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Addis Ababa University

School of Graduate Study

This is to certify that the thesis prepared by **Berhanu Keneni**, entitled *Hydrogeological assessment in upper Awash basin with Particular emphasis to Berga and Kare Catchment, Central Ethiopia* and submitted in partial of the requirements for the degree of master of Science (Hydrogeology) compiled with the regulation of the University and meets the accepted standards with respect to originality and quality.

Signed by Examining Committee

(Internal Examiner)

Dr. Seifu Kebede Signature _____ Date _____

(Internal Examiner)

Dr. Dassie Nidow Signature _____ Date _____

Advisor

Prof. Tenalem Ayenew Signature _____ Date _____

Co-advisor

Ato Tilahun Azagegn Signature _____ Date _____

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ABSTRACT

The general objective of the research is hydrogeological assessment of Upper Awash basin with particular emphasis to berga & kare river catchment, central Ethiopia.

Berga and Kare rivers catchment is located in west part of Addis Ababa with 72km distance at North and 48 km at south stretch SW to NE between of 8⁰54'00" N to 9⁰18'00" N latitude and 38⁰15'49" E to 38⁰29'33" E longitude. It is a sub-catchment of Awash basin, found at water divide of Awash and Abay drainage basins with total area of 625.3km².

Using field survey and secondary data analysis method, area description from climatology and geomorphology point of view explained.

The basaltic lava flow Tarmaber Megezaze formation; Trachytic and Rhyolite volcanic rocks, Ignimbrite and Quaternary Alluvial are major geologic units in the area.

The main aquifer visible in the catchment is weathered and fractured basalt. From borehole log and field geomorphological observation the area is mainly covered by volcanic rocks.

Ground water is generally a localized flow system controlled by topography and geology. Water in the catchment is mainly of Ca-HCO₃, Ca-Na- HCO₃ and Na-CHO₃ type. Almost all water in the study area is soft to very hard and TDS is generally below 574mg/L.

All water in the catchment is fresh which is suitable for almost all purposes. Almost all parameters are within the limits of acceptable values of WHO and EU standard/guide line except some hand dug wells showing bacterial pollution due to lack of scheme management

Chapter One Introduction

1.1 Background

Water is an essence food and Basic component of life. The need for water is strongly ascending and has a diversified purpose, which is not only important for drinking purpose but is also vital for development activities. It gets more complex due to population growth, urbanization and industrialization. Any development is related either directly or indirectly with water utilization.

In spite of its huge water resources, Ethiopia is frequently affected by drought and the people are not food secured. These problems, to same extent, are related to underutilization of existing water resources. It is obvious that for the full utilization of the existing water resources good understanding of hydrogeological, hydrological and geological of the system that controls the evaluation of potential water resources of a catchment is a highly impact of climatic variability and Aquifer pumping on water resource.

Ground water is a precious and most widely distributed resource of the earth and unlikely any other mineral resources it gets in annual replenishment from the meteoric precipitation. At present one fifth of all water used in the world is obtained from the ground water resources (Raghunath, 1987). In area where surface water is not available, ground water is the second alternative for irrigation purpose if the demand for the irrigation and ground potential is promising without negative environmental effect.

Ethiopia is implementing a policy which is agricultural development lead industrialization and considers the potential water resources as an entry point for any development interventions. Based on this, the country has defined a number of development corners of intensified agricultural practices. Among the others, the Berga and kare rive catchments particularly in Upper Awash Basin is the potential area for agricultural practices. With this context the research paper addressed the hydrogeology study of the area for the purpose of hydrogeological assessment.

To use water for drinking purpose, the water should be analyzed in terms of quantity and quality. By doing so, obtaining health, productive and prosperous community will be the final output of supplying potable water. As that water supply needs chemical, physical and bacteriological analysis irrigation water hydro chemical analysis for different major cat ions and anions.

Water which is absolutely pure is not found in nature; even water vapor condensing in the air contains solids, dissolved gases. As condensed water falls, it sweep up other material from the air and becomes more contaminated on recharging the ground, running on the surface and percolating through the various strata of the soil and rocks. Some contamination may be removed by passage the soil as the result of infiltration and adsorption and exchange reactions; some may be removed in the surface water by sedimentation and biological activity; specific engineered processes in the treatment plants may remove some of them.

The activity of using water especially for irrigation is low except Lencha Bulo Spring and Side River of Berga River tributary. The paper is addressing the effective utilization of the water resources of the catchment by giving due attention to the Hydrogeology assessment and recommending possible development activities.

Generally, the project gives detailed hydrogeological assessment in order to launch developmental activities using access of ground water in the catchment. It is believed that this research will play important role toward the sustainable use of water resource in the catchment.

1.2. Statements of the Problem

One of the most important issues for government decision makers now a day in Ethiopia is the proper solution of water supply problems through the implementation of research programs on surface and ground water in order to satisfy the present and future needs of population. To achieve the global Millennium Development Goals (MDG)-the country is committed to exercise on water use in all direction, Understanding the alarmingly increasing water demand and its economic impact towards the acceleration of the economy. This research work, hence, is intended to incorporate and contribute towards the effort to understand and conceptualize the groundwater system of the Berga and Kare River catchment for those interested to develop water resource in the area.

1.3. Objective of the study

1.3.1 General Objective

The general objective of the research is hydrogeological assessment of Upper Awash basin with particular emphasis to berga & kare river catchment, central Ethiopia.

1.3.2 Specific Objectives

- ✚ To evaluate the components of hydrologic cycle in the catchment
- ✚ To estimate the Recharge over catchment
- ✚ To produce hydrogeological map
- ✚ To produce geological map
- ✚ To give high lights on the water resource management
- ✚ To identify the recharge and discharge zone of the catchment.
- ✚ To determine the ground water flow directions and potential zonation

1.3.3 Methodology

- ❖ Literature review, which include published and unpublished reports.
- ❖ Collecting hydrometeorological data, borehole log data and pumping well results.
- ❖ Analysis of the topographic map (1:50,000) for the drainage map.
- ❖ Conducting insitu physical parameter measurement and collecting water samples for laboratory analysis during field work.
- ❖ Site investigation to map the soil and land use conditions, to identify geological setting, to collect borehole GPS reading and water Level measurement.
- ❖ Preparing geological map based on the site investigation and published reports
- ❖ House hold survey of water use.
- ❖ Using different software code (surfer version 11, Arc GIS version 10, Global mapper etc.)

Chapter Two General overview of the study area

2.1 Location and accessibility

The study area is located in Oromia Regional state, West showa administrative zone, around Addis- Alem town (Berga River Basin). It is about 60km from Addis-Ababa on the way to Ambo city and 80km on the way to Muger. More proportion of the catchment lays in the northern part of the Asphalt road, but the road to Echini (Mugher) passes through most part of the catchment. Berga and Kare River Catchment is about 625.3 km². The average elevation of the catchment area ranges from 2,060m to 2,844m above mean sea level. The area is enclosed with in the geographical coordinate of 8^o54'00" N to 9^o 18'00" N latitude and 38^o 15'49" E to 38^o 29'33" E longitude.

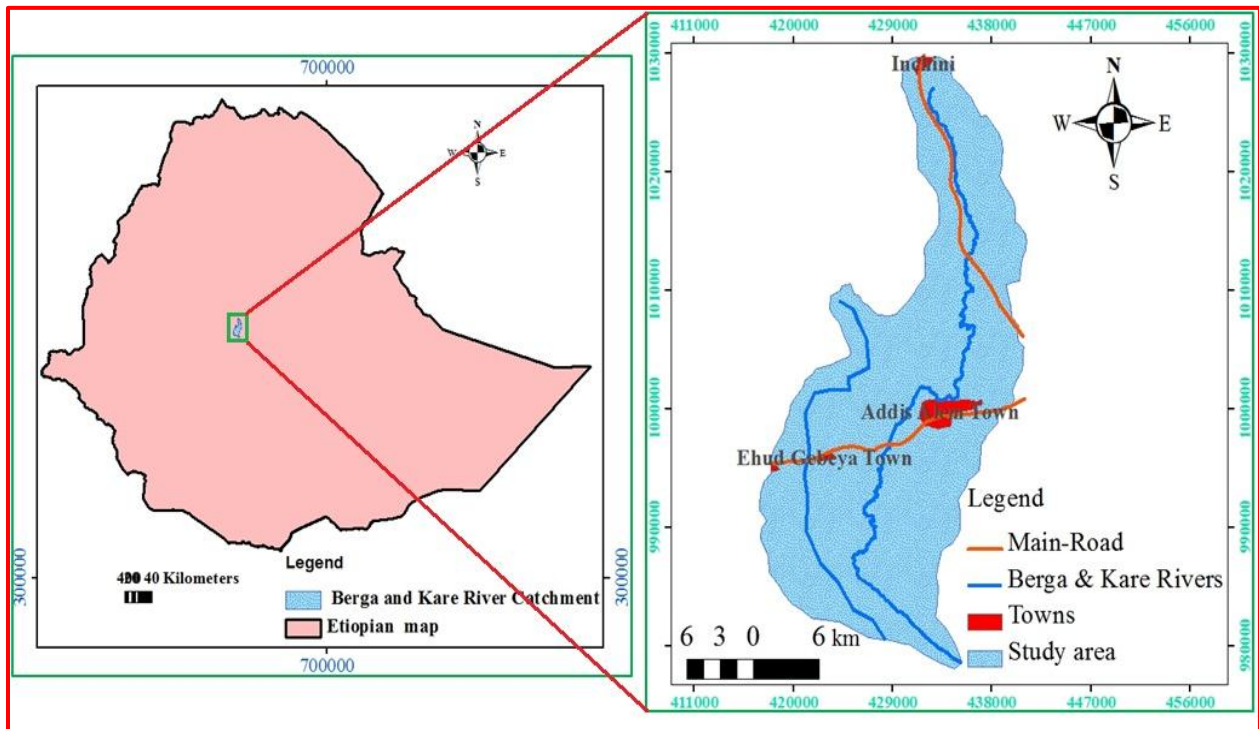


Figure 2-1 Location Map of Berga and Kare River catchment

2.2 Climate

The climate of any area is mostly depends on altitude. Berga and Kare river catchment has 1161.3mm, 16.5^oc, 60.1%, 1.18m/s and 6.6hr/d annual rainfall, average temperature, relative humidity, wind speed and sunshine hour respectively. About 73% of precipitation is received in the months June to September, showing unimodal rainfall distribution in the catchment. According to Ethiopian Mapping Agency (1981) the climate of Berga river catchment ranges from temperate to cool-temperate (Weinadega to Dega).

2.3 Previous works

Andarge Y. (2009) Hydrogeological and hydrochemical framework of complex volcanic system in the Upper Awash River basin, Central Ethiopia: with special emphasis on inter-basins groundwater transfer between Blue Nile and Awash rivers. University of Poitiers, PhD, Thesis, France

He stated that Based on the lithohydrostratigraphic relationship correlated from the drilling data of the exploratory boreholes coupled with the respective geological structure scenarios, groundwater movement could be connected to each other through the permeable and porous scoriaceous lower basaltic aquifer all the way from the Blue Nile Plateau to the study area. From the constructed relationship, the scoriaceous, Tarmaber and/or Amba Aiba formation together with the tectonic structures is therefore responsible in conveying the recharge from the adjacent Blue Nile plateau to the Upper Awash groundwater system.

Andarghe et al. (2012) Hydrogeological and hydrochemical framework of Upper Awash River basin, Ethiopia: With special emphasis on inter-basins groundwater transfer between Blue Nile and Awash Rivers. Journal of African Earth science

They state that the aquifer properties in the basin are controlled by the lithostratigraphy of the volcanic rocks and the structures that affect them. The volcanic rocks have highly variable primary porosity because of the nature and conditions of the lava flow. Later on through time, these volcanic rocks have been subjected to weathering and fracturing related to tectonic activities giving rise to secondary porosities. These volcanic aquifers can be considered as a double porosity medium due to the fact that both the matrix and the fracture porosity contribute to the circulation and storage of groundwater.

The aquifers in Upper Awash can be divided broadly into two categories; primary porosity aquifers and double porosity aquifers. The first category comprises aquifers related to Quaternary alluvial and lacustrine deposits and the second broad category refers to the basaltic volcanics and which again is subdivided into upper and lower basaltic aquifers separated by less permeable, along fractured and weathered zones and/or impermeable, otherwise, of acidic volcanic. Recharge is possible directly from precipitation; due to the presence of both primary and secondary porosity and permeability of the basaltic rocks. Acidic volcanics are overlain by thin soil cover and are near to the surface. Acidic volcanics are characterized by low permeability and porosity, except along weathered and fractured zones; in this case, direct recharge is limited and is restricted to the zones of fracturing and weathering.

Tilahun A. (2008). Hydrogeochemical characterization of aquifer systems in upper Awash River basin and adjacent abay plateau University of Addis Ababa, unpublished M.Sc. Thesis. Addis Ababa. He described the CaHCO_3 water types are found in plateau zone of the flow path. In plateau zone relatively shallow wells and local spring emanating from the basaltic aquifer are characterized by this water type. In transition zone this water type is associated with local faults of small aerial extent and vesicular quaternary basalts and the NaHCO_3 Water type is characteristic to the deeper wells in the plateau and transition zones and thermal waters. According to his analysis all boreholes of known aquifer lithology except Amaro borehole (TIK47) have basalt and scoraceous basalt aquifers. In Plateau zone of the flow path the aquifer system is generally basalt and scoraceous basalts with intercalations of clay and paleosol layers. In this zone, shallow wells have higher Ca/Na ratio and it is low for the deeper ones. TDS concentration is generally low for the boreholes that penetrate the shallow and deep aquifers in plateau zone. The Na increment at the expense of Ca with little change in TDS reflects the dominance of cat ion exchange process which could be ascertained by the presence of the intercalated clay. Since pH for deep wells is higher than the pH for shallow wells in the plateau zone, which might signify the process of Silicate hydrolysis. Therefore the plateau zone can be considered as recharge area for the regional aquifer of the flow path. In addition he states that the tuff, ignimbrite and volcanic ash are considered as productive aquifers if only affected by faults and lineaments. In this zone different orientation and different aerial extent fault is highly affected surrounding Becho plain.

2.4 Physiographic setting and drainage

The geomorphology of an area depends on the general geology and climatic conditions of that particular area. Berga and Kare river catchment is situated in the Ethiopian high land plateau, particularly in Showa plateau, covering some part of upper Awash Basin and the upstream of the catchment is the water divide of Awash and Abay river basins.

The study area has geomorphic features characterized by undulating ridges, hills and valley. Except fewer flat areas at Berga and upper Bacho plains following the direction of river flow, most of the catchment is covered by Tarmbarer magazaz, Aiba basalt, ignimbrites, rhyolites/trachyte forming hills and ridges in western and eastern parts having trends nearly SW to NE.

The elevation of the area generally decreases to the south and south west. The peak altitude is estimated to 2844m above mean sea level in NE of the area and lowest is about 2060m above

mean sea level at SW (mouth of the catchment) .Numerous streams originate from hills and ridges and merge subsequently to form Berga perennial river. Dobbi, Adama, Fachi and Kerbo are among the most tributaries of Berga River. Berga and Kare Rivers flows to Awash River. Small valleys originated from ridges and hills forming dendritic drainage pattern in the area especially at NE and SW part of the area. The area has nearly northeast southwest oriented drainage.

2.5 Soil and land use

2.5.1 Soil type

Soil characteristics of an area depend on topography (geomorphology), geology (parent material) climate, drainage, type of land use practice and agricultural activities. In the catchment the volcanic rocks are subjected to high rain fall and temperature, which are favorable conditions for chemical weathering to produce clay soils.

Its topography can broadly group under sloppy area with few plains around the river. The drainage can be related with its topography i.e. the sloped part with well drained conditions, which favor extreme discharge while the plain is poorly drained which facilitates limited discharge but more deposition. From field observations and according to Awash Basin master plan study (Hal crow, 1989), the dominant soil type of the study area is classified in to three.

- a. Lithosol:** - This soil is formed at high relief hillside slops and highly susceptible to erosion. It is highly drained and found on steep hills, not well developed and also dominated by boulder and coble size.
- b. Nitosols:** - This soil unit is characterized by reddish residual soil having an average of 20-50cm thickness with ignimbrite, rhyolite/trachyte origin rock fragment. Formed mainly on cultivated land of the area and dominated by sand size soil.
- c. Fluvialsol:**-this soil is developed along flat land areas (flood plains). As observed from well logs the Fluvialsol has thickness up to 30m in Bacho plain localities, color is different at different locations (black, brownish& reddish) and dominated by clay size soils.

2.5.2 Land use

Land use/land cover of an area depends on climatic factors, land escape, land use practice and agricultural activities of the area. Accordingly, the land use of the study area is mainly classifies as cultivation, grass & grazing (swampy area) and plantation (Eucalyptus tree, shrubs & bushes).

The plantation species is mostly found in some valleys and near settlements, where cultivation is impossible.

