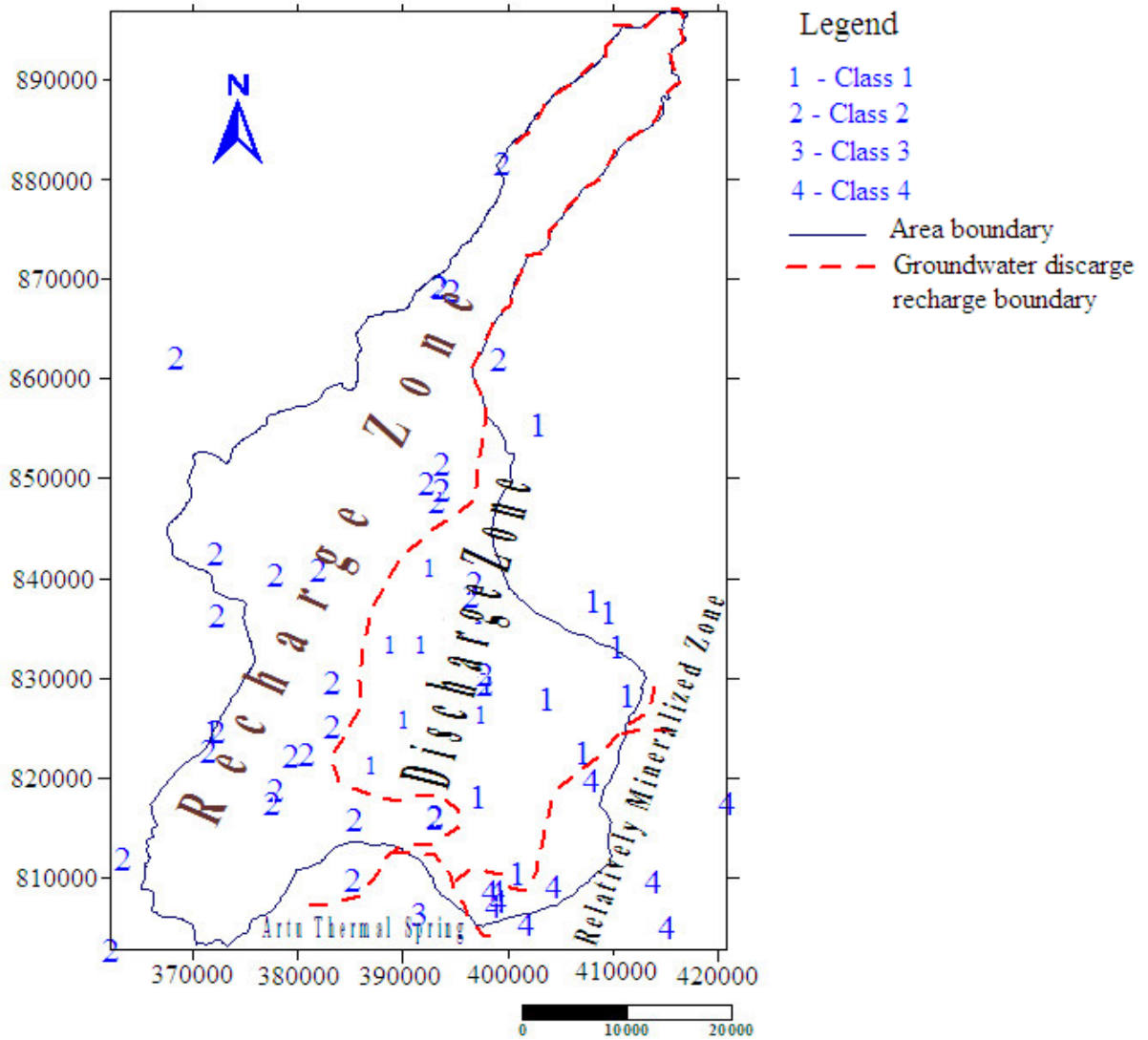


Figure 5. 7 Spatial distribution of different class of water

Basic volcanic rocks which contain Anorthite and Olivine mineral are not surficially exposed in the study area, however borehole log reports around west and north part of the area suggest that the Nazereth series is underlain by Jimma volcanic. So, the concentration of Ca^{2+} ion is not significant as it would be the dominant cation in shallow groundwater circulating system. In the scatter plot of EC versus

(Ca+Mg)/(Na+K) there is unusual water with very high (Ca+Mg)/(Na+K) it is strictly associated with basaltic aquifer (Jimma volcanics) in the western part of the area.

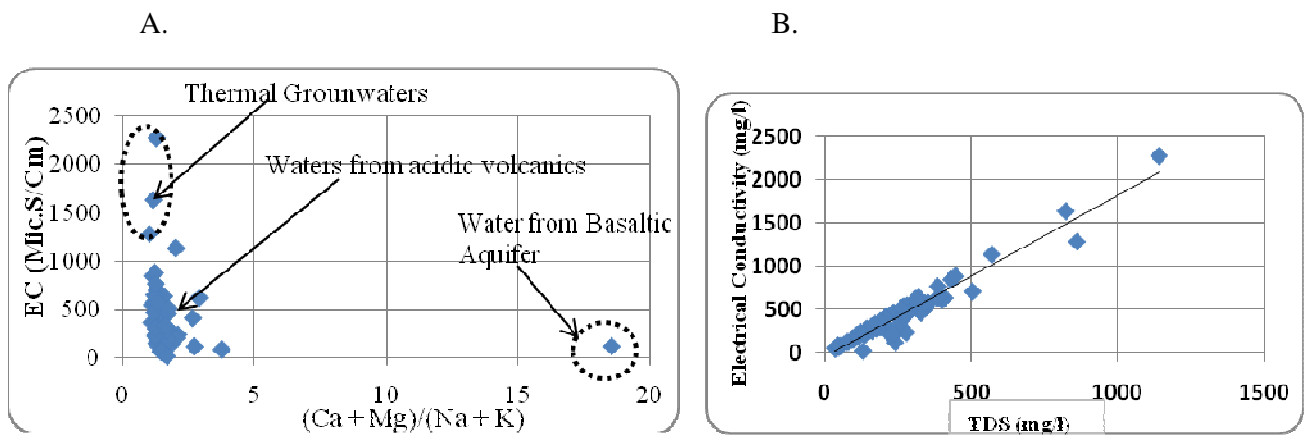
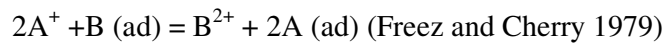


Figure 5. 8 A. EC correlation with (Ca+Mg)/(Na+K) and B. EC versus TDS.

In addition to silicate hydrolysis, cation exchange plays significant role in concentration of major ions in groundwater of the study area. The most important cation exchange reactions in groundwater systems are those involving monovalent and divalent cations such as $\text{Na}^+ - \text{Ca}^{2+}$, $\text{Na}^+ - \text{Mg}^{2+}$, $\text{K}^+ - \text{Ca}^{2+}$ and $\text{K}^+ - \text{Mg}^{2+}$. For these reaction;



It involves the replacement of ions adsorbed on the surface of fine grained materials in aquifers by ions in solution. Because the exchange involves principal cations (sodium, Calcium and magnesium), the process is known as base, or cation exchange. Ion exchange is known to soften groundwater naturally (Todd 2004). It results in higher sodium and lower Calcium and Magnesium concentration in water. An ammonium ion increases the cation exchange and release of sodium and calcium, but calcium will be precipitated as insoluble calcite, whereas sodium (soluble) remains in a dissolved form and increases in concentration. This is clearly seen from Collins Bar diagram in Figure 5.4. that the concentration of Ca^{2+} and Mg^{2+} cations dramatically decrease towards the discharging zone.

The Na-HCO_3 type waters grouped under class – 3 are highly mineralized ($\text{TDS} \geq 860\text{mg/l}$) and exclusively represent the thermal wells and springs aligned along NNE – SSW trending fault line. This group has low/almost null Ca^{2+} and Mg^{2+} cations and high

EC indicating long groundwater resident time and/or relatively higher rock – water interaction. According to Ayenew (2003) many thermal waters in the Ethiopian rift and adjacent escarpments are characterized by high Na and almost exclusively dominated by a single HCO_3^- anion. Though some thermal water samples are not classified using XLSTAT as class – 3, the water type of them is Na – HCO_3^- type and relatively high TDS concentration than the rest of the samples. The Ca^{2+} ion which is observed in class – 2 and 1 water is lost through the insoluble precipitation of CaCO_3 by the process of ion/base exchange. Spatially these types of waters localized to lower elevation or discharge zones particularly south east of Shahogo woreda and Northern and central part of Alaba Special woreda.

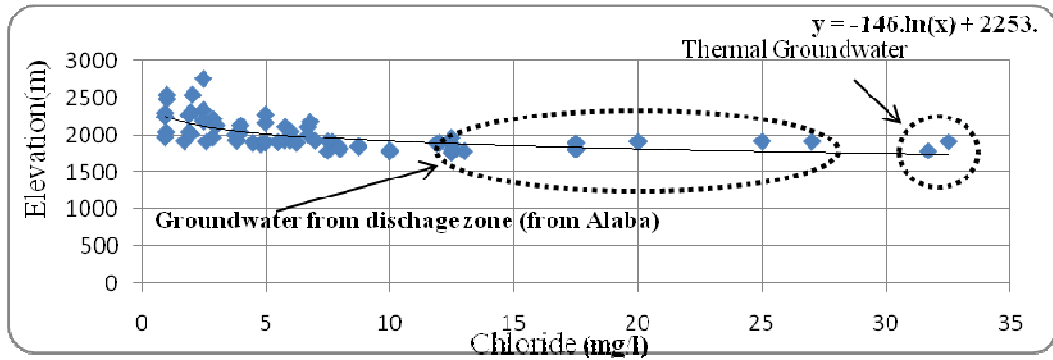
The scatter plots in Figure 5.9. also show very impressive patterns indicating different groundwater types, flows and sources. The ionic concentration increases generally in the direction of groundwater flow towards lower elevation.