Almost the entire plain areas are used for grass and grazing (except around Bacho plain and near Fachi River). The cultivation areas are located on sloppy areas and at Bacho plain, covering most part of the study area. The dominant crops are cereals like Teff, maize, barley...and some vegetation following the river valley are cabbage, potato and onion

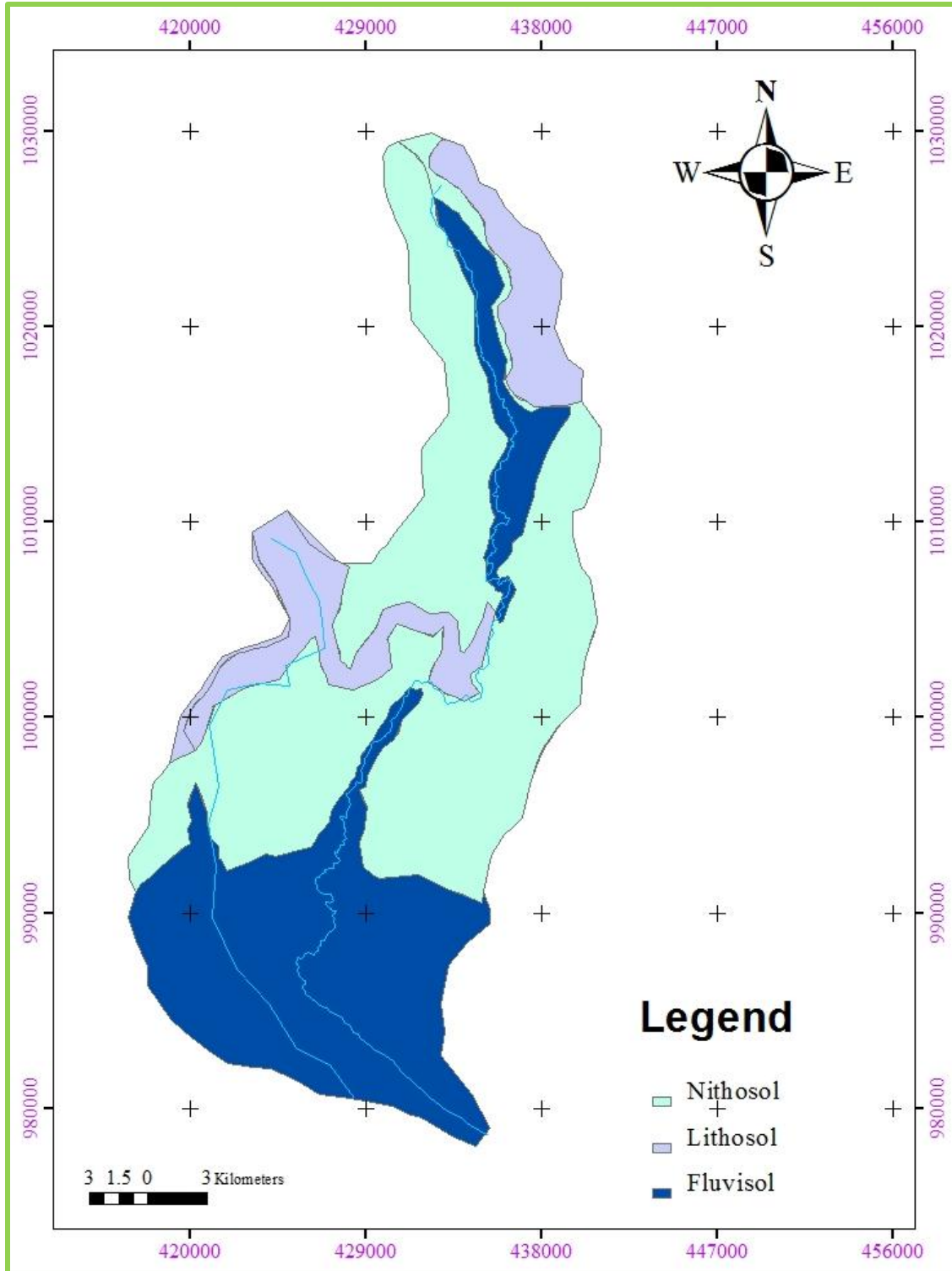


Figure 2-2 Soil type Map of Berga and Kare River catchment

Chapter Three Hydrometeorology

3.1 General

Hydrometeorology is a science which links hydrology and meteorology. It studies the hydrological cycle which involve processes in the atmosphere and at the earth's surface (Shaw,1994). Hydrometeorological data are required to determine the water balance of a basin for developing and managing its water resource.

The most use full hydrometeorological elements are precipitation, evaporation, evapotranspiration, solar radiation (sunshine hours), humidity and air temperatures.

3.2 Precipitation

Precipitation is the process by which water falls to the land surface, such as rain and snow. The formation of precipitation requires the lifts of the air mass in the atmosphere so that it cools and some of its moisture condenses. The three main mechanisms of air mass lifting are frontal lifting, where warm air is lifted over cooler air by frontal passage; orographic lifting, in which an air mass rises to pass over a mountain range; and convective lifting, where air is drawn upwards by convective action, such as in the center of a rainstorm cell.

The physiography and geomorphology of the Berga and kare Water shade, together with the vegetation, influence the relationship between precipitation over the water shade and water drained from it. Rainfall in the study area is mainly caused by orographic and direction of moisture bearing seasonal air currents. The duration, amount and spatial distribution of the rain fall in the area is controlled by south-westerly winds, which is small rains originate from Indian Ocean. The monthly average rainfall shows a unimodal pattern with the heavy rains between June and September. Owing to high temperatures near the equator, the lower layers of air are heated. It thus expands and rises rapidly producing a lower pressure belt known as the Inter Tropical Convergence Zone. Inter Tropical Convergence Zone is the major rain causing mechanism and its movement in the north ward direction brings moisture from the South Atlantic Ocean.

This results in the big kiremt rainfall in most parts of Ethiopia. Because of the location of Berga and Kare river catchments, in the central high lands of Ethiopia, Inter Tropical Convergence

Zone reaches late and leaves early in this area, which explains the short rainy season (June-September).

In general, the rainfall distribution of the study area and neighbors are more or less similar to that of the Ethiopian central plateau. The temporal rainfall distribution indicates that the occurrence of two main seasons, the dry and wet seasons. As displayed in precipitation bar graph below, the maximum and minimum rainfall is recorded in the month of August and December respectively. The majority of rainfall in the catchment is obtained in the months June to September covers about 69.3% of the total annual rainfall.

Accordingly, there are four meteorological stations within and around the study area, Such as Echini, Holeta, Addis Alem and Olenkom

Table 3-1 coordinate system station Locations

No	Station	UTM(m)		Altitude(m)	Annual rain fall(mm)	Recorded period range
		latitude	longitude			
1	Echini	430353	1029717	2687	1287.3	1993-2013
2	Holeta	444250	10001300	2380	1034.8	1986-2013
3	Addis Alem	434750	999850	2340	1159.7	1993-2013
4	Olenkom	417986	994943	2165	1140.1	1984-2013

From the mentioned above four stations, only Addis Alem station is within the study area, the remaining three stations are around the water shade. Geographically Echini station is locate at Northern, Holeta station at Eastern, and Olenkom station is at southwestern part of the catchment.

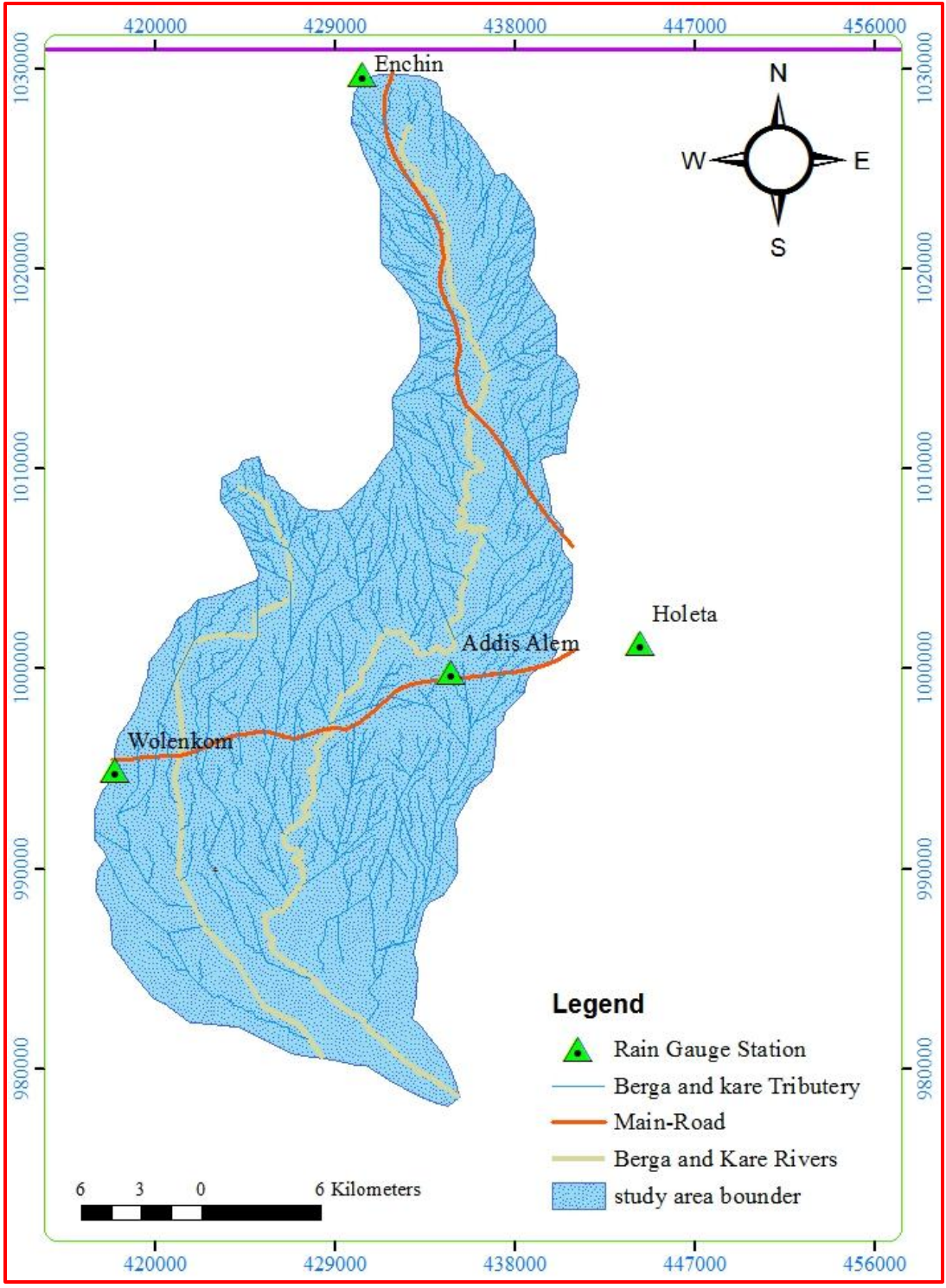


Figure 3-1 Geographical Location of Rain gauge Stations

Table 3-2 Rain fall at four Different Gauges (1984-2013)

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Addis Alem	20.6	43.2	76.8	72.7	74.4	147.0	265.5	264.3	138.4	30.6	13.6	12.6	96.6
Echini	33.7	35	78.7	90.2	82.5	154.1	292.5	273.9	146.8	52.7	30.2	17	99.8
Holeta	22.3	39.7	64.5	77.3	65.6	111.5	242.5	244.9	128.9	20.3	7.5	9.8	80.7
Olenkom	17.5	52.6	64.9	102.5	70.9	124.2	249.1	291.8	125.8	29.9	2.2	8.7	95

The oscillation of Inter Tropical Convergence Zone (ITCZ) north and south of the equator governs the country’s seasonal rainfall variability. The catchment receives highest precipitation during rainy season (June to September) which is called kiremt from Equatorial westerly winds from Atlantic Ocean and moderate precipitation (January to April) southerly winds from Indian Ocean. The dry months (October to December) of the catchment have little rain .Air currents that traverse Arabia during this period are North easterly trade winds and dominates the region. The study area has unimodal rainfall characteristics of peaking in July and August

Table 3-3 Mean monthly rain fall of Berga and Kare catchment

Months	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
Pm	23.5	42.6	71.2	85.7	73.4	134.2	262.5	268.7	135.0	33.4	13.4	12.0	95.5

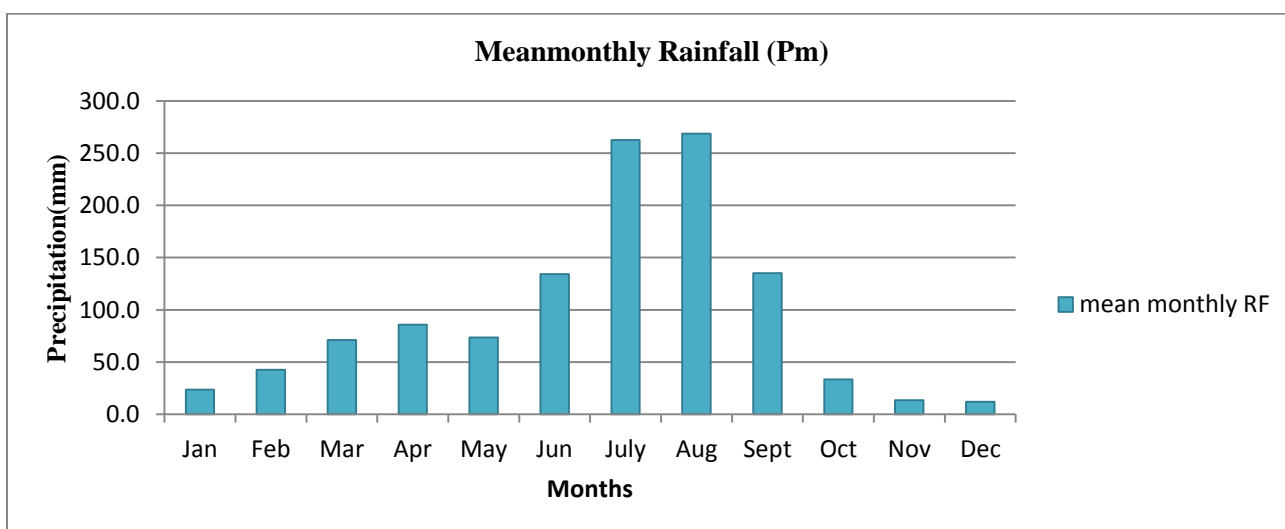


Figure 3-1 Mean monthly rainfall of Berga and Kare catchment

The distribution of rainfall in the study area is more or less similar to that of the Ethiopian central plateau. Based on temporal rainfall distribution, generally two main seasons can be identified for the study area: the dray and the wet season. More quantitative seasonal category based on rainfall distribution can be explained by using the rainfall coefficient (R.C) which is the ratio between mean monthly rainfall and one twelfth of the annual mean of the total rainfalls

(Daniel Gamachu, 1977)

$$R.C. = 12P_m/P_a$$

Where R.C= rainfall coefficient

P_a = Annual total rainfall of the area, which is 1161.3mm

P_m = Mean monthly rainfall

Table 3-4 Mean monthly rainfall (Pm) and rainfall coefficient (R.C) for the study area

Months	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Pm (mm)	23.5	42.6	71.2	85.7	73.4	134.2	262.5	268.7	135.0	33.4	13.4	12.0
R.C	0.24	0.44	0.73	0.88	0.75	1.38	2.7	2.8	1.4	0.34	0.14	0.12
Description	Dry	Dry	Small rain	Small rain	Small rain	Mode rain	Big rain	Big rain	Mode rain	Dry	Dry	Dry

Based on R.C values the following precipitation category can be made for Berga and Kare Catchments.

- ✚ Dry month (R.C < 0.6): October, November, December, January and February.
- ✚ Rainy month (R.C ≥ 0.6): This can be further grouped in to the following
 - ❖ Small rain (0.6 – 0.9) March, April and May.
 - ❖ Big rain (≥ 1.0)
 - Moderate concentrations(Moderate rain) (1.0 – 1.9) : June and September
 - High concentrations (Big rain) (2.0 – 2.9) July and August.
 - Very high concentration (≥ 3.0)

3.2.1 Determination of aerial depth of rainfall

Precipitation over certain duration for a given basin is rarely produces uniform rainfall depth over the entire area. Certain gauges may record maximum rainfall depth with relative to others. Rainfall measurement is a point observation and may not be used as a representative value for the area under consideration (say for a basin). Therefore, point measurements have to be averaged over the area (Tenalem Ayenew and Tamiru Alemayehu, 2001). Aerial depth of rainfall in the catchment is estimated using the following methods.

3.2.1.1 Arithmetic mean method

This is the simplest objective method of calculating the average rainfall over an area. The simultaneous measurements for a selected duration at all gauges are summed and the total divided by the number of gauges (Shaw, 1994).

Since only four stations (Holeta, Addis Alem, Echini and Olenkom) are located within and around Berga and Kare Rivers catchments, the estimated average uniform precipitation (PA) is computed as follows.

$$PA = \sum_i^n pi/n = 1155.5\text{mm}$$

Where PA = average rain fall of the total area

Pi = Measured precipitation at a given station and time

n = Number of rain gauges

Table 3-5 Long term average monthly rainfall at different stations

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Addis A	20.6	43.2	76.8	72.7	74.4	147.0	265.5	264.3	138.4	30.6	13.6	12.6	1159.7
Echini	33.7	35	78.7	90.2	82.5	154.1	292.5	273.9	146.8	52.7	30.2	17	1287.3
Holeta	22.3	39.7	64.5	77.3	65.6	111.5	242.5	244.9	128.9	20.3	7.5	9.8	1034.8
Olenkom	17.5	52.6	64.9	102.5	70.9	124.2	249.1	291.8	125.8	29.9	2.2	8.7	1140.1
Average	23.5	42.6	71.2	85.7	73.4	134.2	262.4	268.7	135.0	33.4	13.4	12.0	1155.5

There for, An Annual aerial precipitation computed by Arithmetic method is 1155.5 mm from four gauges enclosed and near Berga and kare Rivers catchments.

3.2.1.2 Thiessen polygon Method

This method provides a good result for none uniformly distributed rain gauges over the area for both flat and hilly terrain by determining a weighted factor for each gauges. As a result of, four

stations are considered to construct Thiessen polygon, there are also four gauges station are used for computing weighted annual rainfall of Berga and Kare River catchment (Addis-Alem, Holeta, Echini and Olenkom) stations.

The method is given by

$$PA = (P_1a_1 + P_2a_2 + \dots + P_n a_n) / A_t = 1167.29\text{mm}$$

Where: - PA= average rain fall for the total area

P_i =measured precipitation at i^{th} station

a_i = area of the i^{th} polygon around i^{th} station

A_t = total area of the catchment

Using this method, the computed annual rainfall of Berga and Kare rivers catchment is 1167.9m

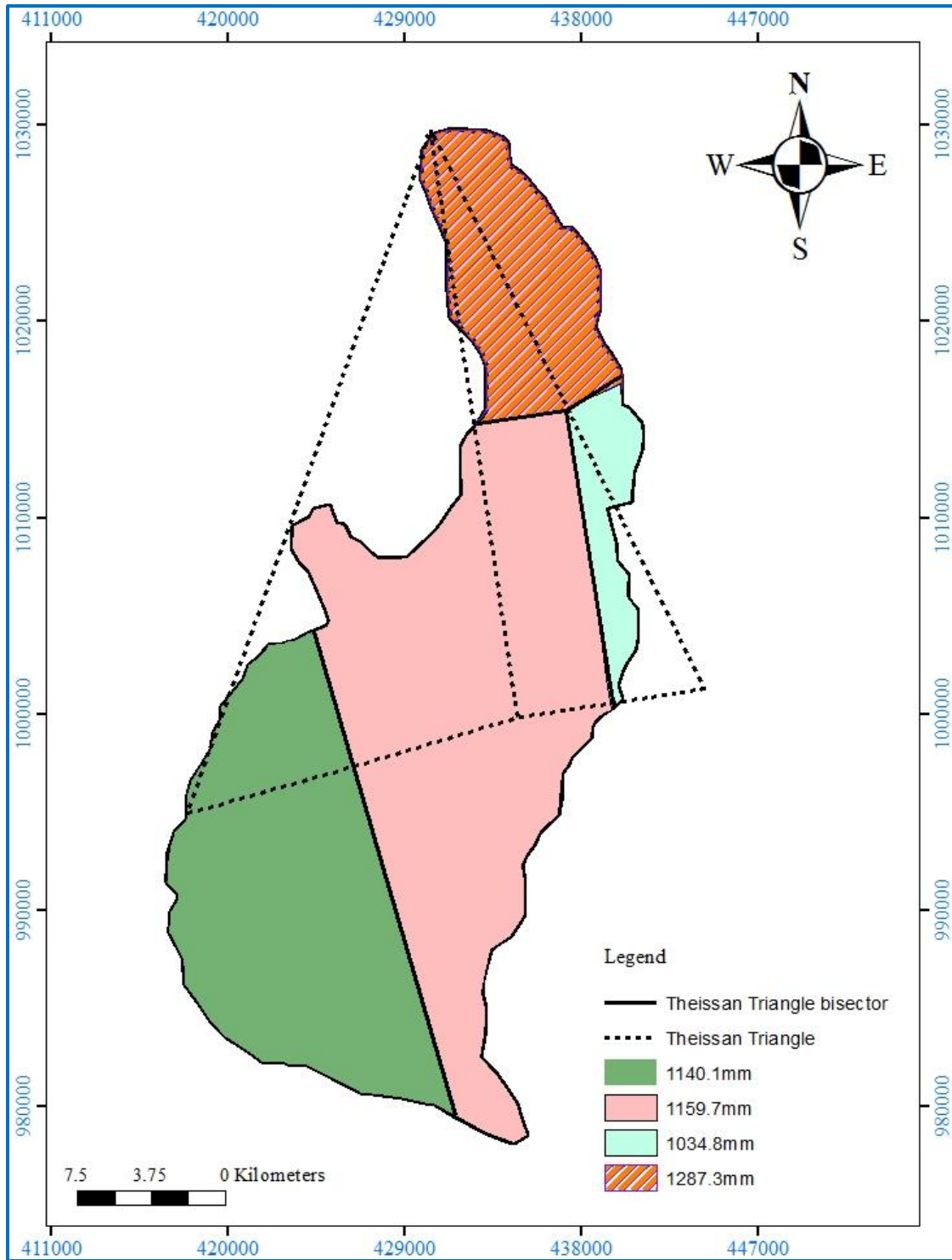


Fig 3-2 Theissen polygon maps of Berga and Kare river catchment

Table 3-6 Mean annual rain fall (mm) and area influenced (km²) at each Station.

Stations	Mean Annual Rain fall (mm)	Area influenced (km ²)	Weighted area in (%)	Weighted Rain fall (mm)
Addis Alem	1159.7	300.2	48	556.78
Echini	1287.3	90.52	14.48	186.35
Holeta	1034.8	31.99	5.12	52.94
Olonkom	1140.1	203.6	32.56	371.22
Total		625.3	100.16	1167

Table 3-7 Annual average rain falls over the catchment

methods	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Theissan	21.6	44.9	72.7	85.3	74.1	144.1	268.4	263.8	135.2	33.1	12	11.8	1167.0
Arithmetic	23.5	42.6	71.2	85.7	73.4	134.2	262.4	268.7	135.0	33.4	13.4	12.0	1155.5
Average	22.6	43.8	72	85.5	73.8	138.2	265.4	266.3	135.1	33.3	12.7	11.9	1161.3

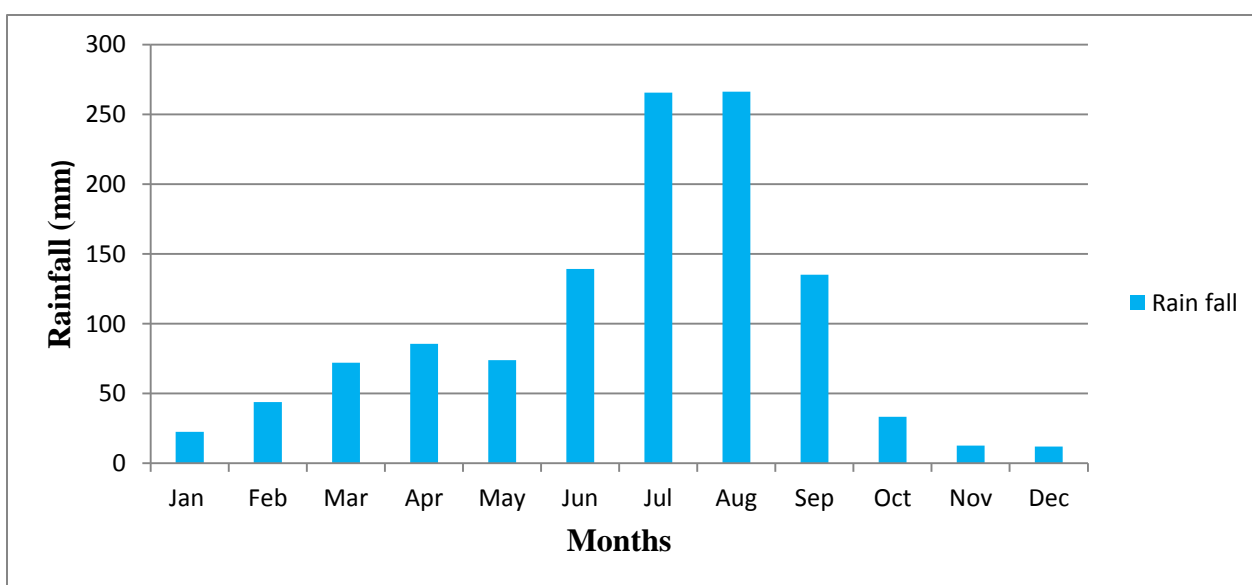


Figure 3-3 Average Rain fall in the study area

3.2.2 Spatial and temporal variation of rainfall

There are many factors affecting the amount and distribution rainfall in a given region, these are: geographic position with respect to air and moisture circulation pattern, climate factors, orographic influence, distance from moisture source, and latitude. Among different factors, surface elevation is the major parameter controlling the depth of precipitation.

Table 3-8 Rain fall with Elevations difference

No	M/Stations	Elevation	Rain fall(mm)
1	Echini	2687	1287.3
2	Holeta	2380	1034.8
3	Addis Alem	2340	1159.7
4	Olenkom	2165	1140.1

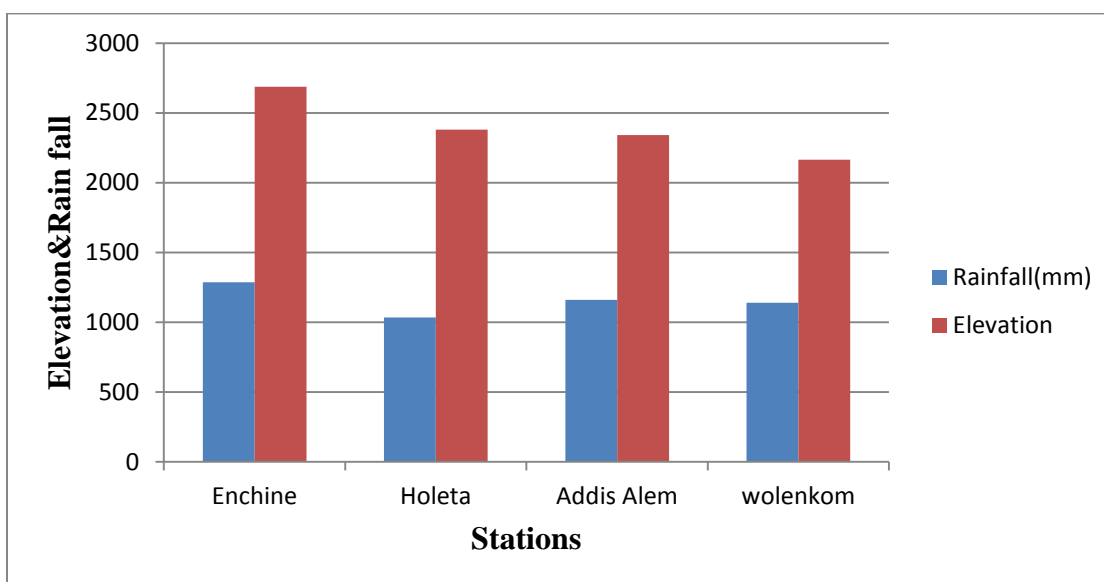


Figure 3-4 Rain fall variation with Elevation

As shown from the above graph the rain fall variation and elevation variation are direct proportional to each other in the study area.

3.2.3 Temporal variation of rainfall

The variation of rainfall with time can be explained by looking at the plot of rainfall versus time for stations. From the four Stations in and around the catchment, let we try to observe the variation time and rain fall of Addis Alem station, locate in the center of water shed.

Table 3-9 Rain fall variation in different years at Addis Alem station

Years	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Rain fall(mm)	1278.5	952.8	858	1430.6	1199.5	1760	1477.5	1325.5	1151.3	1051.8	1139.1	1022	1501.7	1237.9	1350.4	1045.2	1337.9	1104.4	778.6	723.8

3.3 Temperature

High daily temperature associated with longer sunshine hours duration and clear sky increases evapotranspiration. Temperature data are the major factor in computing potential evapotranspiration of an area. Temperature in the tropics is constantly high; the annual range, year to year variability, is low. Altitude is the major factor in reducing temperature in the tropics as compared to the high in coming solar radiation. The Annual series of mean, maximum and minimum temperature of Berga and Kare rivers catchment for the period of long time is shown the table 3.10. (Analyzed from Addis Alem, Holeta, Olenkom and Echini stations) Accordingly the average monthly temperatures are shown in the table below, maximum temperature occurs in February, March, April, May and minimum in November & December.

The rate of evaporation is dependent on the temperature at the evaporating surface and atmospheric air. The amount of water vapor in the atmosphere is directly related to the temperature. The higher the air temperature, the more vapor it can hold, and similarly if temperature of evaporating water is high, it can more readily vaporize (Shaw, 1994).

Mean monthly minimum, maximum and mean annual temperature of the catchment is listed in table 3.10

Table 3-10 Mean Monthly Temperature of Berga and Kare Rivers catchment (°C)

Temperature in (°c)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
T max mean	23.8	25.0	24.9	24.9	24.7	22.9	20.7	20.4	21.4	22.7	23.4	23.7
T mean min	8.9	9.9	10.6	11.1	11.2	10.7	10.5	10.6	10.1	9.2	7.7	7.7
Tmean mont	16.4	17.5	17.8	18	18	16.8	15.6	15.5	15.8	16	15.6	15.7

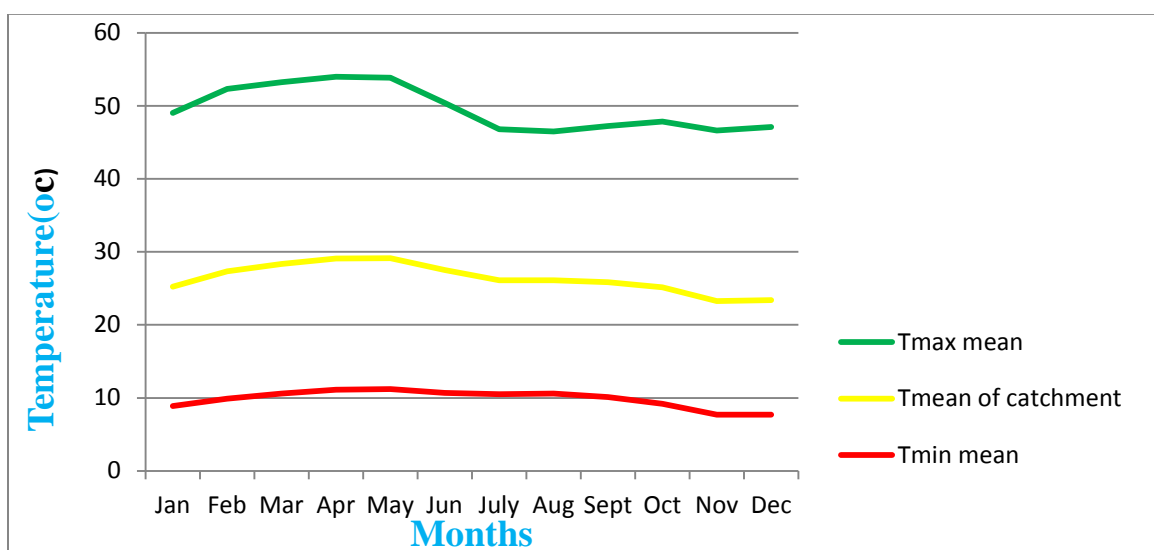


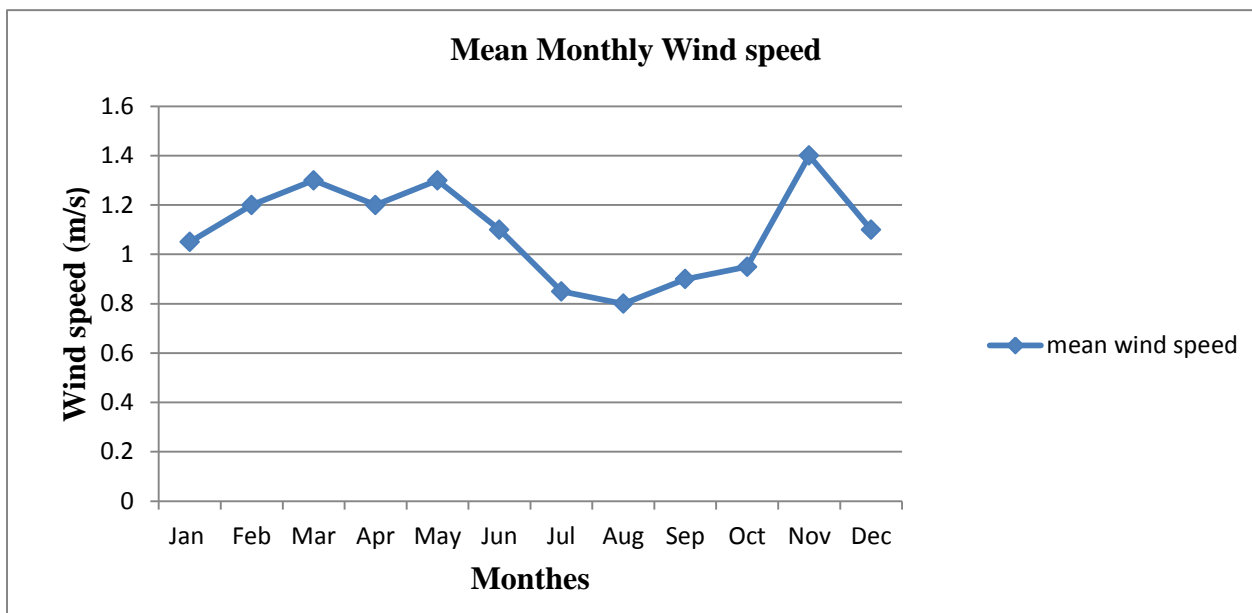
Figure 3-5 Mean Monthly Temperature of Berga and Kare Rivers catchment (°C)

3.4 Wind Speed

Wind speed can increase the rate of evaporation by removing vapor from evaporating surface, the saturated air above the evaporating surface replaced by dry air. This movement of air and moisture depends on wind speed and it enables evaporation to proceed. Thus, wind speed is a key factor in controlling the rate of evaporation. The movement of air and moisture transfer depends on wind speed and turbulence. Evaporation has a direct relation with wind speed and turbulence (Tenalem Ayenew and Tamiru Alemayehu 2001; Shaw, 1994). In the study area, only the Holeta station can measure the wind speed of Berga and Kare Rivers catchment, from the four stations considered in the study area. From the data of wind speed measured in Holeta station, the mean monthly wind speed varies from 0.8m/s to 1.4m/s with average value of 1.1m/s.

Table 3-11 Average monthly wind speed of the Berga and Kare River catchment

months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
mean	1.05	1.2	1.3	1.2	1.3	1.1	0.85	0.8	0.9	0.95	1.4	1.1	1.1

**Figure 3-6 Average monthly wind speed of the Berga and Kare River catchment**

3.5 Sunshine

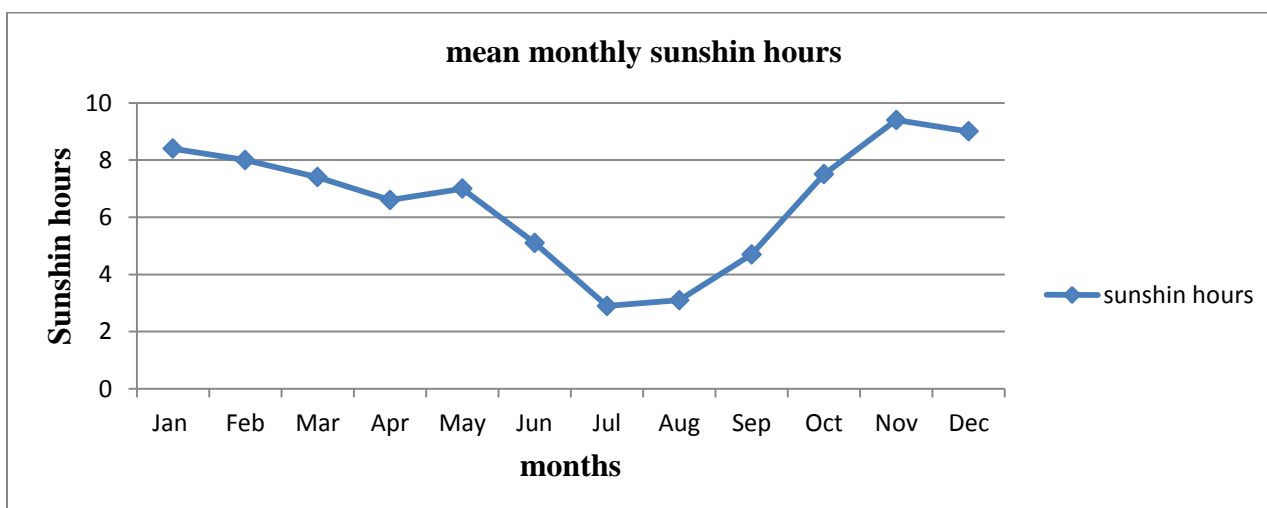
Sunshine hour is the time in hours of sunshine in a day. To Evaporation takes place energy inputs is very important. Solar energy is the major input of energy for evaporation to takes place. Thus, sunshine hours play significant role in controlling the rate of evaporation. When the day is cloudy, sunshine hour's decreases and evaporation rate also decreases, it has a direct relationship with dry and rainy seasons. During rainy seasons the cloud coverage is greater and the mean sunshine hour is relatively small.