On the EC versus $(\text{Ca}+\text{Mg})/(\text{Na}+\text{K})$ plot Figure 5.9, waters with high Na^+ and low Ca^{2+} and Mg^{2+} are often derived either from thermal sources or from groundwaters that are localized in the acidic volcanic rock. In this Figure the sample that is from Misha Woreda Geja spring is characterized by high Ca^{2+} , Mg^{2+} and low EC value it indicates that the groundwater reservoir is basaltic composition probably Jimma basalt which overlain by Nazereth series.

Contrary to Freez and Cherry (1979), it says that it should be noted that Cl^- and SO_4^{2-} are not significant constituents in silicate rocks and there is no tendency to towards development of SO_4^{2-} or Cl^- facies as groundwater moves along flow paths in these rocks, the concentration of chloride increases logarithmically as the groundwater moves along the flow path in the study area. Although there is no SO_4^{2-} and Cl^- type water in the samples, the concentration of these ions is far higher in the Thermal springs and few high TDS and Na- HCO_3^- type boreholes in the low lands of the area. Their occurrence can normally be attributed to atmospheric sources, to decomposition of organic matter and to the trace impurities in rocks and minerals (Freez and Cherry 1979). It is correlated to Chebutarev (1955) reaction series, highly soluble minerals are commonly present in deep groundwater zones because very little groundwater flushing will be occurred. High Cl^- concentration and high total dissolved solids are characteristics of this zone. From Collins bar diagram of the area, Figure 5.4, we can easily see that the concentration of HCO_3^- at higher altitude

around Mugo and Ambericho Ridge is far greater than 40% and the concentration of SO_4^{2-} and Cl^- is very small. The concentration of HCO_3^- decreases towards Shashogo, Alaba and Sankura woreda, while the concentration of SO_4^{2-} and Cl^- increase in this direction.

A/



B/

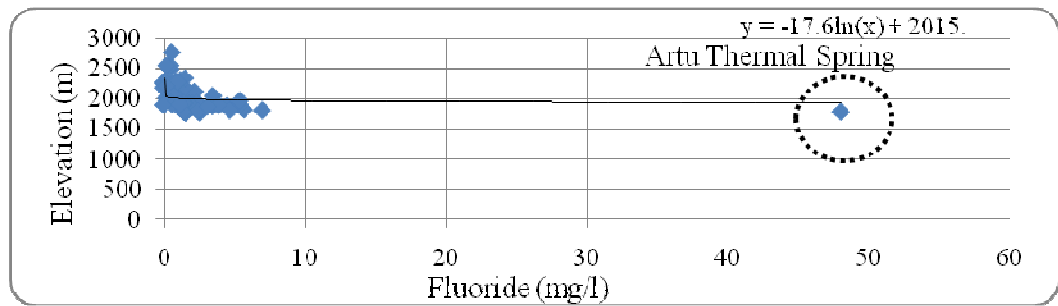


Figure 5. 9 A/ Chloride versus Elevation and B/ Fluoride versus Elevation

Metals solubility particularly iron increases with increasing degree of reduction. As the groundwater loses oxygen it becomes more alkaline with dominant sodium – bicarbonate composition, which in turn allows dissolved fluoride and chloride to increase in concentration (Pyne *et al.* 1995). The concentrations of Iron increase with decrease altitude in the study area.

5.5 Fluoride genesis and distribution

Fluorine is the most electronegative of all the elements. “Electronegativity” is the relative tendency of an atom to acquire negative charge. Fluoride ions have the same charge and nearly the same radius as hydroxide ions; thus the ions may replace each other in mineral structures (Hem 1985). The concern of fluoride genesis and distribution is high in this area.

High F^- concentration is often associated with active and sub-active regional thermal fields and acidic volcanic within high temperature rift floor (Ayenew 2007). The Fluoride distribution map shows that generally the concentration of fluoride is dramatically increases towards the lower elevation.

The main sources of fluoride are Fluorite (CaF_2), Apatite $Ca_5 (Cl, F, OH) (PO_4)_3$, amphiboles, such as hornblende and micas, rocks rich in alkali metals, and obsidian. Fresh volcanic ash may be rather rich in fluoride, and ash that is interbedded with other sediments could contribute fluoride concentrations in groundwater. Hydroxide ions provide a high cation exchange capacity replacing the F with in the minerals (Hem 1985; Ayenew 2007). The spatial variability of F with respect to lithology from surface geological maps is difficult to observe clearly owing to complex volcanic stratification (Ayenew 2007). However, obsidian is exposed surficially at the top of mountains in the study area such as in rift ward direction of Lissana ridge and at the top of Antezo ridge around Besheno, which partly contributes for the increase of fluoride concentration. In addition to this, the wide coverage of volcanic ash and ash interbedded with quaternary sediments which cover the lower elevation of the area give significant concentration of fluoride to the groundwater.

The solubility of F is governed by the solubility of its least soluble compound, which in the case of the area is calcium fluoride (CaF_2). In solutions that contain sufficient amounts of calcium there may be equilibrium with respect to fluorite. Higher dissolved calcium in the groundwater brings about lower level of F (Hem 1970). Hence; any increase in the calcium content must be compensated for by the precipitation of CaF_2 . Fluorine occurs as fluorite (CaF_2) in igneous rocks. It is also common in apatite, and as a substitute for the hydroxide ion in amphibole and mica minerals. Rocks rich in alkali metals (such as sodium and potassium) and obsidian, both of which are common in the south part of the area, tend to have relatively high amounts of F. Thus the F in the rift groundwater is likely to be derived from the weathering of volcanic rocks with F-containing minerals with more additions from geothermal fields (Ayenew 2007).

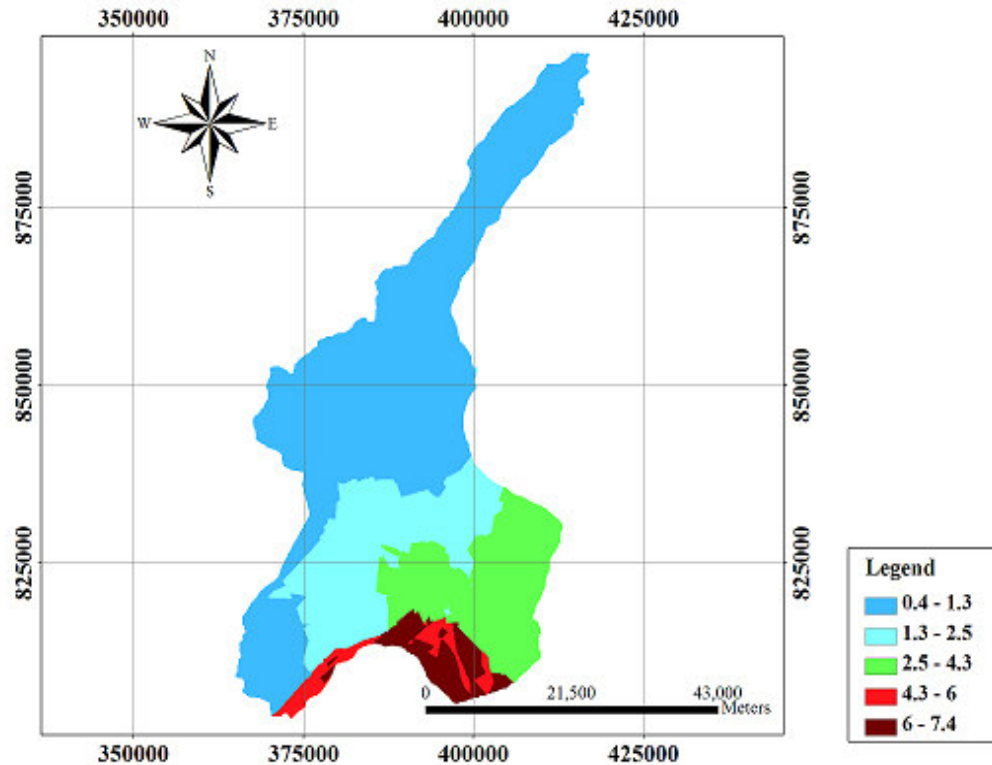


Figure 5. 10 Spatial Distribution of Fluoride the area

The scatter plot Figure 5.12. shows the relation of F with TDS, EC, Ca and Cl. There is strong linear correlation between F and Cl. To a certain extent there is moderate linear positive correlation of F with TDS and EC. On the other hand, there is negative correlation between ions of Ca and Mg, which are abundant in basic volcanics. This illustrates that F is inherently associated with the acidic volcanics. The F content increases as altitude decreases following the groundwater flow path.

According to Ayenew (2003), cited in Ayenew (2007), most of high temperature thermal springs and rift floor bore holes have high ionic concentrations and F content. Almost all deep bore holes drilled surrounding Alaba special woreda, all thermal springs and thermal boreholes have high F concentration following the depletion of Ca^{2+} and Mg^{2+} cations.

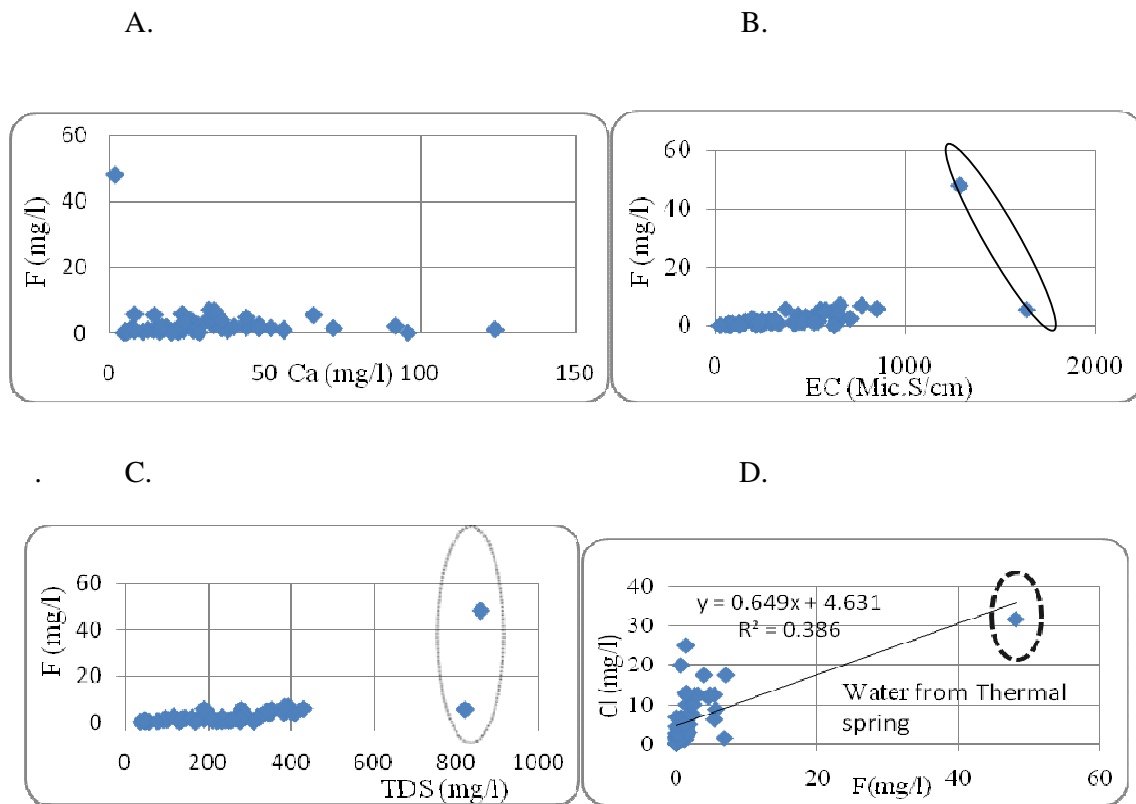


Figure 5. 11 A. Calcium versus Fluoride, B. Electrical conductance versus Fluoride, C. TDS versus Fluoride D. Chloride versus Fluoride.

5.6 Water Quality Assessment

In water resource potential evaluation, the quality of water is as important as the quantity. Therefore, determination of quality of natural water for certain use according to certain standards set by different organization such as WHO for specific water use is required.

Water is essential to sustain life, and a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking-water can result in tangible benefits to health. Every effort should be made to achieve a drinking-water quality as safe as practicable.

The water quality used for irrigation is essential for the yield and quantity of crops, maintenance of soil productivity, and protection of the environment. The physical and mechanical properties of the soil for example soil structure (stability of aggregates) and permeability, are very sensitive to the type of exchangeable ions present in irrigation waters.

In this section the quality of water assessed from drinking water point of view and from agricultural point of view.

5.6.1 Drinking water Quality Assessment

Drinking water is water that is of sufficiently high quality so that it can be consumed or used without risk of immediate or long term harm. Such water is commonly called potable water. Safe drinking water, as defined by the Guidelines, does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. Those at greatest risk of waterborne disease are infants and young children, people who are debilitated or living under unsanitary conditions and the elderly (WHO 2004).

5.6.1.1 Microbial aspects

Securing the microbial safety of drinking-water supplies is based on the use of multiple barriers, from catchment to consumer, to prevent the contamination of drinking water or to reduce contamination to levels not injurious to health. Safety is increased if multiple barriers are in place, including protection of water resources, proper selection and operation of a series of treatment steps and management of distribution systems.

Owing to most of the community living in the study area are farmers and have no as such awareness about safe water concept, the water resources are prone to microbial contamination. Series microbial contamination problem is observed at the lower elevation plain land or the floor of the rift particularly Shashogo and Ana Lemo woreda and south west of Wulbareg woreda. The greatest microbial risks are associated with ingestion of water that is contaminated with human or animal (including bird) faeces. Faeces can be a source of pathogenic bacteria, viruses, protozoa and helminthes (WHO 2004). As mentioned above most of the community is rural people and they used open field as a toilet and their livestock graze around rivers and pond. During rainy season the runoff washes all these wastes from the highland down towards the floor of the rift.

Microbial water quality often varies rapidly and over a wide range. Short-term peaks in pathogen concentration may increase disease risks considerably and may trigger outbreaks of waterborne disease. Furthermore, by the time microbial contamination is detected, many people may have been exposed (WHO 2004). According to the respective zonal and

woreda officers, this problem is frequently happened during rainy season especially from June to September and by the time it happened most people will suffer from the disease called 'ATET'.

5.6.1.1.1 Disinfection

Disinfection is an effective barrier to many pathogens (especially bacteria) during drinking-water treatment and should be used for surface waters and for groundwater subject to faecal contamination. Residual disinfection is used to provide a partial safeguard against low-level contamination and growth within water supply scheme. An effective overall management strategy incorporates multiple barriers, including source water protection and appropriate treatment processes, as well as protection during storage and distribution in conjunction with disinfection to prevent or remove microbial contamination.

Chemical disinfection has both advantage and disadvantage. The use of it is not totally safe the supply system but it reduces faecally contaminated water supply system. According to WHO (2004), chlorine disinfection of drinking-water has limitations against the protozoan pathogens in particular *Cryptosporidium* and some viruses. However, using it is the best way of disinfection in the study area. High levels of turbidity can protect micro organisms from the effects of disinfection, stimulate the growth of bacteria and give rise to a significant chlorine demand.

The disadvantage of using chemical by product is the formation of chemical by products that may precipitate as a result of chemical reaction. But still its advantage is greater over not using it. The regional water resources bureau incorporation with UNICEF has emergency program to overcome this problem. The program has preventive, such as drilling of shallow wells, and remedial program. However, still it is not satisfactory and the laboratory test of most shallow well haven't been under taken this may lead to the most serious problem such as fluoride.

5.6.1.2 Chemical aspects

There are many chemicals that may occur in drinking-water; however, only a few are of immediate health concern in any given circumstance. For example exposure to high levels of fluoride which occurs naturally can lead to mottling of teeth and in severe cases crippling skeletal fluorosis. Though it is not analyzed, arsenic has also critical risk of

cancer and skin lesions. In addition to these, there are many elements and organic compounds that may lead health problem if they present in excess.

Since the area is found within the MER, from all the above chemical aspects the effect of fluoride is significant. The genesis and spatial distribution of fluoride is discussed under Section 5.5.

Accordingly, by comparing the measured value of major ions and some parameters from the catchment area with WHO guide line for drinking water, it can be seen that except fluoride and sodium (207 mg/l) at Elo Leka deep bore hole all major ions and all parameters are much below the WHO guide line. Owing to rifting out of the analyzed 62 water samples 42% waters have fluoride concentration greater than WHO guide line which is 1.5mg/l.

The water chemical analysis suggests that except Alaba Water Supply Deep bore hole #4 all water samples collected from Alaba special wored have fluoride concentration above WHO guide line. In addition to Alaba area, most shallow wells, hand dug wells and thermal wells and springs have greater concentration of Fluoride. The area prone to fluoride problem within Shashogo woreda is the area south of Boyo Plain near the escarpment.

5.6.2 Agricultural Water Quality

The economic condition of the inhabitants in this river catchment strongly depends on rain-fed agriculture and its products. To insure sustainable agricultural production the governing parameters and chemical elements should be studied well. In this research work only SAR value is analyzed.

5.6.2.1 SAR (Sodium Adsorption Ratio)

High sodium ion in water affects the permeability of soil and cause infiltration problems. This is because sodium when present in the soil in exchangeable form replaces calcium and magnesium adsorbed on the soil clays and cause dispersion of soil particles (i.e if calcium and magnesium are the predominant cations adsorbed on the soil exchange complex, the soil tends to be easily cultivated and has a permeable & granular structure). This dispersion results in breakdown of soil aggregates. The soil becomes hard and

compact when dry and reduces infiltration rates of water and air into the soil affecting its structure.

Sodium Adsorption Ratio (SAR) is an index that expresses the relative activity of sodium ions in the exchange reactions with the soil. This ratio measures the relative concentration of sodium to calcium and Magnesium using the following equation;

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

Where [x]: ion concentration in meq/L, Na⁺: Sodium, Ca²⁺: Calcium, and Mg²⁺.

The SAR value map of the area shows that the Northern and Western part of the area has SAR value ranging from 0.81 – 3 and the southern part of the area has SAR value ranging from 3 – 9. According to Lenntech Water treatment & air purification Holding B.V (2003), the northern and western part of the area is free of the adverse effect of sodium while starting from Lisana ridge towards Alaba; it has adverse effect ranging from slight to moderate. The measures that should be taken are presented in below.