Solar radiation is the primary source of energy to change the Earth's surface and in the atmosphere. Mean daily sunshine hours durations of Berga and Kare River catchment is shown in the table 3.12

. It is analyzed from Holeta station. Sunshine hours duration is maximum in November and minimum in July at the mid of rainy season.

Table 3-12 Average daily sunshine hour's duration for Berga and Kare Rivers catchment

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Yearly Average
Average	8.4	8	7.4	6.6	7	5.1	2.9	3.1	4.7	7.5	9.4	9	6.6

**Figure 3-7 Average daily sunshine hour's duration for Berga and Kare Rivers catchment**

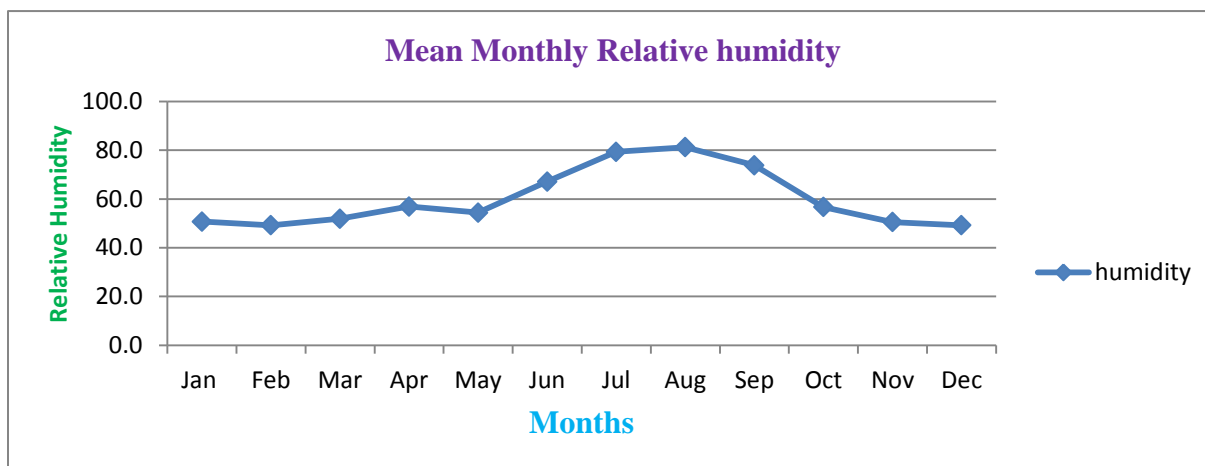
3.6 Relative Humidity

The relative Humidity measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature is defined as relative humidity. The higher the relative humidity the lower will be the rate of evaporation (Shaw, 1994). Higher values of relative humidity indicate the air close to saturation point and lower values indicate less water vapor in the atmosphere. The maximum relative humidity is found in Rainy months and the minimum in dry months. Of four stations used for this work, only Holeta station has relative humidity records. The mean monthly relative humidity attains maximum in July & August and minimum in December and February in table below.

In general, this change is related to the rainy and dry seasons of the country which it raises during summer (kiremt) and decline during dry seasons.

Table 3-13 Average Relative humidity of Berga and Kare Rivers catchment

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	YrlyA
RH.mea	50.7	49.2	51.9	56.9	54.4	67.1	79.3	81.2	73.8	56.7	50.5	49.2	60.1

**Figure 3-8 Humidity (%) of Berga and Kare River catchment**

3.7 Estimation of Evapotranspiration

There are two types of evaporation: evaporation from an open water surface and evaporation from the transpiration process. Evaporation from an open water surface E_o , is the direct transfer of water from lakes, reservoirs and rivers to the atmosphere. The second form of evaporation, evaporation from the transpiration process from vegetation, E_t (Shaw, 1994).

Thus, evapotranspiration can be defined as the transfer of water vapor by direct evaporation from the land surface and vegetation and by transpiration process from the plant surface.

3.7.1 Estimation of Potential Evapotranspiration (PET)

PET is defined as the evapotranspiration which would occur under unrestricted availability of water to a fully vegetated surface (Shaw, 1994) or it is the maximum possible evaporation under given meteorological conditions (Tenalem and Tamiru, 2001).

PET has a positive relation with temperature, sunshine, and wind speed but has a negative relationship with air humidity. For calculating potential evapotranspiration there are different formulae but for this research, Penman modified method and adjusted Thorenthwaite are used based on the available data.

3.7.1.1 Thornthwaite Approach

Thornthwaite method is based upon the assumption that potential evapotranspiration is dependent only on meteorological conditions and ignores the effect of vegetation density and maturity. However the method is still practical. The formula based on temperature with an adjustment being made for latitude location and the number of daylight hours (Shaw, 1994).

This method uses air temperature as an index of energy available for evapotranspiration, assuming that air temperature is correlated with the integrated effects of net radiation and other controls of evapotranspiration, and the available energy is shared in fixed proportion between heating the atmosphere and evapotranspiration (Dunne and Leopold.1978).

PET_m, calculated on a monthly basis is given by:

$$PET_m = 16Nm (10t/I)^a \text{ mm}$$

Where: m: months

N_m: is monthly adjustment factor depending on latitude and season (10^0N for the Study area, taken from standard tables)

t: mean monthly temperature

I: annual heat index obtained by adding monthly heat index (i_m) of 12 months.

$$i_m = (t/5)^{1.5}$$

$$a = 6.7 \times 10^{-7} I^3 - 7.7 \times 10^{-5} I^2 + 1.8 \times 10^{-2} I + 0.49.$$

N is mean daily duration of maximum possible sunshine hours

Potential evapotranspiration of Berga and Kare river Catchment (mm) using Thornthwaite method

Table 3-14 Potential evapotranspiration using Thornthwaite method

Parame	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
T _m	16.4	17.5	17.8	18.0	18.0	16.8	15.6	15.5	15.8	16.0	15.6	15.7	16.6
N	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5	12.1
N _m	0.97	0.98	1	1.03	1.05	1.06	1.05	1.03	1.01	0.98	0.97	0.96	1
i _m	5.9	6.5	6.7	6.8	6.8	6.2	5.5	5.5	5.6	5.7	5.5	5.6	6.
I	79.1												
A	1.7												
PET	54.9	62.1	65.3	68.9	69.9	62.9	54.8	53.1	53.6	53.1	50.3	50.6	53.9

Therefore, the mean annual Potential evapotranspiration of the Berga and Kare River catchment using Thornthwaite method is 699.6mm/year

3.7.1.2 Penman modified method

Penman produced a formula which was later modified by MAFF (cited in Shaw, 1994) to allow the condition under which evaporation plus transpiration takes place, which is given by:

$$PET = (\Delta / \gamma) HT + E_{at} / (\Delta / \gamma) + 1 \text{-----eq (1)}$$

Where the extra subscript t signifies inclusion of transpiration effects

$$HT = 0.75R1 - R_o \text{-----eq (2)}$$

Where: γ is the reflective coefficient for incident radiations or the Albedo of the basin that depends on the nature of the surface? For the specific study area, this is taken as 0.23 assuming majority of land cover of the study area as short grass surface and the average and dominant crops, forests, soil and grass are cereal crops, clay soil, silly soil, Eucalyptus tree, grass and pasture and bare soil with their Albedo 0.25, 0.13, 0.3 0.2, 0.25 and 0.22 respectively (Dunne and Leopold, 1978). Therefore by averaging the above albedo the value of γ is taken as 0.23.

The term E_{at} is very similar to E_a (Which is equal to $0.35[0.5 + u^2 / 100]$ (ea- ed)) the coefficient 0.5 being replaced by 1 to allow for extra roughness.

$$E_{at} = 0.35[1 + u^2 / 100] (ea - ed) \text{-----eq (3)}$$

The empirical equations for the incoming and outgoing radiation in the energy term HT are given by:

$R1 (1-r) = 0.95 R_a f_a (n/N)$ and $f_a (n/N)$ for the study area within latitudes south of 54.5^0 .

(Shaw. 1994) is equal to:

$$f_a (n/N) = (0.16 + 0.62 n/N) \text{-----eq(4)}$$

The empirical equation for the outgoing reduction takes the form:

$$R_o = eTa^4 (0.47 - 0.075 \sqrt{ed}) (0.17 + 0.83n/N) \text{-----eq(5)}$$

Where: eTa^4 is the theoretical black body radiation at T_a , which is then modified by functions of the humidity of the air (ed) and the cloudiness (n/N), temperature in °c.

The parameters e_a saturated vapor pressure at air temperature.

$e =$ the Stephan Boltzmann constant (2.01×10^{-9})

Ta=mean air temperature for a month, °c. is obtained from standard table of air temperature and saturation as:

$$e_a(Ta) = 6.11 \exp (17.3 Ta /Ta+ 273.3) \text{-----eq(6)}$$

Relative humidity (RH) in % used to calculate the value of actual Vapor pressure(ed) as:

$$ed = ea RH\% \text{-----eq(7)}$$

The energy for evaporation E_{at} is given by

$$E_{at} = 0.35 (0.5 + u^2 /100) (ea - ed) \text{-----eq(8)}$$

Where - ea =the saturated vapor pressure at air temperature, Ta

ed =the saturated vapor pressure at the dew point = ea*Hr/100

(u²)= mean wind speed in m/s was converted to mile/ day

Table 3-15 potential evapotranspiration using penman modified model

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
T(°c)	16.4	17.5	17.8	18	18	16.8	15.6	15.5	15.8	16	15.6	15.7	
ea(mm/d)	13.4	15	15.6	15.9	15.9	14.3	13.6	13.4	13.9	14.2	13.6	13.7	
RH (%)	50.7	49.2	51.9	56.9	54.4	67.1	79.3	81.2	73.8	56.7	50.5	49.2	
ed(mm/d)	6.79	7.38	8.1	9.05	8.65	9.6	10.8	10.9	10.3	8.1	6.9	6.7	
U ₂ (mil/d)	59.9	64.4	69.8	64.4	69.8	59	45.5	43.5	48.3	50.9	75.1	59	
Tk(°k)	289.7	290.8	291.1	291.3	291.3	290.1	288.9	288.8	289.1	289.3	288.9	289	
n(hr/d)	8.45	8.13	7.36	6.62	6.99	5.13	2.93	3.06	4.68	7.52	9.44	8.39	
N(hr/d)	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5	
n/N	0.73	0.69	0.6	0.54	0.55	0.4	0.23	0.25	0.39	0.64	0.81	0.73	
fa(n/N)	0.61	0.59	0.54	0.5	0.5	0.41	0.3	0.32	0.4	0.56	0.66	0.61	
Ra(mm/d)	12.8	13.9	14.8	15.2	15	14.8	14.8	15	14.9	14.1	13.1	12.4	
RI(1-r)(mm/d)	7.42	7.79	7.59	7.22	7.13	5.76	4.22	4.56	5.66	7.5	8.21	7.19	
δT _a ⁴	14.16	14.37	14.43	14.47	14.47	14.24	14.	13.98	14.04	14.08	14	14.02	
Ro	2.12	2.01	1.59	1.59	1.74	1.28	0.98	0.98	1.26	1.83	2.24	2.1	
H(mm/d)	5.3	5.78	6	5.63	5.39	4.48	3.24	3.58	4.4	5.67	5.67	5.09	
Ea(mm/d)	2.5	3.1	3.1	2.7	3	1.8	0.9	0.8	1.2	2.2	2.9	2.7	
ΔΓ	1.82	1.94	2	2.02	2.02	1.86	1.78	1.73	1.8	1.67	1.78	1.79	
Eo	100.9	118.8	119.7	118.4	115	98.9	70	66.7	89.7	112.3	105.5	109.1	1225

The average albedo value of γ is taken as 0.23. The calculated annual potential evapotranspiration of the study area according to penman is 1225 mm

For estimation of potential evapotranspiration of the study area, the average of the two methods; penman and Thornthwaite; have been used and presented in table 3.16.

Table 3-16 Average potential evapotranspiration of the study area

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
P.m	100.9	118.8	119.7	118.4	115.9	98.9	70	66.7	89.7	112.3	105.5	109.1	1225
T.w	54.9	62.1	65.3	68.9	69.9	62.9	54.8	53.1	53.6	53.1	50.3	50.6	699.58
Ave	77.9	90.5	92.5	93.7	92.9	80.9	62.4	59.9	71.6	82.7	77.9	79.9	962.3

From the two methods approach evapotranspiration of Berga and Kare River catchment is calculated, based on meteorological data available is estimated 962.29mm yearly.

3.7.2 Actual evapotranspiration (AET)

AET is the amount of water lost through evapotranspiration under the existing field condition. A value of actual evapotranspiration (AET) over a basin is often obtained by first calculating the potential evaporation plus transpiration (PET), and then modifying the answer by accounting for the actual soil moisture content (Shaw, 1994). The term actual evapotranspiration is used to describe the amount of evapotranspiration that occurs under the existing field conditions (Dunne and Leopold, 1978). The majority of the water loss due to evapotranspiration takes place during the winter months (dry hot seasons in Ethiopian case) while little loss is during the summer (wet cold season in Ethiopian case).

Always actual evapotranspiration is less or equal to potential evapotranspiration. When the vegetation is unable to abstract water from the soil, then the actual evapotranspiration becomes less than potential.

Various approaches exist for the determination of Actual evapotranspiration. The method employed in this paper is those developed by Thorenthwaite and Mather (1957) and Turc method

3.7.2.1 Turk method

The method determines the annual actual evapotranspiration (AET), directly from two meteorological parameters, precipitation and temperature.

It is an empirical formula developed based on data from various catchments of different climates, and hence could be applied in humid or arid climates, either hot or cold, (Shaw,1994)

This is given by the formula:

$$AEP = (P) / (\sqrt{[0.9 + (P/L)^2]})$$

Where AET= Actual evapotranspiration of a year in mm.

P= Annual mean precipitation in mm.

T= Annual mean temperature in °c

L= $300 + 25T + 0.05 T^3$ in mm

For the study area annual mean P and T are 1161mm and 16.5^oc respectively.

Then L=637.1 and the value of AET becomes 566.5mm/year

3.7.2.2 Thornthwaite and Mather soil water balance model.

This method is introduced by Thornthwaite in the early 1940's estimates actual evapotranspiration using precipitation and soil moisture. Actual evapotranspiration is the amount of evaporation that occurs when soil moisture is limiting. When moisture conditions are suitable, the actual rate of evapotranspiration is equal to the potential rate. Soil moisture budget can be made on a monthly basis for various types of vegetation classified. Thus, the catchment area has been classified in to two groups of soil texture (silt clay and loam clay) and moderately deep rooted cereals and deep rooted shrubs grown on them. Based on the soil texture and the land cover type in the catchment, the actual evapotranspiration is estimated using Thornthwaite and Mather soil moisture balance model. To evaluate actual evapotranspiration over a catchment area, the proportions of different types of vegetation covering the basin must be known. The values of soil moisture deficit and actual evapotranspiration vary with soil type and vegetation (Shaw, 1994).

In the model, accumulated potential water loss, 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.

The soil moisture during the dry moths is then obtained from the following formula:

$$S_m = S_{m-1} \exp((PET_m - P_m) / S_{max})$$

$$AET = PET \times f(AW/AWC)$$

Where AET and PET are actual and potential rates of evapotranspiration respectively, f (AW/AWC) is some function of the term inside the parentheses, AW is the available soil moisture which is equal to soil moisture content minus permanent wilting point times the rooting depth of vegetation (cm), AWC is the available water capacity of soil which is equal to field capacity minus permanent wilting point times rooting depth of vegetation (cm).

Penman (1950, in Shaw introduced the concept of 'root constant' that defines the amount of soil moisture (mm depth) that can be extracted from a soil without difficulty by given vegetation. A soil moisture budget can be made on a monthly basis for various types of vegetation classified according to their root constants (Dunne and Leopold, 1978). Therefore, to evaluate actual

evapotranspiration over a basin area, the proportions of different types of vegetation covering the basin must be known.

Accordingly, the study area has been classified in to three major groups of soil type (Clay loam, gravel-silty loam and sandy-silty loam) with average field capacity of 200 mm, and the types of rooting depth of vegetation cover are taken 1m on average, which are often cereal crops such as wheat, Barley, Maize, and Sorghum and Grass, Shrubs and Wood lands. Based on these categories and available meteorological data, the actual evapotranspiration is calculated using Thornthwaite and mother (Ding man, 1994) standard soil water balance model.

S: - is soil moisture surplus, it is the amount of water contributing to runoff and groundwater recharge.

For dry months, $S=0$ and for wet months, $S= (P-PET) - \Delta S_m$ whereas ΔS_m is change in soil moisture.

D:-is soil moisture deficit, it is the amount of water needed to satisfy the demand of PET of a given month.

$$D=PET-AET$$

If $P_m < PET_m$, a soil moisture deficit develops or increases. The soil moisture for this case is given as:

$$S_m = S_m - 1 \exp\left[\frac{PET_m - P_m}{S_{max}}\right]$$

S_m :- is monthly soil moisture, found from reading retained water for a given condition from a standard graph for dry months, but for wet months it is found by adding excess precipitation ($P-PET$) to soil moisture content at the end of that month. The soil moisture cannot exceed its field capacity.

ΔS_m : - is change in soil moisture, given as; $\Delta S_m = S_m - S_{m-1}$

The monthly actual evapotranspiration, AET_m is then found as:

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

$$AET_m = P_m + S_{m-1} - S_m$$

Using this method the actual evapotranspiration (AET) of the study area is 767.6 mm/ year

Table 3-17 Estimated Actual evapotranspiration (AET), by using Thornthwaite-Mather method

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tota
P _m	22.6	43.8	72	85.5	73.8	139.2	265.4	266.3	135.1	33.3	12.7	11.9	1161
PET(mm)	77.9	90.5	92.5	93.7	92.9	80.9	62.4	59.9	71.6	82.7	77.9	79.9	962.8
P _m -PET	-55.3	-46.7	-20.5	-8.2	-19.1	58.3	203	206.4	63.5	-49.4	-65.2	-68	
Acc.pot.W L	-237.9	- 284.6	- 305.1	- 313.3	- 332.4	-	-	-	-	-49.4	- 114.6	- 182.6	
S _m	24.7	17.9	12.7	9.3	7.4	67.7	200	200	200	135.9	59.1	38.9	
ΔS	-14.2	-6.8	-5.2	-3.4	-1.9	60.3	132.3	0	0	-64.1	-21.4	-20.2	
AET	36.8	50.6	77.2	88.9	75.7	80.9	62.4	59.9	71.6	97.4	34.1	32.1	767.6
D	41.1	39.9	15.3	4.8	17.1	58.3	0	0	0	14.7	43.8	47.8	282.8
S	0	0	0	0	0	0	70.7	206.4	64.1	0	0	0	341.2

In order to have reasonable value of AET for the study area, the average value, obtained from two methods average (Thornthwaite & Mather soil water balance model and Turc method) is used. Because during the calculation of AET employing various methods, some parameters that may affect evapotranspiration are either estimated or totally neglected. Therefore the average Actual Evapotranspiration over the catchment is estimated 667.05mm/years.