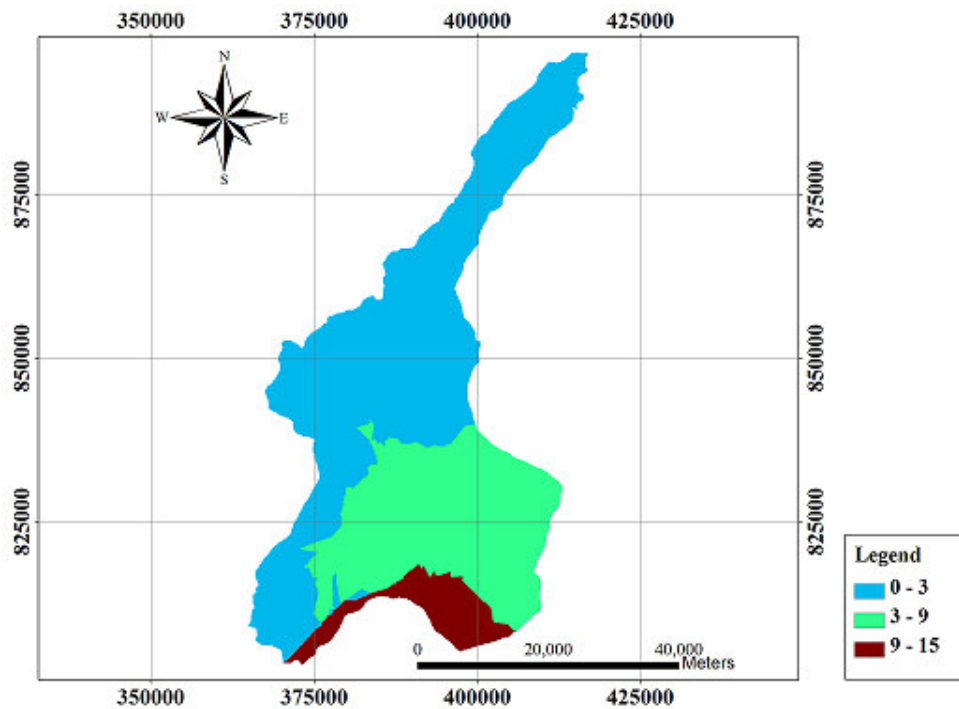


Figure 5. 12 Spatial trend of SAR value with in the area

5.6.2.1.1 Solutions to SAR problems in soils

To decrease the adverse effect of sodium in agriculture it is advisable to change the source of water if there is a choice. Blending irrigation water with lower water in sodium level is another method of reducing the adverse effect. This method can be practicable in this river catchment because it does not need any chemical that cost much and does not need experts.

Increases aeration and application of surfer, gypsum and sulfuric acid injection will facilitate the solubility of calcium and magnesium which in turn decrease the concentration of sodium in soil.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Upper Bilate River Catchment is found within rift valley drainage basin south western escarpment of MER. The catchment area has an area of 2,075 km² and a perimeter of 295km from which an area of 4.3 km² is occupied by Boyo Lake/swamp. This part of the basin is the main source of surface water for Bilate Irrigation project which is situated around north of Biate Tena. It has majorly two perennial rivers that feed Bilate River; Weira and Guder that emanate from the shoulder of Gurage Mountain and the highlands of Misha woreda north of Hossana town. These tributaries also have intermittent tributaries Konkoye and Batena respectively.

The river catchment has two climatic zones. The western and northern plateau characterized by sub humid while the lower part of the area is characterized with semi arid climatic zones. Long term average areal depth of precipitation is calculated by Arithmetic mean, Thiesson Polygon, and Isohytal Contour Map methods. The estimated values are 1236.05 mm, 1234.59 mm and 1231.65 mm respectively. However, due to the effect of topography in the area the value obtained by Isohytal Contour Map is taken to be the annual average areal depth of precipitation to the area. The northern part of the area receives relatively high precipitation 1284.7mm and shows uni modal rainfall pattern and the southern part receives 1216.6 mm and bimodal rainfall pattern. The long term minimum and maximum temperatures of the area are 12.7⁰C and 25.76⁰C respectively.

Potential Evapotranspiration of the area was calculated using two methods; Penman Combination Method and Thornthwait and Mather, in addition to these Pan Evaporation Method was also estimated for the open water body. Due to uneven distribution of meteorological data PET was calculated for the whole catchment though it has three physiographic zones; highland, escarpment, and rift floor. The estimated PET of the area using Thornthwaite empirical formula and Penman combination methods are 842.4 mm and 1222.93 mm respectively. The value obtained by Penman Combination method is assumed to be the PET of the area because it considers more meteorological data than Thornthwaite empirical method. Evapotranspiration of the open water body (Lake Boyo) was calculated by taking the pan evaporation of Bilate Irrigation project and the pan

coefficient was obtained using FAO – 24 Pan Method. The pan coefficient and the pan evaporation of the lake are 0.6 and 2.57 mm respectively.

The Actual Evapotranspiration of the area was calculated using Turc empirical method and Thornthwaite and Mother Methods. Using Turc empirical method the AET is estimated as 800.92 mm. To calculate AET of the catchment using Soil Moisture Balance Method the area was reclassified into four classes; class – 1, 2,3 and 4 depending on FAO (1975) textural soil classification and land use/land cover of the area. The estimated values are 1017, 1017, 1094 and 1057 mm respectively. Having long rooting depth the area classified under class three have very high AET than the rest of the classes. The average annual AET of the area is 1019.8 mm this is used to compute the average recharge of the catchment and water balance of the catchment.

The surface water and groundwater runoff has been computed from partitioning the stream hydrograph of Guder, Weira and Bilate Rivers using Spreadsheet Time Plot that takes attenuation coefficient (which is a factor of surface slope and land use/land cover) into account. Having variable geology, topography, precipitation and surface area, the three gauging stations result in different surface runoff and base flow. The values are 139.93, 181.34, and 51.26 runoff and 211.24, 317.24, and 129 mm base flow respectively. Relatively Bilate River has low runoff and baseflow than Weira and Guder Rivers. It is due to the damping effect of Guder River to Lake Boyo and high infiltration of Weira River to Boyo Plain which is covered with alluvial and lacustrine sediments.

Regarding to the groundwater recharge, two different methods had been adopted to estimate the groundwater recharge of the catchment which is used to plan how to use the resource without harming. The methods include the long term mean minimum stream flow (129mm) and conventional water balance (96.7mm) methods. The average of the two values is taken as the recharge of the area (113mm) which is 9.2% of the total precipitation of the catchment.

The surface hydrogeological mapping was performed by classifying the hydrogeologic units based on surface geology, borehole lithologic log, pumping test and water chemical analysis result of the area. In the study area majorly there are Four hydrogeological units; Jima – Volcanics, Volcanic Aquifer of different time episodes, Lacustrine and Alluvial

sediments. From which the most productive aquifer is Alluvial Sediment aquifer situated at the rift floor and along the bank of existing and buried streams.

Type of aquifers is distinguished using three integrated approach; observing lithological logs of wells, construction of diagnostic (log – log) plot and specialized plot (semi – log) plot of drawdown versus time and by care full observation of static/piezometric water level with respect to the water bearing horizon. In the area unconfined, confined and leaky types of aquifers are identified. The presence of many deep and shallow wells in escarpment and floor of the rift enables to calculate hydraulic parameters in this area but the hydraulic parameters of the most of the plateau cannot be determined due to the absence of wells. This is strictly associated with the depth of groundwater is quite deep and the groundwater storage is very low.

Due to using low capacity pumps while performing pumping test, almost all data collected from the respective organization cannot be representative of the actual potential of aquifers within the area. However, to have insight of the area the collected samples are analyzed with their appropriate model. The hydraulic conductivity of the area ranges from 0.17 – 8.8 m/d and the transmissivity ranges from 2.5 – 242.8 m²/d. In general, the hydraulic conductivity and transmissivity decreases radially from the center of Boyo plain towards the periphery of the area.

Regarding the groundwater recharge and discharge zone of the area, it is conceptualized from precipitation, geology including structural geology, yield of wells, and hydrochemical study of the area. In general, the northern and western plateau are recharging zone and the central part of the area which is occupied by Boyo plain is the recharging zone while the area east of this graben is deep groundwater zone. From these integrated approach the groundwater flow system is also determined for the area. In this river catchment local and intermediate groundwater system is detected. The general groundwater flow direction is from the north and north western part of the area which is the plateau to south and south eastern part of the area which is the floor of the rift. A plot of contours of the hydraulic heads and the stream networks reveal that most reaches of the stream gain water from the groundwater system and those that are at the lowest reaches loose water to the sub-surface system.

The springs in the study area are generally of two types: gravity and non-gravity. The gravity springs are fracture, contact and depression springs. Whereas the non-gravity (hot) springs are located along fault zones particularly along the western escarpment of the rift. The heat source is believed to be result of deep circulation of groundwater (geothermal gradient) from the escarpment to wards to the rift center with high geothermal gradient.

Measurements of the major cations, anions and in situ test of parameters such as PH, TDS, EC and T have been used for two four general purpose;

- a. To delineate recharge/discharge zone, regional/local/intermediate flow systems through mapping the increasing/decreasing trends (evolution) and associating the trends with the intrinsic chemical and physical properties of each parameter
- b. To identify source and origin by clustering (grouping) water types
- c. To analyze the water sample from groundwater quality point of view; domestic and agricultural point of view.
- d. Applicability of the chloride mass balance to evaluate the groundwater recharge

The water chemistry analysis results which were collected from the respective organization and primary data from laboratory are checked for their quality not to mislead the interpretation. It includes laboratory versus in situ test comparison. Graphical Presentation methods such as Piper diagram, Colin bar diagram, Scholler and Pie plot of the area and Multivariate Statistical (HCA) methods was used in order to facilitate interpretation and analysis of the chemical data. The piper plot of the water chemical analysis shows that shallow wells, bore holes and spring water samples are Ca-Na - Mg-HCO₃ type in the discharging area and Na-HCO₃ type towards recharging zone. Maps and Scatter plots of concentration trends of PH, TDS, EC, Elevation, F, Cl, (Ca+Mg)/(Na+K) show a very good correlation. All the maps clearly mark the recharge, discharge and transitional zones. The Multivariate Statistical method is also in very close agreement classified the water samples in to four classes. The water sample which are classified under class 2 are from the northern and western plateau, class 1 waters are from the major discharge zone, class 3 waters are from deep circulating hot springs and Class 4 waters area from the deep groundwater zones around Alaba. The spatial distribution of these classes was mapped and clearly delineates these zones.

The high value of TDS for hot springs while others are low at the same elevation can be partly attributed to the influence of geothermal heating, deep circulation and to rock water interactions due to long residence time. From composition diagram interpretation boreholes and hot spring waters in the catchment are the most evolved waters from the river, hand dug wells and cold springs.

High concentration of fluorine noticed around Shahogo, Alaba and Sankura area. Its concentration increases towards Alaba. The source of fluoride in the area is strongly associated with Fluorite (CaF_2), Apatite $\text{Ca}_5(\text{Cl,F,OH})(\text{PO}_4)_3$, Amphibols such as hornblende and micas, rock rich in obsidian and the presence of thick deposits of fresh ash.

Form agricultural point of view, SAR value was analyzed. Accordingly, the area very close to Artu Thermal Spring and around Alaba special woreda suffers from the adverse effect of sodium.

6.2 Recommendation

In the light of the findings obtained and conclusions reached the following recommendations are forwarded.

- The respective governmental and nongovernmental organizations should assign professionals during well site selection, construction, pumping test and data compilation time in order to avoid scientific data errors and miss leading of data.
- The data base management system of all the woreda, zonal and regional offices should be improved and updated with uniform data base system.
- During pumping test, it is strongly advisable to use high capacity pumps in order to use the maximum capacity of the aquifer and to accurately characterize the aquifer system of the Catchment.
- The zonal and regional water resources development offices should control any organization who is willing to construct wells and develop springs not to distribute the system before physiochemical and biological test like that was done at Shashogo, Lemo and Angacha Woredas.
- Paying attention to structural and tectonic effect is highly recommended which suppose to be in charge of groundwater evolution to larger extent.
- The natural vegetation has been greatly affected by agriculture and deforestation. Detailed land use land cover study should be conducted to quantify the extent of land cover change during the last century and its effect on the base flow of the catchment.
- Detailed hydrogeological, Isotope, remote sensing and geophysical investigation should be conducted to delineate major water bearing zones, aquifer thickness and aquifer depth in the volcanic and alluvial formation particularly in the northern part of the area.
- Detailed geological and structural investigation should be conducted to know the structure that controls the emergence of thermal springs and the source of heat.
- During well construction observation pipes must be installed. It enables to monitor the water level of the well that has scientific significance and also used during well rehabilitation.

- Meteorological data are crucial to calculate the water balance components effectively but about 75 % of the meteorological stations are rainfall stations, i.e class 4 stations and the existing stations are also out-of-date so, meteorological station have to be installed evenly and upgrading of the existing stations has to be done.
- To determine the depth and thickness of the water bearing formation and to quantify the groundwater resource of the area, geophysical investigation especially Vertical Electrical sounding (VSE) is recommended at selected sites.

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Appendices

Annex 3. 1 Arthemetically estimated mean monthly rainfall

Station	Mean monthly rainfall over the study area													
	Duration	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Areka	1988 - 2003	42.19	67.02	105.85	216.31	190.6	162.89	217.22	218.77	186.93	126.23	30.99	30.06	1595.06
Bilate	1971 - 2004	28.52	34.88	49.95	104.18	92.46	84.74	99.3	75.39	62.72	78.89	32.4	23.43	766.86
Boditi	1976 - 2007	32.09	47.98	103.37	164.33	158.33	125.16	149.69	139.95	109.79	83.92	43.42	38.06	1196.09
Durame	1978 - 2007	26.54	55.23	95.47	146.8	146.8	102.63	132.97	155.24	132.39	93.97	29.43	25.76	1143.23
Fonko	1986 - 2007	31.57	52.08	129.44	162.22	135.07	124.44	164.05	188.2	152	98.26	12.16	26.38	1275.87
Hossana	1978 - 2007	32.47	53.8	104.74	141.84	136.56	121.41	151.25	181.38	145.46	77.91	18.45	26.4	1191.67
Gunchire	1988 - 2007	29.52	38.14	95.06	101.93	124.78	194.38	258.84	236.62	172.52	78.07	14.89	18.11	1362.86
Aje	1972 - 1991	23.6	42.2	74.1	86.9	137.4	88.5	131.5	119.7	116.8	62.4	12.3	11	906.4
Imdiber	1980 - 2007	25.01	27.53	71.99	89.16	96.22	167.79	230.23	214.5	118.98	71.87	12.28	7.87	1133.43
Shone	1978 - 2007	58.28	81.71	136.64	196.1	182.96	138.63	184.65	212.31	191.59	116.56	46.99	43.19	1589.61
Alaba	1985 - 2007	35.3	56.21	98.36	152.16	120.17	89.17	112.73	135	114.61	77.96	22.37	23.3	1037.34
Wulberg	1978 - 2007	30.35	53.82	104.89	133.52	149.93	154.39	212.32	187.81	163.05	74.56	12.02	12.8	1289.46
Angacha	1987 - 2005	42.5	59.2	119.2	191.5	159.8	133.1	183.6	195.7	187.5	110.9	51.7	29.2	1463.9
Welkite	1978 - 2007	22.9	44.29	80.74	107.29	124.49	201.98	291.64	251.81	149.39	49.33	18.6	10.4	1352.86
MMP		32.92	51	97.84	142.45	139.68	134.94	180	179.45	143.12	85.77	25.57	23.28	1236.05

Annex 3. 2 Potential evapotranspiration estimated using Thornthwaite Method

Potential Evapotranspiration (Thornthwaite Method)												
Month	Jan.	Feb.	Mar.	Apri.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Tm	19.85	20.55	20.55	20.1	19.37	18.58	17.75	17.51	18.62	18.91	19.23	19.38
Nm	0.97	0.98	1.00	1.03	1.05	1.06	1.05	1.03	1.01	0.98	0.97	0.96
Im	7.91	8.33	8.33	8.06	7.61	7.17	6.69	6.55	7.18	7.35	7.55	7.64
I	90.37											
a	1.95											
PET	72	77.8	79.4	78.3	74.3	69.2	63	60	66.2	66.2	68	68
Annual PET of the area is 842.4 mm												

Annex 3. 3 Soil moisture model for cultivated land, moderately deep rooted crops (corn and cereals) and clay texture, available water capacity root zone of 150mm.

Parameter	AET for cultivated land, moderately deep rooted crops (corn and cereals) and clay texture, Available Water capacity root zone of 150mm												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	32.92	51	97.84	142.45	139.68	134.94	180	179.45	143.12	85.77	25.57	23.28	1236.02
PET	109.12	114.24	113.15	108.3	110.98	88.8	78.43	80.91	88.8	107.26	110.1	112.84	1222.93
P – PET	-76.2	-63.24	-15.31	34.15	28.7	46.14	101..57	98.54	54.32	-21.49	-84.53	-89.56	13.09
APWL	-272	-335	-350							-21.49	-106	-196	
S _m	25	16	15	49.15	77.85	123.99	150	150	150	130	74	40	
ΔS _M	-20	-9	-1	34	29	46	26	0	0	-20	-60	-34	
AET	48	60	98.84	108.3	110.98	88.8	78.43	80.91	88.8	105.77	81.57	67	1017
SMD	61.12	54.24	14.31	0	0	0	0	0	0	1.49	28.53	45.84	205.53
S	0	0	0	0	0	0	75.56	98.54	54.32	0	0	0	228.42
TARO	7.6	3.8	1.9	1	0.5	0	75.56	136	122	61	30.5	15.25	
RO	3.8	1.9	0.95	0.5	0.25	0	37.78	68	61	30.5	15.25	7.6	
D	3.8	1.9	0.95	0.5	0.25	0	37.78	68	61	30.5	15.25	7.6	