3.8 Runoff

3.8.1 Mean Monthly and Annual Flows.

Runoff is the water which moves in defined channels or all the water that moves over the land surface in undefined channel. Runoff process is strongly influenced by rainfall intensity and infiltration capacity of the soil. Infiltration capacity varies not only from soil to soil, but also different for dry versus moist conditions in the same soil. If the rainfall intensity is lower than the infiltration equilibrium capacity, but less than the initial infiltration capacity, at the beginning all the water will infiltrate, but when the infiltration capacity drops below the rainfall intensity, some of the water will remain on the land surface. The water which does not infiltrate forms flow as a thin sheet across the land surface, which is called over land flow or surface runoff (Tenalem Ayenew and Tamiru Alemayehu, 2001). The pattern of runoff volume of any basin is a function of duration of intensity and aerial distribution of rainfall, evapotranspiration, size of catchment, vegetation cover condition, topography and geology of

the catchment. Topography determines the slope and location of drainage channels and the storage capacity of the basin. Channel slope and configuration are directly related to the rate of flow in a basin and the magnitude of the peak flow. Steep water shed will generally indicate a rapid rate of runoff with little storage, where as a relatively flat area is subjected to considerable storage and lower rate of flow (Tenalem Ayenew and Tamiru Alemayehu, 2001). Berga and Kare River is the main feeding river to the Upper Awash River that originate from the adjacent of Abay and Awash basin water divide area an altitude of 2680m a.b.m.sl and decreases to 2060 m a.b.m.sl at its southern end around River Awash. The Berga and kare Rivers themself have many small tributaries. Based on River discharge data of the past 15years collected by minister of water (1995 -2009) recorded, the mean annual discharge of Berga River is 127.8 million cubic meters (mcm), out of this; 171.8 million cubic meters (mcm) of water leaves the catchment in the form of runoff. Peak discharge occurs at the month of August; and often dries during extreme dry season from December to April.

Estimating runoff or discharge from rainfall measurements is very much dependent on the time scale being considered. For short durations (hours) the complex interrelationship between rainfall and runoff is not easily defined, but for prolonged time the connection becomes simpler until, on an annual basis, straight line correlation may be obtained (Shaw, 1994).

3.8.2 Hydrograph Analysis

From river discharge, surface runoff and base flow should be separated using conventional graphic separation and spreadsheet program (software) called TIMEPLOT method. The conventional graphic base flow separation methods may either under estimate or overestimate the components of river discharge whereas the spreadsheet program (software) could estimate reasonably by taking in to consideration the topographic characteristics of the basin.

From software base flow separation methods, the mean annual base flow of 15years data (1995-2009) is analyzed.

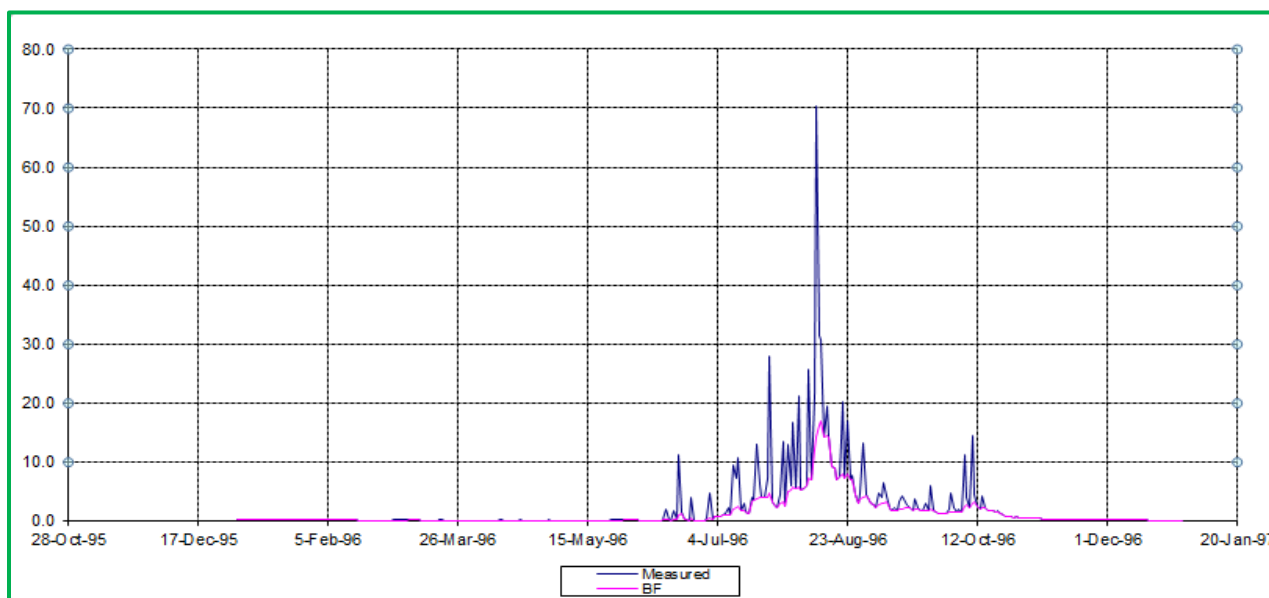
The yearly volume of base flow is spread over the catchment area above the gagging station (248km²) in order to estimate the minimum depth in mm of recharge to ground water in the given catchment.

Table 3-18 River discharge base flow separation

Unit	Total flow	Base flow	Run off
m ³ /s	48.64	32.43	16.21
Mean Annual flow in mcm	127.83	85.23	42.60
Mean annual in mm	515.44	343.67	171.77
Mean annual in mm %	100	66.68	33.32

Accordingly, from the mean annual flow of 48.64 m³ /sec 66.68% (32.43 m³/s) is a contribution from the base flow and 33.32% (16.21m³/s) is a contribution from over land flow.

The method shows that out of the total mean annual River discharge of 127.83 million cubic meters about 66.68% of flow is contributed from base flow covering 343.67mm from total runoff 515.44 mm annually. Direct runoff contributes 171.77mm annually.

**Figure 3-9 Hydrography separation**

3.9 Recharge Estimation

There can be several sources of recharge to a groundwater system. These include precipitation recharge, river recharge, inter-aquifer flows and irrigation losses recharge. Each type of recharge can be quantified by different methods, direct measurement, water balance methods, tracer techniques and other empirical methods

3.9.1 Recharge Estimation Using Water Balance Method

Water balance is the balance between the income of water from precipitation and snow melt and the out flow of water by evapotranspiration, groundwater recharge, and stream flow

(Thornthwaite, 1957). The budget can be computed for a reservoir, soil profile, and aquifer drainage basin over a specific period of time.

General water balance equation form

Inflow= outflow + change in storage

The following assumptions are made to derive the water balance equation of the study area.

- Surface water divide coincides with ground water divide. Hence the groundwater in the basin is in a closed system.
- The change in storage on annual basis is assumed to be zero
- The catchment is bounded by both surface water divide and groundwater divide, except at the mouth of the river where groundwater flow as a base flow
- There is no groundwater inflow
- The water balance is on annual basis.

Based on the above assumptions, the water balance of the catchment is represented by the general equation.

$P=AET+RO+R+\Delta S$, $RO=SRO+BF$ where, SRO is over land flow and BF is base flow

$$\Delta S= 0$$

Finally, the study area will have a water balance equation of the form:

$$P=AET+RO+R$$

P=precipitation (1161 mm) annually

AET=actual evapotranspiration (667.05mm)

RO=annual runoff out of the catchment (171.77mm)

R= Groundwater Recharge

$$R=P-(AET+RO) = 1161\text{mm}- (667.05\text{mm} +171.77\text{mm})$$

From the above equation the ground water recharge of the catchment is 322.18 mm/yr.

Chapter four Geology of the study area

4.1 Regional Geology

Ethiopia can be divided in to four major physiographic regions, widely known as the western plateau, southeastern plateau, the Main Ethiopian Rift (MER) and the Afar Depression (AD)

The study area is located at the western escarpment of the Great East African Rift System in western plateau Adjacent to Abay basin as part of the Ethiopian high lands of Upper Awash Basin, central Ethiopia, in the shoa plateaus, which is made of tertiary volcanic rocks belonging to the trap series were recognized and mapped as flood basalt province and dominated by Tertiary volcanic (Mohr, 1983). It is situated in the western margin of the main Ethiopian Rift and consists of different volcanic rocks that vary from basic too acidic in composition.

Different researchers have been studied the geology of Addis Ababa and its surrounding both locally and regional scale. As the works by Mohr (1967, 1971), Zenettin et al (1977), Kazmin (1975), they described rock units expose the Miocene-Pleistocene volcanic succession ranging from older plateau volcanic to younger Rift volcanic. The volcanic rocks belonging to the trap series include Ashangip and shield group. These rocks have been considered to be related with extensive fracturing that occurred synchronously and immediately following the uplift of the Arabo Ethiopian swell (Mohr, 1971; Kazmin, 1975).

ASHANGE GROUP (Paleocene-Oligocene-Miocene): this broad group is classified into alkali olivine basalt and tuffs, rare rhyolites and dolerite sills and gabbro-diabase intrusive. As a formation it is explained as alkali olivine basalt, pyroclastic and rare rhyolite injected by doleritic sills, acidic dykes and gabbro-diabase intrusion.

SHIELD GROUP (Miocene): It is composed of alkaline olivine basalt, tuff and agglomerates. The alkaline olivine basalts in this group show amygdaloidal textural features. The volcanic rocks thought to be younger than the rocks of the trap series are Magdala and Afar group. These younger volcanic rocks may be related with rift system faulting and occur within the rift and along the adjacent plateau (Mohr, 1971; Kazmin, 1975).

MAGDALAGROUP: (Upper Miocene-pleistone): It is an association of rhyolite and trachytic tuffs inter bedded with lava and agglomerates of basaltic composition i.e. ignimbrites, agglomerates and basalt.

Regional geological setting of this area consists of two major rock groups, namely pre Rift volcanic succession, and Rift/ Post Rift volcanic products and sediments. The pre-Rift Groups are parts of the thick volcanic succession, mainly basalt, in the Trap-series volcanism of Tertiary period, with Fissural and / or central modes of eruptions. They include Ashangi Formation, Aiba Formation, Alaji Fomation, and Tarmaber-Magazaz formation.

The post rift volcanic and sediments include Adama group, Afar group Wanji group, Quaternary plateau basalts and Alluvial and Lacustrine Deposits.

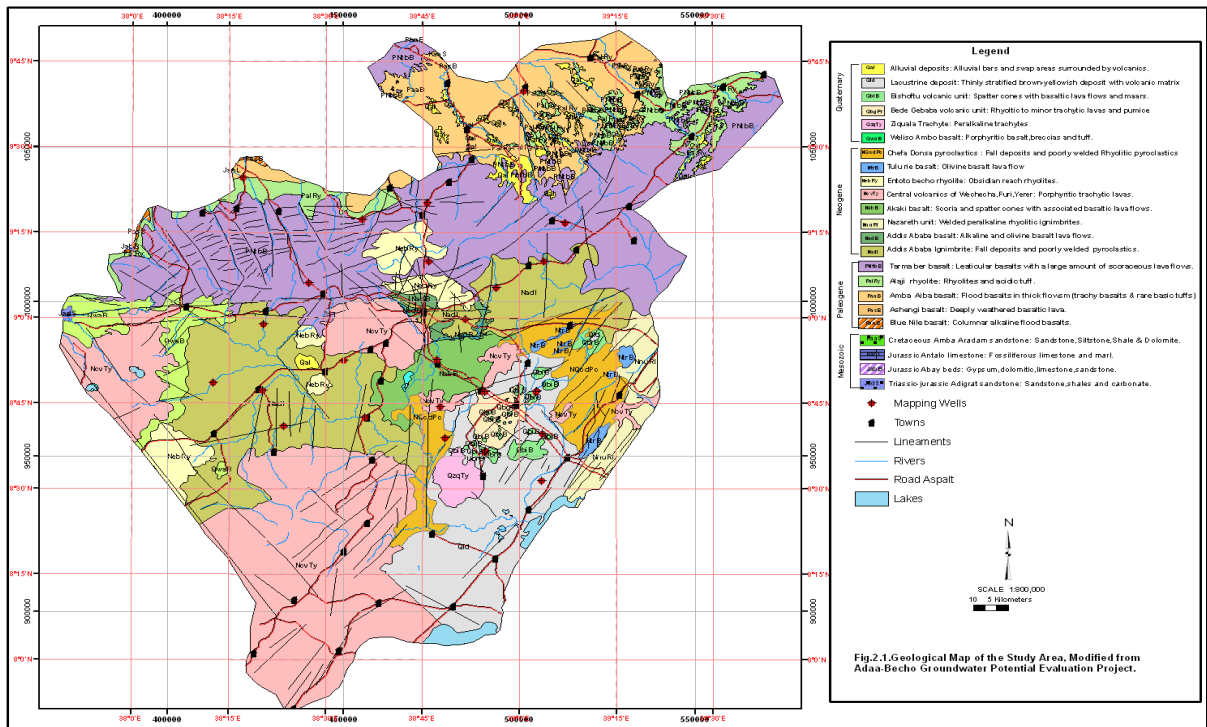


Figure 4-1 Geological map of Upper Awash (modified, Tilahun, 2008)

4.1.1 Ashangi Formation

An extensive development of fissural and central type eruptions in pre-Tertiary Period produced a thick succession of the Trap-Series Basalts that formed the northwestern and southeastern Ethiopia plateau. Blanford (1869) assigned the name Ashangi Group that he considered to have formed during Mesozoic, the oldest basalts of the Ethiopia plateau.

Currently the term “Ashangi Basalts” has been used to describe several hundreds of meters thick highly weathered basalts of the Ethiopia plateau (Zanettin and Mohr, 1988).

It is now generally accepted that in the Ethiopia Plateau, the Trap Series was formed in the course of two clearly separate cycles of eruptions, namely the Ashangi Cycle (50-35MY), the older part, and the younger post Ashangi Cycle (32-15MY) (Zanettin and Mohr, 1988).

The Ashangi Formation occurs in an old northwesterly trending rift system now buried under young volcanic and partially eroded away (Zanettin et al., 1977). It is made of transitional basalts with tholeiitic affinity.

The Ashangi Basalts are exposed in North Showa and Jimma Zones. It consists mainly of several hundreds of meters to a kilometer thick of strongly weathered, tilted basalts with rare trachyte, rhyolited and pyroclastic intercalations. It is commonly intruded by dolerite sills and dykes. Its upper part contains lacustrine deposits containing lignite seams (Zanettin et al., 1977).

4.1.2 Aiba Formation

Aiba Basalts represent part of the second major cycle of fissural basalt volcanism on the northwestern plateau after the Ashangi Formation (Zanettin and Justin, 1974).

This new cycle began with the emission of huge volumes of lava, flooding the pen plain surface of the Ashangi Basalts. The Aiba Basalts whose age is 36-25 MY old are typical transitional basalts, very homogenous in composition.

They are generally followed by the Alaji Volcanics represented by interlay red silica rocks and transitional basalts, but sometimes only by silicic rocks, mostly slightly per alkaline rhyolites. It ranges in thickness from 200 to 600 meters. They are generally aphyric and compact in places showing clear stratification and contain rare basic tuffs (Zanettin and Justin, 1974). Analogous to the Aiba Basalts occur in the southwest of Oromia and adjoining areas, where similar K-Ar age to Aiba Basalts of 34-30 MY have been reported. They are mapped together with the Alaji Formation. The Aiba Basalt flow, however, are missing in the southeastern plateau.

The Aiba Basalts are commonly jointed, aphyric or porphyritic with plagioclase and olivine phenocrysts (Kazmin, 1979).

4.1.3 Alaji Formation

The Alaji Formation was first identified by Zanettin and Justin, (1974) on the central Plateau. Later, Kazmin, (1979) and Zanettin et al (1977) recognized equivalent unit on the southeastern plateau and in the southern segment of the Rift section. The Alaji Formation occurs in both the northwestern and southeastern parts of escarpment of the Rift system.

In central part of the Rift the Alaji Basalts are covered by thick accumulations of younger silicic volcanic rocks and may possibly are missing in some segments of the Rift (Kazmin, 1962). This has been proved near Kalla village north of Buttajira town. The actual extent of the area, where the pre-Rift succession is missing is not known yet (Kazmin, 1962). The Alaji Formation is overlain by Tarmaber- Magazaz Formation and is overlapped by younger volcanic units, where Tarmaber Formation is missing. Absolute age determinations place the Alaji Formation between 30-13 MY (Kazmin, 1979).

In southeastern plateau and northern a succession up to 800 meters thick Alaji Basalts, dominantly aphyric flood basalts, lies unconformably on the eroded surfaces of the Mesozoic sedimentary succession (Kazmin,1979).

It rests mostly on the Cretaceous Sandstone of Ambaradom Formation, where it is missing it overlies the Urandab Formation or as direct fault contact with the Hamanlei Formation. In Northwestern Plateau of Northwestern, North Shawa Zone, it lies either on the Aiba or Ashangi Formations. In southwest Oromia, Jimma Zone, a thick succession of silicic volcanic flows, pyroclastic and subordinate intercalated basalt flows dominate the upper part of the pre- Rift volcanic succession (Mengesha et al., 1996).

4.1.4 Tarmaber-Magazaz Formation

The fissural Alaji volcanism was followed by central volcanism, which formed large volcanoes decreasing in age from north to south (Zanettin and Mohr, 1988).

This change in volcanic regime in space and time is matched by change in lava composition, from transitional basalts to alkali basalts and basanites (Zanettin and Mohr, 1988). On the north western and southeastern plateaus, the fissural eruptions of the Ashangi, Aiba and Alaji Formations were followed by the central type volcanism which built up the large shield

volcanoes of the Mt Ras Dashen, Abuna Josef, Guna Choke, Guassa, Bashillo, Salale, Tarmaber, Magazaz, Mengistu, Arba Guggu and others (Zanettin et. al., 1977)

In the northwestern part of the plateau the shield volcanoes become progressively younger from north to south (Zanettin and Mohr, 1988) and the central type volcanism took place between 26 and 16 MY ago. The age of the shield volcanoes of the southern plateau ranges from 16 to 13 MY.

These two shield volcanoes having an age of (26-16MY) and (16-13MY) are named Tarmaber-Guassa Formation and Tarmaber- Magazaz Formation respectively. They are named after volcanisms that formed the Tarmaber, Guassa and Magazaz Mountains northeast of Addis Ababa. Basalts from Tarmaber Mountain are dated 13 MY old (Kazmin, 1979). Mohr (1967) established a lower Miocene age of (24.3. MY), For the Ras Dashen mountain basalts, and for the Dasse-Bati area central volcanoes 28 to 24 MY age.

Therefore, the classification Tarmaber Guassa Formation for the shield volcanoes of the name Tarmaber Magaza Formation for the younger shield volcanoes with an absolute age range of 16 to 13 My in southern part of the northwestern plateau and the southeastern part of the central plateau became essential (Kazmin, 1979).

In contrast to the tholeiitic and mildly alkaline nature of the underlying fissural basalts, the Tarmaber Basalts are typically alkaline in nature (Kazmin, 1979). Usually individual flows are easily recognizable particularly in areas where plaecosols and scoraceous horizons developed in many places between flows (Kazmin, 1979).

In general, the Tarmaber Basalts and their equivalents have much fresher appearance than the underlying stratoid basalts of Alaji Formation.

4.2 Geological setting of the study Area

The geological setting of the study area consists of four major rock groups, classified in this study, based up on their special distribution and mode of formation. They are Plateau Basalts, and Rift Volcanic and Alluvial Sediments. Wider scope of the geology in most of the cases is as provided in the Regional Setting described earlier. Detail things of the map units and corresponding rock associations, emphasizing ideas and observation absent or less satisfactory in the Regional Geology Part, is given in this section of the report. Stratigraphic nomenclatures of some of the map units in this work area adopted from reports of earlier workers, in order to

enhance clarity and reduce possible confusion in this report. The map units are presented in a decreasing order of eruption and/ or deposition age, as judged from field observation supported by the already constructed stratigraphy by previous workers.

4.2.1 Tarmaber-Magazaze formation

Tarmaber-Magazaze formation is found overlaying the Alaji basalt and exposure is well identified in the north- Eastern, central and south- western part of the study area forming highly rocky and outstanding topography. Sire Berga mountain range on the northern part is typically formed this basalt, which has vast extension towards west through echini town area, in Ada'a Berga and Meta Robi areas, around delate ridge out of the study boundary. Contacts of the units are marked by the presence of up to 3m thick reddish brown paloesosoi horizons that have discontinuous nature of occurrence. Usually individual flows are easily recognizable particularly in areas where plaeosols and scoraceous horizons developed in many places between flows.

During field work such orientation is observed particularly in areas where scoraceous horizons developed near Gaba- Jimata and kerbo village.

The scoraceous formation over layer the Tarmaber magazaze formation is not map able, distributed unevenly patches of Tarmaber sheets having a conic like shapes and usually of smaller aerial extent are observed deposited on top of Tarmaber magazaze basalt of the area.

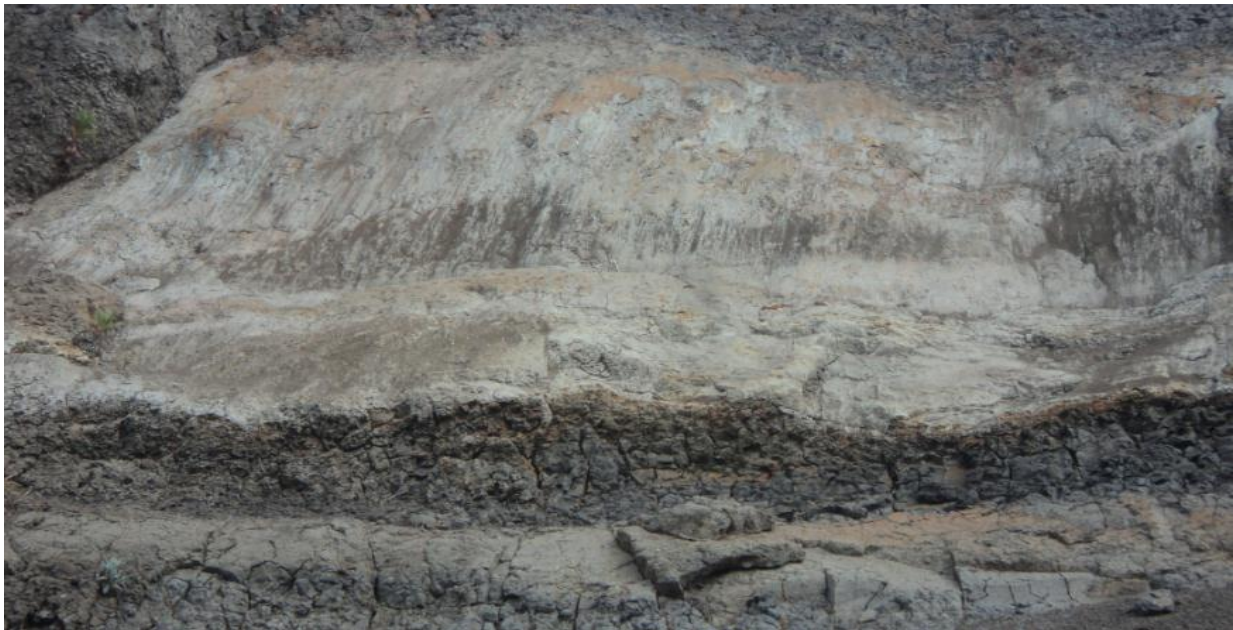


Figure 4-2 Tarmaber-Magazaze formation photo taken from central part of Berga River

4.2.2 Ignimbrite formation

They are distributed around Inaftu, Kimoye and Addis Alem of ignimbrite sheets having more than 15m thickness and usually of large aerial extent are observed to Eastern part of the study area extent to holeta town out of the study area and western of Addis Alem town to kimoye village deposited on top of plateau basalt (Alaji basalt) which exposed near the Berga River bank of the study area.

The Ignimbrite formation of the study area and outside is used as quarry for dimension stone (masonry). Here, the rock is simply extracted using hand equipment such as hammer and crowbars for the purpose of construction. The main exposers of this formation is in three places inside and outside of the study boulder, Inaftu inside and holeta outside of boulder both exposers area are used for quarry site and the third exposers is around kimoye village because of road cut having more than 8m thickness.



Figure 4-3 Ignimbrite photo taken from Inaftu quarry site Eastern part of the study area

4.2.3 Trachytic and Rhyolite Rocks

This rock unit is located in the local geological map, in western, northwest to southwest of the study area, which has vast extension towards west through Ginch Mountain to ward Ambo belt ridge covering chilmo forest ridge area, out of the study boundary. These rocks cover western part of the study area including Tuka, Damotu and Dake Bora area.

They generally form mountain ranges and domes/plugs, with highly rugged surfaces characterizing the larger volcanoes of Tuka, Damotu and Dake Bora.

As one goes from base of the mountain to its top, the component rock grade from more trachytic to rhyolites, with a number of volcanic necks and plugs occur at its vents. The rock generally is porphyritic with large phenocrysts of feldspar, Jointing due to cooling of the magma, and complex flow fold structure commonly occur in the rock.

Trachytic rock of this work was mapped as part of chilallo Formation (NC) in previous works of regional studies. Age of eruption ranges from 4.5-3.0 MY according to reports of the earlier works indicated in the Regional Geology part.



Figure 4-4 Trachytic photo taken from northwest of the study area

4.2.4 Quaternary sediments (Alluvium Deposit)

The other lithological formation mapped in the study area is Quaternary sediments (alluvial deposit) of fluvial origin types of rocks which are encountered and widely distributed over northern and southern part of Berga and Kare River catchment.

The Alluvial which deposited in the Northern part of the study area around Bekete, sire Berga and maru chobet villages plain is accumulated by the erosion of the surrounding highland areas. It is a loose material consisting of sand, silt and clay beds with brown, red or black color and varies thickness from 5-12meters (borehole log of sefara and Bekete villages).

The second place of alluvial deposit mainly outcropped on the Becho Plain, southern part of the study area consisting of regolith, redish brown soils, talus and alluvium with a maximum thickness of about 12 m (Becho area shallow well data), Fine ash material inter bedded with the alluvial deposit in around.

These alluvial deposits area mostly recent and are deposited as a result of transport of sediments from down wash of sloppy area.



Figure 4-5 Northern portion of the study area covered by Alluvium deposit

4.3 Geological Structures of the study area

In the study area the occurrences of faults, joints, fractures and other structures with in the different volcanic rocks were reported by different Authors and researchers for the purpose of different reason which reported the occurrence of an E-W trending faults, joints and other structures. The E-W fault system, which is the upper boundary of the Ethiopian rift margin, is running approximately E-W north of the Addis Ababa -Ambo road. They are major faults on the western plateau part and densely affect Tarmaber basalt in the area (Tilahun, 2008). From field observation the main normal fault in the study area is mapped with geology enclosed in it.

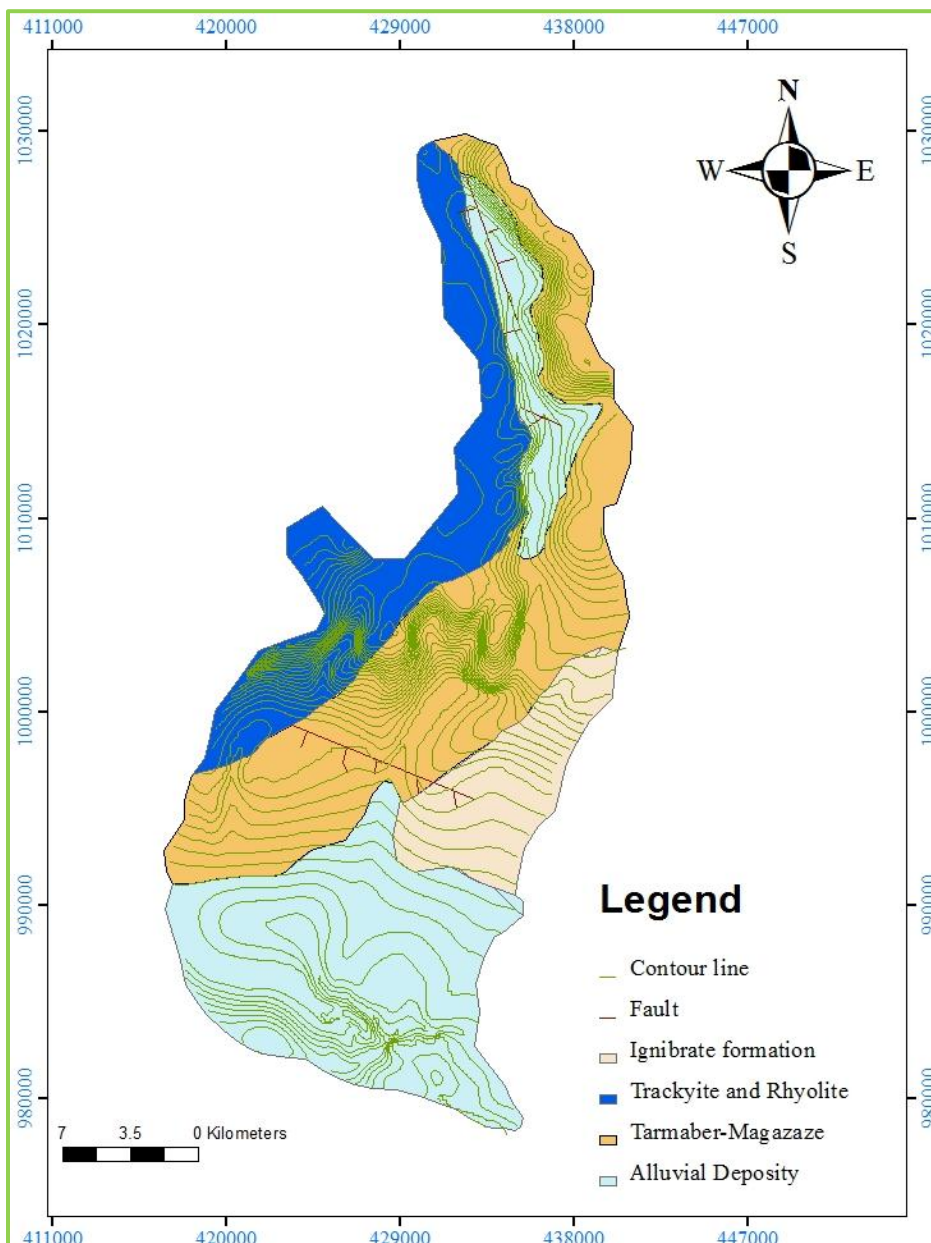


Figure 4-6 Geological Maps of Berga and Kare River Catchment

Chapter Five Hydrogeology of the study Area

5.1 General

Hydrogeology deals with occurrence, distribution, and movement of groundwater in addition to physical and chemical relationship with the surrounding environment. It includes the interrelation ship of geologic materials and processes with water (Fetter, 1994).

The occurrence, movement and distribution of groundwater are a function of many variables such as, meteorological, physiographical and geological formations. The behavior of geological materials towards interaction, storage and transmission of subsurface water constitutes the basic part of hydrogeology, i.e., hydrogeology is strongly associated with geological evaluation of the catchment. Based on their transmissivity and hydraulic properties, geological materials can be categorized in to aquifer, aquitard, aquiclude and aquifuge.

The lateral and vertical extent, shape, and distribution of geological formation are also play a great role in characterizing the hydrogeology of a given area. The presence of permeable geological formation, bottom confining beds and lateral confining beds (barriers) are important for the storage of ground water (Freeze and Cherry, 1979).

5.2 Ground water Occurrence

Groundwater is a part of the earth's natural hydrological cycle. When rainfalls on the land surface, some of the water will infiltrate more deeply, the others accumulate above an impermeable bed, saturating available pore space and forming an underground reservoir.

This water now called Groundwater and the rocks that store and transmit groundwater are called aquifer. An aquifer is a saturated geologic unit that is permeable enough to yield economic quantity of water to well. An aquifer in a given geologic media is largely a function of the degree of weathering, fracturing and faulting. The nature of geologic material, sediment grain size, degree of sorting, weathering and fracturing of geological material characterize the aquifer productivity. Considering all this facts together with topography, spring location, vegetation cover and settlement patterns were used to classify different lithostratigraphic units in to similar groups of hydrostratigraphic units.

The nature and distribution of an aquifer in a geological system is controlled by lithology, stratigraphy and structural features. Accordingly, the lithology of Berga and Kare rivers

catchment is dominated by Tertiary volcano highly weathered and fractured and affected by different direction orientation fault.

5.2.1 Aquifer Systems

The aquifers in Berga and Kare River catchment can be divided broadly into two categories; primary porosity aquifers and double porosity aquifers. The first category comprises aquifers related to Quaternary alluvial deposits and the second broad categories belongs to the basaltic volcanic. The Quaternary alluvial aquifers are found dominantly in the Northern and southern part of the study area in Berga and Becho plain respectively and along the main perennial river courses. The Quaternary alluvial deposits around Berga plain have a thickness up to 16 meters and composed of Brown color clay while the Quaternary alluvial deposit in the Becho plain have a thickness up to 64.4 meters (Bore hole log). The volcanic aquifers can be considered as a double porosity media due to the fact that both the matrix and the fracture porosity contribute to the circulation and storage of groundwater. This unit is composed of basalt of lower Tertiary Tarmaber and Amba Aiba basalts, dominantly weathered and fractured scoriaceous basalt. The recent exploratory wells drilled in Becho, Addis Alem, Gaba-Jimata, Olonkom and Sufera (Upper Berga) are the evidence for this Aquifer. The Static water level varies from artesian condition to a depth of 34.5 meters below ground surface

5.3 Aquifer Characterization

5.3.1 Properties of Aquifer

Quaternary Alluvial and Tertiary volcanic show a wide range of water bearing properties and yield because of their mode of formation, and the secondary processes such as Fractures, faults and weathering that modify the rocks. In Berga and Kare catchment weathering, fracturing and EW, WE and NW-SE faults are the major seconder structure processes infiltrate water to the ground. Groundwater flow in these rocks related to fractures. The intensity of fracture increases the water bearing capacity of rocks.



Figure 5-1 Weathered and fractured Tarmaber Amba Aiba basalt from the Middle of Berga river catchment

The ability of rocks to transmit groundwater is described by its hydraulic properties, hydraulic conductivity, porosity, transmissivity, thickness and storage coefficient using pumping test method. The available pumping test data and well log data analysis in the study area used to characterize the aquifer system in the catchment.

Table 5-1 Hydraulic properties of tertiary Volcano in the study area

local name and Id	x	y	z	Depth	Swl	Q(l/s)	Tr m ² /da	K(m/day)	Aquifer thickness
Kofe (BTW-01)	418679	988365	2086	445	+1	62.05	36.6	0.14	343
Kofe (BTW-02)	423439	988990	2079	450	+1	34.05	410		317
Faki (BTW-03)	420071	983317	2065	350	-3.2	19.12	43.35	0.277	176
Faji Gelila (BTW-04)	428471	995338	2119	250	-25.8 3	56	571	11.41	98
Safera (BTW-05)	432830	1024298	2592	182	-2.1	3.2	14.8		
G/Jimata (BTW-06)	435107	1007000	2563	190	-7	3			
Olonkom (BTW-07)	418710	995419	2144	121	+1	9.3	0.1072		51.3
Dobi1 (BTW-08)	434019	1000122	2349	147	-4.8	1.5	0.34	0.008	45
Dobi2 (BTW)	434162	1000155	2348	221.5	-12	4.5	0.922	0.009	99
Dobi3	435393	1000246	2363	206	-	5.6	4.17	0.13	32

(BTW-09)					9.93				
Dobi4 (BTW-10)	436130	1000470	2372	153	- 36.6 2	1.5	0.24	0.005	52
Side/Giche(B TW-11)	434056	0998276	2340	300	-1.1	24.4	0.177	0.00455	39

5.3.2 Transmissivity

Transmissivity of an aquifer measures how much water can be transmitted horizontally. It is the product of the hydraulic conductivity times the thickness of the aquifer which is employed in most groundwater flow equations to understand the flow dynamics and generally estimated from pumping tests (Freeze & Cherry, 1979). The aquifer pumping test is a frequently employed in situ method which is used to determine the hydraulic properties of water bearing formations.