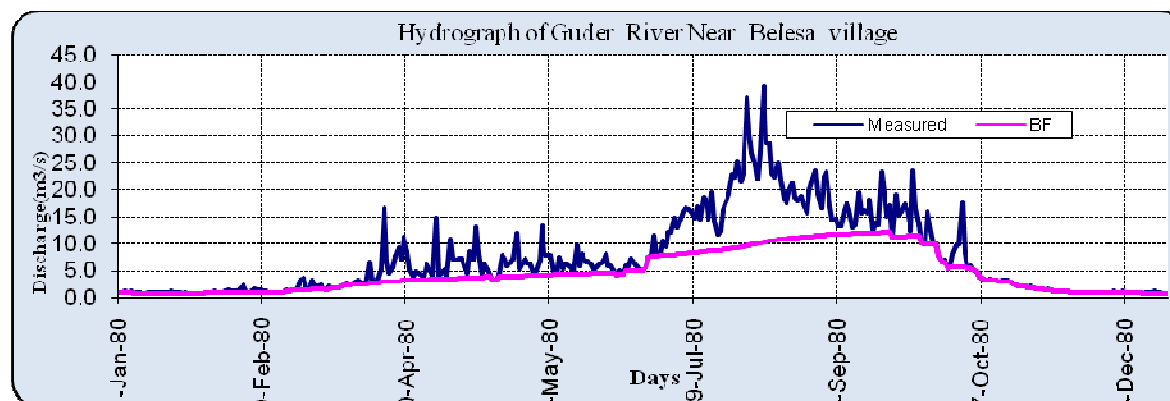
Annex 3. 4 Soil moisture model for woodland and clay texture, available water capacity of root zone of 350mm

Parameter	AET for cultivated woodland and clay texture, available water capacity of root zone of 350mm												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	32.92	51	97.84	142.45	139.68	134.94	180	179.45	143.12	85.77	25.57	23.28	1236.02
PET	109.12	114.24	113.15	108.3	110.98	88.8	78.43	80.91	88.8	107.26	110.1	112.84	1222.93
P – PET	-76.2	-63.24	-15.31	34.15	28.7	46.14	101.57	98.54	54.32	-21.49	-84.53	-89.56	13.09
APWL	-272	-335	-350							-21.49	-106	-196	
S _m	161	134	129	164	192	238	340	350	350	329	259	200	
ΔS _M	-39	-27	-5	35	28	46	102	10	0	-21	-70	-59	
AET	72	78	103	108.3	110.98	88.8	78.43	80.91	88.8	107	96	82	1094
SMD	37	36	10	0	0	0	0	0	0	0.26	14	31	
S	0	0	0	0	0	0	0	89	54.32	0	0	0	143.32
TARO	6.2	3	1.5	0.7	0.38	0	0	89	98.82	49.41	24.7	12.35	
RO	3.1	1.5	0.75	0.35	0.19	0	0	45	50	24.7	12.35	6.2	
D	3.1	1.5	0.75	0.35	0.19	0	0	44	49	24.7	12.35	6.2	

Annex 3. 5 Soil moisture model for exposed or bare, grass, shrubs and silt loam texture available water capacity of root zone of 250mm

Parameter	AET for exposed or bare, pasture grass, shrubs and Silt Loam texture the av. water capacity of root zone of 250mm												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	32.92	51	97.84	142.45	139.68	134.94	180	179.45	143.12	85.77	25.57	23.28	1236.02
PET	109.12	114.24	113.15	108.3	110.98	88.8	78.43	80.91	88.8	107.26	110.1	112.84	1222.93
P – PET	-76.2	-63.24	-15.31	34.15	28.7	46.14	101.57	98.54	54.32	-21.49	-84.53	-89.56	13.09
APWL	-272	-335	-350							-21.49	-106	-196	
S _m	84	66	62	96	125	171	250	250	250	229	164	114	
ΔS _M	-30	-18	-4	34	29	46	79	0	0	-21	-65	-50	
AET	63	69	102	108.3	110.98	88.8	74.43	80.91	88.8	107	91	73	1057
SMD	46	45	11	0	0	0	0	0	0	0.5	19	39.84	
S	0	0	0	0	0	0	22.2	98.54	54.32	0	0	0	175
TARO	6.875	3.4	1.7	0.859	0.5	0	22.2	110	110	55	27.5	13.75	
RO	3.4	1.7	0.859	0.5	0.25	0	11.1	55	55	27.5	13.75	6.875	
D	3.4	1.7	0.859	0.35	0.25	0	11.1	55	55	27.5	13.75	6.875	

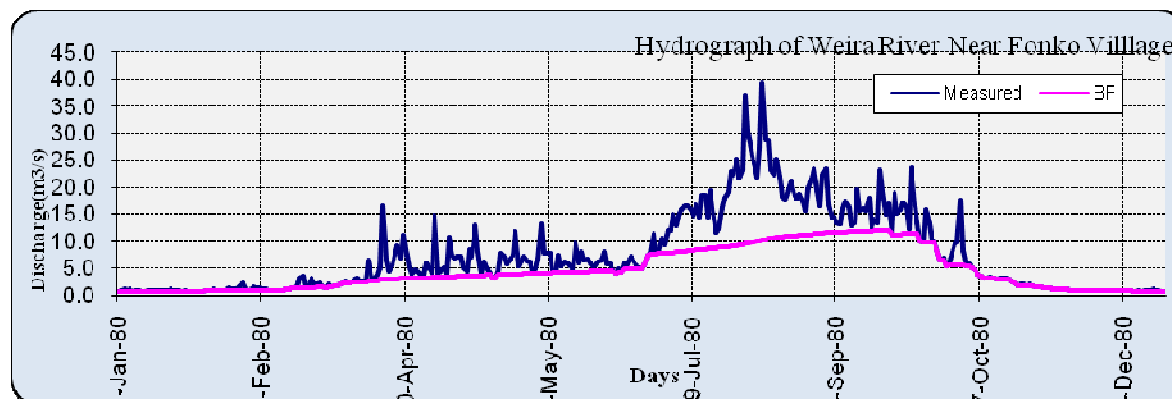
Annex 3. 6 Hydrograph of Guder River



Annex 3. 7 Mean monthly total flow, base flow, and runoff of Guder River.

Year	Measured	Average flow in the month (m ³ /s) Guder river												Average
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
16Years Average	Total Flow	0.074	0.081	0.564	0.87	0.87	1.75	3.1	2.28	2.2	2.06	0.32	0.093	1.187
	BF	0.029	0.034	0.2	0.34	0.34	1.09	1.42	1.59	1.57	1.47	0.31	0.085	0.714
	RO	0.045	0.047	0.363	0.53	0.53	0.66	1.66	0.63	0.63	0.59	0.002	0.008	0.473

Annex 3. 8 Hydrograph of Weira Rivere



Annex 3. 9 Mean monthly total flow, base flow, and runoff of Weira River.

Year	Measured	Average flow in the month (m ³ /s) Weira river												Average
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
20Years Average	Total Flow	0.86	1.15	6.42	6.64	5.79	13.75	23.24	15.74	9.27	8.45	1.8	0.87	7.83
	BF	0.78	0.89	3.11	3.8	4.3	8.315	10.41	11.31	7.2	6.6	1.76	0.814	4.94
	RO	0.08	0.26	3.32	2.83	1.48	5.44	12.83	4.43	2.07	1.84	0.042	0.059	2.89

Annex 4. 1Water point inventories

No	Woreda	Kebele	Source	X	Y	Z	Depth (m)	SWL (m.a.s.l)	Water elevation
1	Alaba	U/Tuqa	BH	407942	819799	1935	286.5	254.7	1680.3
2	Alaba	Kulufo	BH	407117	822518	1912	220	177.13	1734.87
3	Alaba	Besheno	BH	414866	824656	1999	300	266.65	1732.35
4	Alaba	Eleloqa	BH	397150	818125	1812	195	139	1673
5	Alaba	1st Choroqo	BH	400933	810493	1793	183.5	104.15	1688.85
6	Alaba	Qulito	BH	399055	808866	1772	154	85.1	1686.9
7	Alaba	Qulito	BH	398725	808936	1786	147	81.95	1704.05
8	Alaba	Qulito	BH	398840	807421	1759	144	94	1665
9	Alaba	Qulito	BH	399183	807660	1778	147	86	1692
10	Dalocha	Demeke	BH	404755	847131	2004	143	94.4	1909.6
11	Dalocha	Achiraye Fuge	BH	406850	863183	2076	97.5	64.4	2011.6
12	Dalocha	Ambericho Achamo	BH	399004	850346	2091	188	41.8	2049.2
13	Dalocha	Ambericho Gimba	BH	396810	847700	2065	150	98.75	1966.25
14	Sankura	Getem Gurbaye	BH	405258	840627	1943	186	128	1815
15	Sankura	Bercho Kulfo	BH	408565	826559	1910	270	182.6	1727.4
16	Sankura	Gutancho	BH	403494	831512	1932	210	152.12	1779.88
17	Sankura	Kore (Bonesha Kore)	BH	403664	827808	1908	236	155	1753
18	Sankura	Hergedina Matoria	BH	403963	823095	1841	180	110.75	1730.25
19	Shashego	Alage	BH	399094	827908	1899	119	83	1816
20	Shashego	Bonesha Wanchikota	BH	397867	830788	1900	86	17	1883
21	Shashego	Doisha Hule	BH	402651	835554	1969	158	118.2	1850.8
22	Demboya	Damboya 01	BH	383279	810877	2169	300	228.4	1940.6
23	Demboya	Hego	BH	382198	808182	2109	284	181.65	1927.35
24	Sankura	Gumbi Feten	BH	410487	833037	1885	204	142.52	1742.48
25	Doyo Gena	Doyo Gena Town	BH	363355	811819	2299	200	35.2	2263.8
26	Lemo	Hosaina town	BH	375262	836761	2262	200	132.5	2129.5
27	Lemo	Kalisha	BH	375410	831143	2260	189	130.8	2129.2
28	Lemo	Lisana	BH	381012	831847	2166	157	89.21	2076.79
29	Lemo	Fonko	SW	385674	845578	2250	139	74	2176
30	Lemo	Fonko	SW	386196	845921	2233	149	111	2122
31	Shashego	Hirko Fofa	SW	384391	820769	1930	57	12.3	1917.7
32	Shashego	Hirko Fofa	SW	385457	821190	1907	48	4.2	1902.8
33	Shashego	Afto Uterancho	SW	388219	823653	1908	54	4.5	1903.5
34	Shashego	Golicho Boyo(well#4)	SW	390701	824093	1905	50	7	1898
35	Shashego	Doisha Ambericho	SW	396945	840676	1932	46	21	1911
36	Shashego	Doisha Ambericho	SW	396955	841151	1927	46	18	1909
37	Shashego	Doisha Amberich	SW	396864	841786	1947	46	18	1929