The test involves putting an artificial stress on the aquifer by continuously pumping water from the borehole and measuring water level changes in the pumped well. For most of the boreholes in the study area the pumping test lasted between 24 and 72 hours. According to pumping test result of different bore holes in different depth and location in the study area, the transmissivity ranges from 0.1072m²/day to 571m²/day.

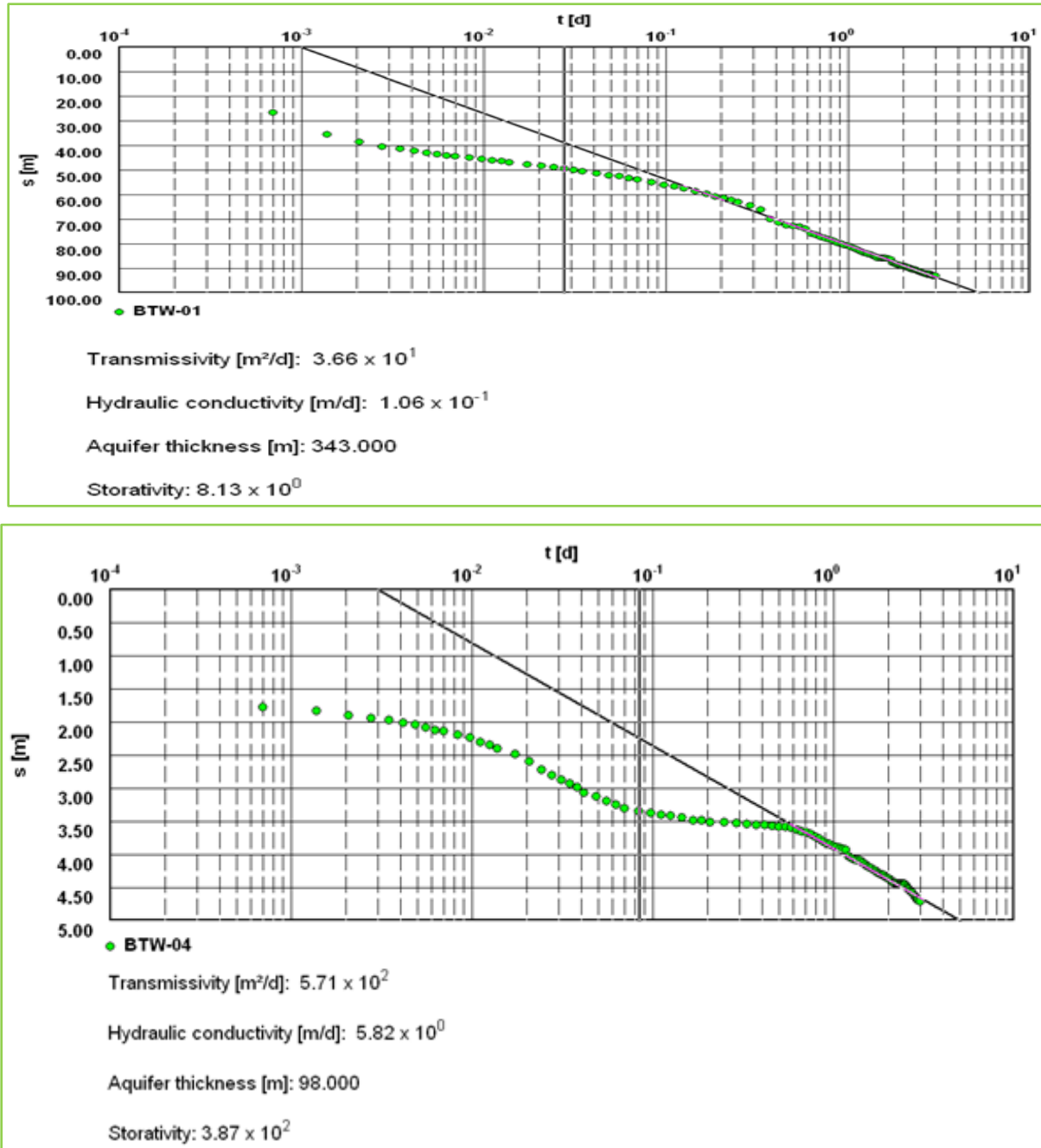


Figure 5-2 Constant Method Analyses after COOPER & JACOB

5.3.3 Hydraulic Conductivity

Hydraulic conductivity (K) defines the rate of movement of water through a porous medium such as a soil or aquifer. It is the constant of proportionality in Darcy's Law and as such is defined as the flow volume per unit cross-sectional area of porous medium under the influence of a unit hydraulic gradient. Measurement of hydraulic conductivity is problematic, considering the parameter can differ over several orders of magnitude across the spectrum of rock types.

Hydraulic conductivity is also scale dependent, so that measurements taken at the core sample level may not be directly extrapolated to the aquifer scale. It is also direction dependent, so that hydraulic conductivity can be markedly different in the vertical from the horizontal (Andarge, Y. 2009). From the borehole data in the study area the hydraulic conductivity of the Aquifer is 0.00455m/day to 11.41m/day.

Depending on the topographic feature of the area, hydrometeorological and borehole data analysis, degree of weathering and fracturing, spring discharge and location, handdug well discharges and location the relative lithostratigraphic permeability and groundwater potential zone of Berga and Kare river catchment are categorized in to three groups.

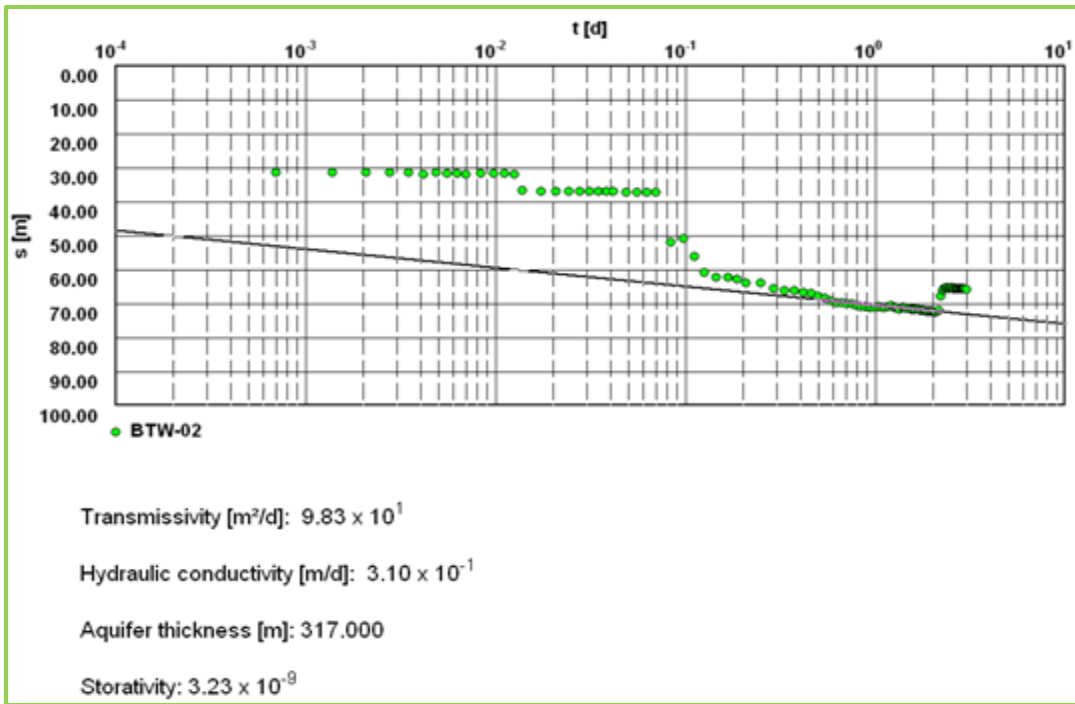


Figure 5-3 Constant Method Analysis after COOPER & JACOB

5.4 High permeability and high groundwater potential zone

This hydrostratigraphic unit covers low lands in the study area part of the Bacho plain. It includes areas near Kimoye village, Faji Galila, kofe and side /Giche. Because of medium to high permeability of discharge area, relatively low topography and flat to gentle slope of the area, the rain water percolated at higher elevation of the catchment flows to this area through different mechanisms locally and regionally. The area is covered by alluvial clay deposits over the top of slight to highly fractured and weathered basalts. From several boreholes drilled in this zone, only six boreholes have complete pumping test data and bore hole logging, the other specially those of Agriflora private investors bore holes have no any data . Wells drilled in this hydrostratigraphic unit gives 9.3-62.5 L/s yield, 0.1072-571m²/d transmissivity and 0.00455-11.41m/d hydraulic conductivity (table 5.1). From the exploratory well pump test result in this zone, the type of aquifer is confined aquifer. The shallow wells are very common in this zone with depth between 38m to 63m and estimated discharge during drilling from 1.5-6.2 l/sec which are fitted with IndianII hand pump. Hand dug wells with estimated yield of 4.6-4.8L/sec are found in this lithostratigraphic unit, this type of wells are very common around Amaro village part of Becho plain.



Figure 5-4 BTW-01, during pump test with $Q=62.5$ l/sec.

The shallow and handdug well fitted with different hand pumps are located in this zone with different estimated discharge during drilling from 0.1 2.5l/s and static water level from artential to depth of 24m. The geological logging of this shallow and hand dug wells shows weathered to fracture of basaltic formation having a good permeability and ground water bearing aquifers.

Table 5-2 shallow and hand dug wells in highly permeable and high potential ground water zone

No	X	y	z	Local name	Id	depth	static	Q(L/s)
1	433935	1012238	2615	Change	shallow	65	+1	2
2	433716	1011603	2602	Baso	shallow	63	-7	1.5
3	433219	996506	2171	kete	shallow	50	-7.7	2.5
4	430840	988933	2070	Hora kere	HDW	21	-11	1.5
5	430291	987552	2066	Amero	shallow	64	-10	2.5
6	430218	987496	2067	Amero	shallow	50	-8	2.5
7	429647	984652	2064	Side	shallow	48	-6	
8	432644	981058	2066	Worerso	Treadle pump	10	-5	
9	428961	982619	2068	Worerso	Treadle pump	23	-4	
10	429213	982649	2069	Worerso	Treadle pump	28	-6	
11	429236	983674	2078	Meco	Treadle pump	22	-7	
12	420234	987374	2072	Dediro	Ella	12	-7	
13	427132	993728	2107	Kimoye	shallow	62	-3	2
14	432179	999978	2318	Andode	shallow	60	13.3	1
15	429531	996966	2132	Gult-2	shallow	60	-12	2
16	437764	1004200	2552	Gult mado	Shallow	56	-10	1.5
17	433770	1020498	2598	Gorba	Shallow	58.5	-8	0.5
18	438479	1005632	2552	Damotu yebeta	Shallow	63	-29	0.1
19	424046	988863	2098	Dibu	Shallow	54	-8	1.5
20	427626	994245	2112	Gulti	Shallow	58.5	-24	0.6
21	433716	1011603	2602	Baso	shallow	63	-7	1.5

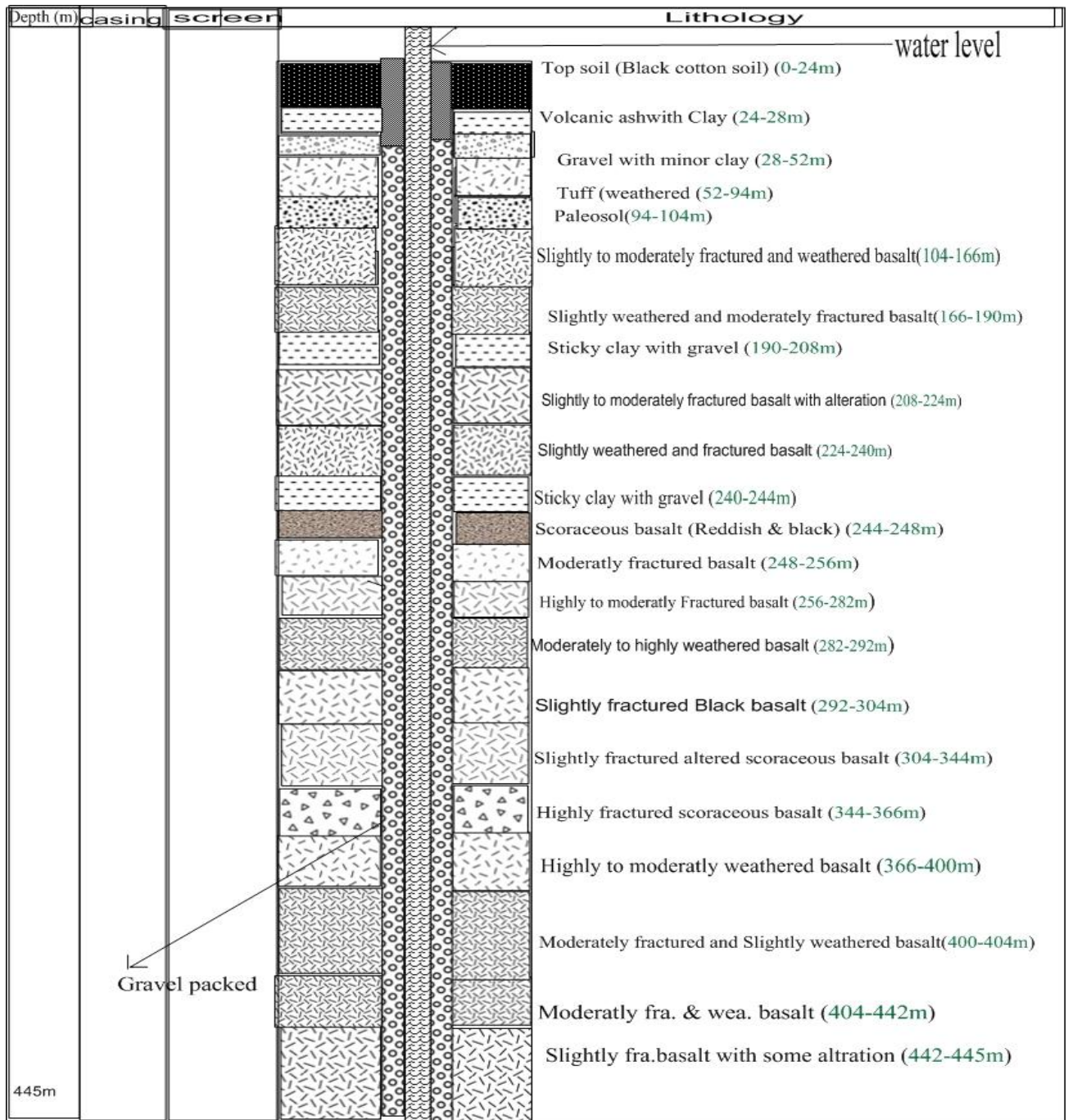


Fig: Lithological log of BTW2 (445m Total depth)

Figure 5-5 Lithological log of borehole diagram

5.5 High permeability and medium groundwater potential zone

This hydrostratigraphic unit covers most parts of the study area. It is characterized by highly weathered, fractured and jointed scoraceous basalt, Ignimbrite and Quaternary alluvial deposit in Berga plain composed of clay silt. This unit is found on a relatively steep slope area. In most places the lateral extent of aquifers are limited in some directions because of undulated land nature. It has a higher elevation than the previous hydrostratigraphic unit. Some boreholes drilled in this hydro-stratigraphic unit have complete pumping test data. The data shows that as depth increases aquifer type changes from unconfined to confine depending on the degree of weathering and fracturing of basaltic rock (table 5.1). Geographically they distribute near Addis Alem, Bekete and sefara in the middle and upper part of the study area.

Wells drilled in this unit gives 1.5-5.6L/s, 0.24-14.8m²/d and 0.005-0.13m/d yield, transmissivity, and hydraulic conductivity respectively. Springs in this zone has an estimated yield of 0.125-0.250L/s. Most handdug wells are found in this lithostratigraphic unit. This unit bounds Berga River and its tributaries in both eastern and western directions, trending nearly in the NE-SW, parallel to Berga River flow direction. There are two dry deep wells in this zone one at Gaba-Jimata the other at Bekete village with drilled depth 120m and 212m respectively.

From Bekete borehole the drilling crew tries to collect the geological log of the well as bellow

Table 5-3 Borehole log at Bekete village, taken from well report

0-24mm	Weathered basalt interaction with top soil
24-56m	Fractured basalt
56-78m	Fractured and weathered basalt
78-105m	Fresh basalt
105-110m	Fractured basalt and weathered basalt
110-212m	Fractured basalt

From this borehole log geologically it is a very good water bearing formation but in all basalt formation there is no water, which indicate that the zone is High permeable and medium groundwater potential. For this village also there is shallow ground water well drilled with estimated discharge 1.5l/sec having depth of 56m. There are hand dug wells following the foot of

Rhyolite /trachyte composition ridge in area of Sire Berga, Maruchobot and Deku- kito with estimated discharge of 1 l/sec to 1.5 l/sec and depth between 12-20m

5.6 Moderate permeability and low groundwater potential zone

This hydro stratigraphic unit is lithologically differ from that of High permeability and medium groundwater potential zone, but found at higher elevation and more divided area. It is characterized by highly weathered, fractured and jointed Tarmaber Amba aiba basalt, Rhyolite/Trachyte and at Northeast ridge upper basalt. It forms the water divide of the Awash and Nile (Abay) Basins in most area and ridges and hills. Due to the presence of joints, faults and high weathering, this lithostratigraphic unit has moderate permeability. Because of undulated topography , rugged valleys and ridges (looks like mountain chain), most of the precipitation goes as surface runoff and infiltrated water immediately drained and leaves the area to discharge area. In this unit, there are some springs having very low discharge which serves as a starting point of streams and for drinking by local community. No borehole and hand dug wells drilled in this zone.