38	Shashego	Doisha town	SW	396971	839360	1925	39	10	1915
39	Shashego	Doisha town	SW	396970	839035	1918	40	11	1907
40	Shashego	Doisha Ambericho	SW	398048	840493	1923	42	14	1909
41	Shashego	Beche Gola	SW	397275	834657	1913	35	8	1905
42	Shashego	Beche Gola	SW	397509	836214	1916	33	9	1907
43	Demboya	Hamancho	SW	380496	811701	2167	53	10.8	2156.2
44	Demboya	Hamancho	SW	381496	811675	2159	79	67	2092
45	Angecha	1st Angecha & Ke'lama	SW	375034	813821	2190	81	45	2145
46	Angecha	Hobicho Miliso	SW	375819	819808	2083	51	21	2062
47	Angecha	1st Angecha & Ke'lama	SW	376894	819378	2048	75	57	1991
48	Angecha	Hobicho Miliso	SW	375639	819314	2090	65	49	2041
49	Doyo Gena	Wunjela	SW	373029	825466	2207	63	19	2188
50	Angecha	Bucha	SW	377705	814550	2160	70	42	2118
51	Lemo	Bobicho	SW	372170	837610	2270	63	39	2231
52	Lemo	Bobicho	SW	373265	839600	2309	62	33	2276
53	Lemo	Ana Limu	SW	386220	838319	2381	60	30	2351
54	Lemo	Hankgela Senfe	SW	386916	846061	2153	56	32.5	2120.5
55	Lemo	Kidigisa	SW	374864	838210	2290	81	34	2256
56	Lemo	Kidigisa	SW	374955	841764	2319	58	32	2287
57	Lemo	Kidigisa	SW	374588	842898	2347	75	52	2295
58	Lemo	Kidigisa	SW	374048	843353	2333	62	43	2290
59	Lemo	Kidigisa	SW	373555	839631	2306	69	34	2272
60	Lemo	Lefto Lenka	SW	387776	848148	2111	78	52.15	2058.85
61	Lemo	Lembuda	SW	372018	842250	2332	52.2	19	2313
62	Lemo	Lembuda	SW	370709	841682	2382	63	30	2352
63	Lemo	Lembuda	SW	369964	841754	2418	79	59.8	2358.2
64	Lemo	Lisana Sena	SW	380237	836029	2152	51	22.5	2129.5
65	Lemo	Mento Akebela	SW	396229	845563	1981	33	7	1974
66	Lemo	Mento Akebela	SW	394759	845030	1993	62	40	1953
67	Lemo	Sheshe Gimba	SW	393674	851433	2050	70	45.8	2004.2
68	Lemo	Mesena Bako	SW	367819	826806	2139	80	60.8	2078.2
69	Lemo	Tachignaw Ambicho	SW	377016	833345	2217	84	69	2148
70	Lemo	Tachignaw Ambicho	SW	377604	829973	2135	74	52.5	2082.5
71	Misha	Was Gebeta	SW	366318	843654	2462	96	62	2400
72	Lemo	Sheshe Gimba	SW	390733	850293	2000	70	1.35	1998.65
73	Lemo	Denfa	SW	393752	848772	2040	80	58.06	1981.94
74	Lemo	Hongolame	SW	374090	838472	2297	51	24.2	2272.8
75	Lemo	Harbucho	SW	377863	843078	2351	63	42.08	2308.92
76	Lemo	Guder fofate	SW	377908	840303	2304	70	34.25	2269.75
77	Lemo	Dakaye	SW	376000	844016	2345	81	58.8	2286.2
78	Lemo	Belela	SW	392282	849451	2010	63	19.19	1990.81
79	Lemo	Site 2	SW	393752	848772	2128	87	47.6	2080.4

80	Lemo	Duna	SW	393198	847668	2043	72	45.7	1997.3
81	Shashego	Shemo Boyo	SW	388671	831746	1900	40	3	1897
82	Shashego	Ajacho Boyo	SW	390717	833370	1912	45	19	1893
83	Shashego	Biramora Kemo	SW	394420	835135	1923	43	16	1907
84	Shashego	Biramora Kemo	SW	395080	838470	1925	43	14.5	1910.5
85	Shashego	Doisha Belaye	SW	395080	838486	1924	43	18	1906
86	Shashego	Doisha Belaye	Sw	395640	840360	1930	40	17.4	1912.6
87	Shashego	Mololicho	DW	384741	825452	1910	7.5	3	1907
88	Shashego	Suta	DW	386645	827094	1909	7	0.95	1908.05
89	Shashego	Golocho Boyo	DW	389402	825311	1900	6	1	1899
90	Shashego	Golocho Boyo	DW	389143	825973	1901	6	1	1900
91	Shashego	Urbecha	DW	383047	823021	1904	7	4	1900
92	Shashego	Afto Uterancho	DW	387722	823762	1907	9	3.5	1903.5
93	Shashego	Golocho Boyo	DW	390993	825079	1900	11	5	1895
94	Shashego	Golocho Boyo	DW	391993	824075	1901	11	5	1896
95	Shashego	Sheyembe Wanchikota	DW	398360	832630	1899	14	12	1887
96	Shashego	Sheyembe Wanchikota	DW	398731	833527	1908	16	13	1895
97	Shashego	Sheyembe Wanchikota	DW	398731	833827	1908	16	14	1894
98	Demboya	Geremba	DW	379751	811243	2232	7	5.45	2226.55
99	Kedida Gemila	Kerchicho	DW	380878	804315	2105	22	17	2088
100	Kedida Gemila	Durame 08	DW	380093	803146	2097	24	8	2089
101	Angecha	Bondena	DW	372223	809187	2384	18	9	2375
102	Angecha	Bondena	DW	372310	809436	2380	15.5	13	2367
103	Angecha	Kerekicho	DW	373319	813523	2257	10	5	2252
104	Angecha	Gede Genet	DW	374897	823305	2134	13	9	2125
105	Angecha	Shino Funomura	DW	373156	818544	2179	24	14	2165
106	Angecha	Shino Funomura	DW	373271	816411	2178	14	10	2168
107	Angecha	Shino Funomura	DW	373478	815926	2178	13	7	2171
108	Doyo Gena	Wunjela	DW	373029	825466	2207	16	8	2199
109	Doyo Gena	Dinika	DW	372753	821990	2178	13.5	7	2171
110	Doyo Gena	Murasa Woiramo	DW	367437	818615	2273	23	13	2260
111	Shashego	Mololicho	DW	386013	828572	1895	8	4	1891
112	Lemo	Dubanco	DW	376580	839387	2324	8	4	2320
113	Shashego	Jello Adancho	DW	383037	820444	1919	8	4	1915

BH –Bore hole, DW – Hand dug well, SW – Shallow well

Annex 5. 1 Collected primary and secondary water chemical test results

No	Site Name	Zone	Source	X	Y	Z	Class	P/S	PH	EC	TDS	Na	K	Mg	Ca	Cl	SO4	HCO3	CO3	NO3	F
1	AlemGbeya T	Silte	BH	409588	836570	1875	1	S	7.64	637	410	84	13.4	6.5	44.1	4.8	0	392.8	0	0.8	3.5
2	Getem Ziko	Silte	BH	408056	837697	1907	1	S	7.63	531	348	90	12.1	3.78	30.9	7.7	3.5	308.7	0	0.43	3.5
3	Tebela	Silte	Spring	399166	861832	2040	2	S	6.78	155	96	22	5.9	1.1	7.1	1	0	84.18	0	1.5	1.34
4	Wulbareg T	Silte	BH	402892	855307	2040	1	S	7.5	434	276	59	11.1	4.41	26.5	1.92	0.32	249.7	0	2.15	3.5
5	Gerema	Alaba	BH	393153	816091	1924	2	S	7.47	213	138	17	5.9	4.9	17.6	5.76	0.5	120.7	0	4.94	1.3
6	Bonosha tT	Haddiya	BH	397949	829286	1904	1	P	6.93	498	320	60	17	7.6	33.5	7.7	2.54	291.8	0	7.54	2.24
7	Artu	Alaba	Spring	391659	806311	1779	3	S	9.13	1287	860	304	20	0.54	1.76	31.68	61	498.98	72	0.5	48
8	Heba Hego	Danboya	Spring	385225	809699	2105	2	S	6.11	154	100	14	3.5	2.16	12.4	6.7	8.99	50.51	0	23.2	0.9
9	Kefo spring	Haddiya	Spring	385329	815734	2002	2	S	6.04	125	80	11.2	4.5	1.6	10.58	3.8	11.3	58.9	0	4.4	0.24
10	Gudeya		Spring	362091	802796	2251	2	S	5.98	52	36	5.4	2.4	1.64	4.4	0.96	0.11	29.28	0	5.14	0
11	Doyo Gena T	Kenbata	BH	363355	811819	2299	2	S	6.98	297	190	32	12	8.1	17.6	0.96	1.69	190.32	0	0.6	1.19
12	Ambicho	Kenbata	Spring	383256	825133	1921	2	S	7.75	314	210	38	11.7	3.78	18.5	3.84	7.19	182.39	0	0.86	1.8
13	Elbua	Alaba	Spring	382016	840736	2267	2	S	6.2	80	56	7.5	2.6	2.7	5.28	1.92	2.86	38.06	0	12.6	0
14	Fulame	Kenbata	Spring	377893	818757	1963	2	S	7.6	280	178	27	10.4	6.48	22	2.88	0.11	175.68	0	1.1	1.63
15	Kindo	Kembata	Spring	377604	817352	1999	2	S	7.8	254	162	18	7.6	7.02	23.76	6.7	1.2	136.69	0	6.2	0.71
16	Weira River	Haddiya	River	396810	839450	1960	2	P	7.57	149	92	11.5	5.2	2.16	14.08	0.96	0.85	84.91	0	0.38	0.81
17	Guder River	Haddiya	River	379411	822112	1972	2	P	6.95	68	48	5	4	4.3	5.3	0.96	3.81	43.92	0	0.46	0.28
18	Elo Leka	Alaba	BH	397150	818125	1812	1	S	8.12	850	430	207.1	12	2.88	23.2	8	0	522.16	26.4	1.02	5.7
19	Bonosha Kore	Sankura	BH	403664	827808	1908	1	S	7.97	468	328	80	9.6	4.86	27.2	2.61	0	285.46	7.2	2.2	2.49
20	Kulfo Shagder	Alaba	BH	407117	822518	1912	1	S	7.25	710	504	120	17.5	7.3	36.8	1.74	0	473.4	0	3.96	2.37
21	Gumbi Feten	Alaba	BH	410487	833037	1885	1	S	7.44	610	400	102	13.9	6.5	32.9	11.9	1.8	399.4	0	0.2	4.5
22	1st Mekala	Alaba	BH	401784	805265	1763	4	S	8	485	292	119.95	10.25	9.6	28	12.5	1.7	305	60	7.48	2.56
23	Lafto Lenka	Haddiya	SW	393752	848772	2128	2	P	7.33	245	248	15	5.4	22	22	3	4	162	22	14.22	0.49
24	Lemo Duna	Haddiya	SW	393198	847668	2043	2	S	8.05	121	241	16	6.2	14	38	4	13	209	11	2.56	0.66
25	Lemo Danfa	Haddiya	SW	393767	848789	2128	2	S	7.22	236	278	29	5.1	11	22	4	8	221	2	6.35	0.2
26	Lemo Side	Haddiya	SW	393677	851426	2047	2	S	7.91	331	254	35	7.3	8	27	6	12	155	4	16.84	0.71
27	Lemo Belela	Haddiya	SW	392282	849451	2010	2	S	8.04	210	222	22	6.2	5	29	2	1	143	5	15.22	0.2

28	Guder Fofate	Haddiya	SW	377908	840303	2304	2	S	8.23	215	233	28	9.1	4	22	2	12	178	0	9.22	0.33
29	Sheshera Small	Silte	Spring	394688	868790	2480	2	P	6.1	70	46	7.4	3.9	1.53	5.04	1.03	0.38	48.68	0	1.05	0.48
30	Moshoshe	Silte	Spring	393469	869183	2545	2	P	6.09	71	46	7.3	4	2.04	5.04	1.03	0.29	40.99	0	1.74	0.48
31	Sheshera Large	Silte	Spring	393606	869021	2543	2	P	6.15	73	48	9.1	3.9	1.53	5.88	2.06	0.19	51.24	0	0.69	0.21
32	Gumer Arekit	Gurage	Spring	399445	881417	2760	2	S	6.96	90.1	45	2.20	0.7	2.4	8	2.5	0	31.72	0	5.28	0.59
33	Alaba T#3	Alaba	BH	398894	808533	1775	4	S	8.1	452	272	56.35	16.75	16.8	48	7.5	0	280.6	48	8.8	1.67
34	Alaba T#4	Alaba	BH	398342	808626	1768	4	S	7.9	452	270	72.36	17	16.8	44	10	1	314.76	43.2	10.56	1.5
35	Gerema	Alaba	BH	393084	815946	1921	2	S	7.6	193.1	115.8	27.4	6.25	12	24	7.5	0.2	158.6	0	11.88	2.35
36	Musagessa	Haddiya	HDW	394351	834862	1895	1	S	6.83	1140	570	120.1	3.3	9.6	124	5	0	732	0	5.72	1.03
37	Urbecha	Haddiya	HDW	371736	824689	1902	1	S	7.77	886	446	187.89	1.9	14.4	40	5	52.1	600.24	0	20.24	1.87
38	Doisha Gola	Haddiya	HDW	396468	838242	1907	2	S	6.75	417	209	31.06	2.9	6.72	56	20	9.9	183	30	13.2	0.64
39	Golicho Boyo	Haddiya	HDW	389395	825322	1894	2	S	6.73	466	234	91.29	2.2	3.84	28.8	12	5.3	319.64	0	4.4	1.89
40				380774	822332	1912	2	S	7.1	415	208	89.52	1.8	3.36	36	25	0	231.8	36	11.44	1.35
41	Biramora	Haddiya	HDW	395080	838470	1925	1	S	7.35	540	270	93.72	19	12	52	6	0	457.7	0	0.88	1.48
42	Biramora	Haddiya	HDW	394420	835135	1923	1	S	7.4	640	320	105.6	22	4.08	72	7	3	536.8	0	0.264	1.44
43	Urbeha	Haddiya	HDW	386514	824867	1841	1	S	8	370	190	102.11	9.5	3.84	8	8.75	5	265.96	14.4	0.528	5.6
44	Urbecha	Haddiya	HDW	385621	823270	1894	1	S	7.75	550	280	141.	10.5	5.76	14.4	6.25	0	439.2	0	0.396	5.4
45	Alaba T#2	Alaba	BH	398645	807090	1756	4	S	8.4	441	267	74.2	14.5	16.8	48	12.5	1.2	219.6	96	6.6	1.55
46	Layegnaw Tuka	Alaba	BH	407975	819791	1960	4	S	8.1	579	352	139.97	20.5	9.6	24	12.5	1.3	329.4	72	6.6	5.4
47	chobare	Alaba	BH	420878	817496	1802	4	S	7.9	655	393	180.55	9	9.6	32	17.5	27.1	341.6	96	14.52	7
48	Amecho wato	Kenbata	BH	371502	822583	2183	2	S	6.84	287	144	31.37	4.5	12.48	22.4	2.5	0	195.2	0	17.6	1.51
49	Wonjela - Amecho	Kenbata	SW	372332	824570	2177	2	S	7.35	21.8	130.5	28.26	1.7	7.2	20	6.8	0	146.4	0	14.52	0
50	Lembuda	Haddiya	SW	372196	842414	2333	2	S	7.13	243	121.4	71.55	1.3	14.4	16	2.5	0.6	300.12	0	1.15	1.51
51	Debeso	Alaba	BH	415246	804946	1888	4	S	8	639	383	139.62	18.75	16.8	36	17.5	29.4	273.28	108	21.56	3.9
52	Choreke/Side	Alaba	BH	400967	810469	1791	1	S	7.9	475	288	94.4	16.25	7.2	48	10	0.2	414.8	0	4.4	2.45
53	HossanaT#3	Haddiya	BH	372332	836148	2277	2	S	7.02	226	134	37.98	1	9.6	8	5	0	146.4	0	22.8	0.99
54	Geja Spring	Haddiya	Spring	368328	862080	2205	2	S	7.5	124	75	0.21	0.7	9.6	16	2.5	0	85.4	0	11	0.21
55	Wetete	Alaba	BH	411356	828262		1	S	7.8	770	385	134.29	12	5.28	33.6	1.5	1	440	0	0.198	6.8
56	Gofesa	Alaba	BH	413813	809616	1867	4	S	7.9	473	285	136.03	9.75	4.8	24	12.5	1.2	268.4	72	25.96	3.14

57	Alaba T#1	Alaba	BH	399091	807648	1776	4	S	7.9	463	277	51.82	15	24	48	13	0.3	268.4	60	9.68	1.42
58	Lenda	Alaba	BH	404398	809111	1802	4	S	7.6	574	342	116.03	14.75	19.2	44	12.5	0.9	439.2	36	11	4.71
59	Mololicho	Haddiya	Spring	383194	829562		2	S	6.92	310	160	70.31	6	4.32	16.8	3	0	244	0	14.08	1.76
60	Becha gola	Haddiya	SW	397278	834657	1893	1	S	6.52	625	310	44.7	6	7.2	96	4.5	36.4	402.2	0	0	0
61	Wanchicota	Haddiya	SW	397787	829409	1903	2	S	7	520	260	71.7	5	4.8	56	5	1.4	373.32	0	7.48	1.16
62	Wanchicota	Haddiya	SW	397908	830296	1905	2	S	6.5	340	170	41.93	5.3	4.32	28.8	5.5	0.7	219.6	0	0	0

S – Secondary and P - Primary

DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any university and that all sources of materials used for the thesis have been duly acknowledged.

Candidate: Sintayehu Legesse Gennoro

Signature: _____

Date of Submission: _____

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

Advisor: Tenalem Ayenew (PhD)

Signature: _____

Date of Approval: _____