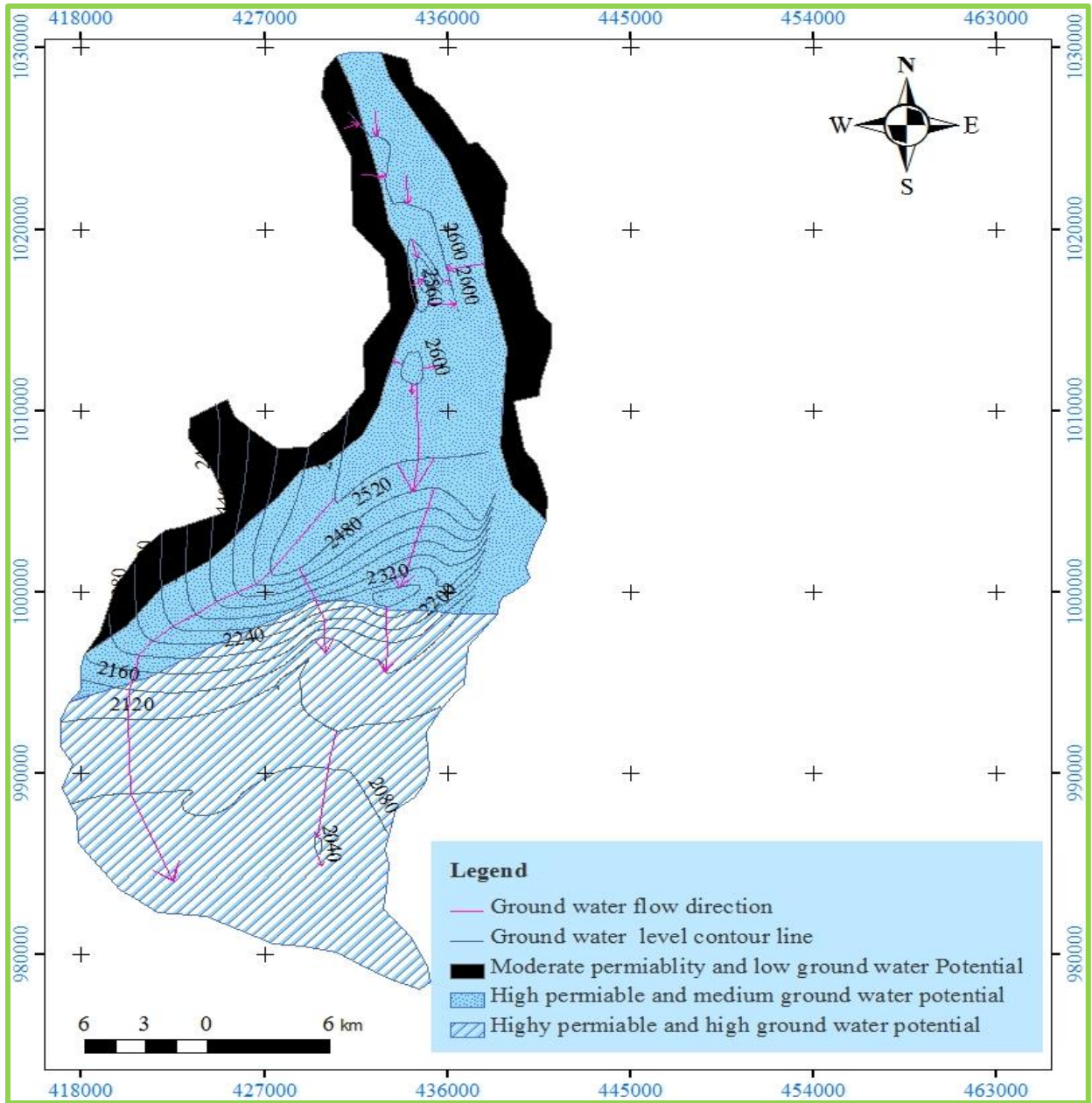


Figure 5-6 Hydrogeological map of Berga and Kare River catchment

5.7 Recharge and Discharge Areas

Recharge areas are usually in topographical high places; discharge areas are located in topographic lows. In the recharge areas, there is often a rather deep unsaturated zone between the water table and the land surface. Conversely, the water table is found either close or at the land surface in discharge areas (Fetter, 1994).

Flow lines on a flow net tend to diverge from recharge areas and converge to ward discharge areas. This convergence will not occur if the discharge zone is large. This is exemplified by the study area. A water table contour map can often be used to locate ground. Water recharge and

discharge areas. Flow lines can be drawn on the basis of ground water contours, crossing them at right angles.

Topography and geology govern groundwater flow system. Moreover, their feature on a given area significantly determines the amount of recharge to groundwater and discharge to surface water. Recharge area is usually found in topographically higher places where as discharge areas are located in a relatively lower topography.

In the field, vegetation and surface water can sometimes be used to locate discharge areas. There may be some physical manifestation of the discharging groundwater, which can take the form of springs, seep, lake, or stream. The presence of vegetation common to wet soils may be indicative of discharge areas.

In recharge area the water table usually lies at some depth where as in discharge area it is usually at or very near the surface (Freeze and Cherry, 1979; Tenalem Ayenew and Tamiru Alemayehu, 2004).

The main recharge areas of the catchment are elevated parts that found at the peripheries of the catchment, mainly in western, eastern and central parts of the water shed and some scoriaceous domes and cones inside the central at Gaba-Jimata extended to Inne village catchment. When compared to discharge area, recharge area is relatively covers larger part of the catchment. Different streams start from recharge areas and flow down to join the main river in the central part of the catchment or disappear in thick clay soil area. Springs are manifestations of ground water in this area.

Geologically the recharge area is mainly composed of weathered and fractured Tarmaber Amba aiba basalt intercalated with scoriaceous basalt covered by thin section of top clay soil and exposed in different place in different horizontal extension except local discharge of Berga plain which is covered by Alluvial clay deposit adjacent to Awash and Nile Basin water divide area.

Discharge areas are those topographically lower parts of the catchment located, mainly adjacent to Berga River, in north central part of the study area (Berga plain) locally and around Kimoye and Dobi village and mainly southern part of the study area Bacho plain regionally in area of relatively flat topography and covered with thick clay soil.

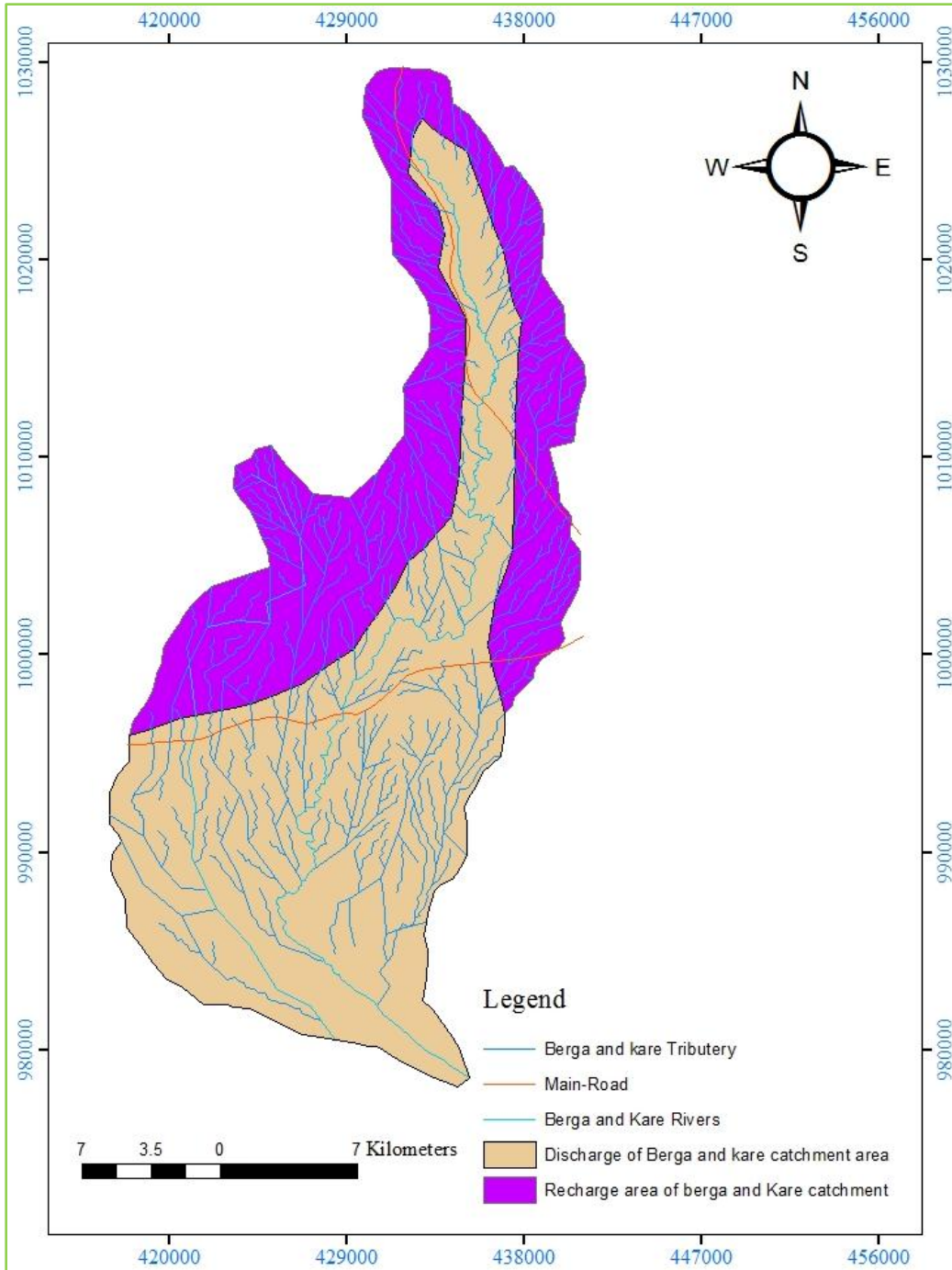


Figure 5-7 Recharge and Discharge map of Berga and Kare River catchment

5.8 Groundwater flow direction

Groundwater is an important source of water, always occur in the form of liquid state, it may provide a base flow for rivers, or act as an underground reservoir from which water can be pumped as a location in to which water can be drained. Usually groundwater movement is

continues and slow from recharge to discharge areas (UNESCO, 2004). Groundwater is feed by surface and subsurface waters by means of infiltration and percolation processes. Topography governs the direction of groundwater flow. Groundwater table is coincident with the ground surface in the valleys, and forms a subdued replica of the topography (Tenalem Ayenew and Tamiru Alemayehu, 20001).

It is desirable, wherever possible, to determine the position of the water table and the direction of groundwater movement. To do so, it is necessary to determine the altitude, or the height above the datum plane, of the water level in well. However in most areas, general but very valuable conclusion about the direction of groundwater movement can be derived from observation of land surface topography.

Gravity is the dominant driving force in groundwater movement. Under natural conditions, ground water moves “downhill” until, in the course of its movement, it reaches the land surface at a spring or through a seep along a side or bottom of a stream channel.

Thus, if we ignore minor surface irregularities, in the study area we find that general slope of the land surface is toward the south, suggesting that the groundwater flow is in the same direction.

According to (Andarge Yitbarek. 2009), the Upper Awash ground water flow is from North to south parallel to the land surface flow regionally.

In the study area, groundwater flow follows topography. Ground water provides a base flow for streams, manifested by many springs which flow towards streams from sloppy area. The general flow of groundwater, as can be deduced from the spring’s elevation and flow direction, is towards the Berga River from both the eastern and western high land areas. The total increase of electrical conductivity (EC) and total dissolved solid (TDS) down the Berga river indicates that groundwater flow direction in the catchment is nearly parallel to river flow direction from north to south.

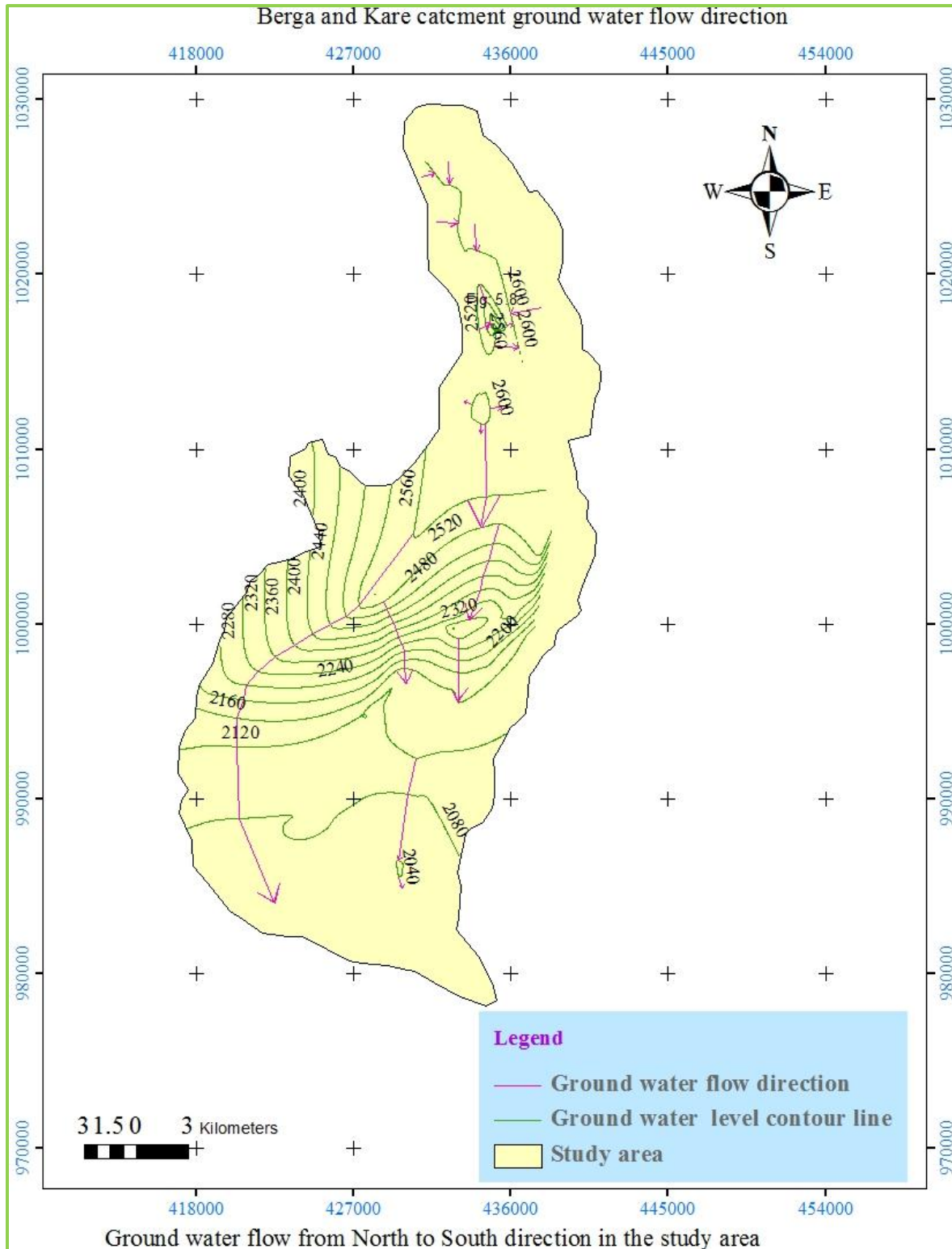


Figure 5-8 Ground water flow from North to South direction in the study area

Chapter six Hydrochemistry

6.1 General description

For most of its uses, the chemical properties of water are as important as the physical properties and available quantity. The mineral composition of the ground water reservoir, the ground water flow patterns in the basin and the length of time the water have been in contact with different rock formations influence area variations in chemical characteristics of water. In other words, the chemical composition of natural water is derived from many different sources of solutes including gases and vaporizers from the atmospheres, weathering and erosion of rocks and soils solution and precipitation reactions occurring below the surface and cultural effects resulting from the human activities. The solute taken up or precipitated and the amount present in the solution are influenced by many environmental factors, especially climate, structure and position of rock strata and biochemical effects associated with life cycle of plants and animals, both microscopic and macroscopic (Hem, 1992).

The chemical composition of surface and groundwater is generally influenced by the amount of precipitation, rate of evaporation, geology (rock type with which the water is interacting) and the presence or absence of active volcanism in that particular area. These factors combine to create diverse water types that change spatially and temporally (Cuneyt.G et al, 2002; Halcrow, 1989).

As a result of chemical and biological interaction between groundwater and geological materials through which it flows and to a slighter degree, because of contribution from atmosphere and surface water bodies groundwater contains a wide variety of dissolved inorganic chemical constituents in varies concentrations (Freeze and Cherry, 1979). Therefore, hydro chemical data are important tools to study different water samples and safely limit of their utilization for varies purposes.

The study of water chemistry gives important indication on geologic history of the enclosing rock, the velocity and direction of movement, and the presence of hidden ore bodies (Tenalem Ayenew and Tamiru Alemayehu, 2001). Two of the fundamental controls on water chemistry in drainage basins are the type of geologic material that are present and the length of time that water is in contact with those materials(Winter et al,1999).

To know the general chemistry variation (spatial variation) and the possible sources for variation (natural or manmade activities) water samples have been taken for chemical analysis and field parameters were measured at field in the catchment.

6.2 Water sampling and analysis

Samples are collected from different water sources, i.e. boreholes, springs, Shallow wells and handdug wells following the direction of River flow, from North to south to compare parameters among these sources. To analyze geochemical properties of water with in the catchment, water samples are taken from appropriate and representative sites.

Totally 13 water samples are collected from 5- boreholes, 4- handdug wells, 2-springs 1-River from middle of Berga River and 1-shallow well. But due to limitation of budget, only 4-samples, 1-spring, 2-hunddug wells, 1- shallow wells chemical laboratory analysis was done in Ethiopia Health and nutrition research institute. Additionally 5-boreholes water chemistry data analyzed by water works design and supervision enterprise, done from 2009-2010, were collected from different government organization such as water works design and supervision enterprise, Oromia water, mine and energy Bureau and west showa Water, mine and energy office.

6.3 Water type classification

In order to utilize water for different purposes, it is essential to classify water on the basis of needs. Classification, interpretation and presentation of chemically analyzed water sample results depend on the specific objective of the analysis. For instance, water used for drinking has different quality and analysis from that of agriculture and industries.

According to laboratory result of water chemistry of the study area, Analysis is made for different parameters and purpose.

The analysis is made for major cations and anions; total hardness (TH), Compere field tested data with laboratory measurements of PH, EC, TDS and Temperature have been conducted.

The accuracy of the analytical results of the chemical data was examined for analytical error prior to the interpretation. Those data within the limit of acceptable error (<5%) used for the purpose of data processing.

Reaction errors are determined as a method to assess data quality. The sum of cations equals the sum of anions in each solution. The deviation from such equality provides a way to assess the data quality. The equations were: $RE = \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}}$.

Where RE is reaction error and Σ is the summation.

Accordingly most secondary data's collected from the study area were not used for analysis as their reaction error is greater than 5%.

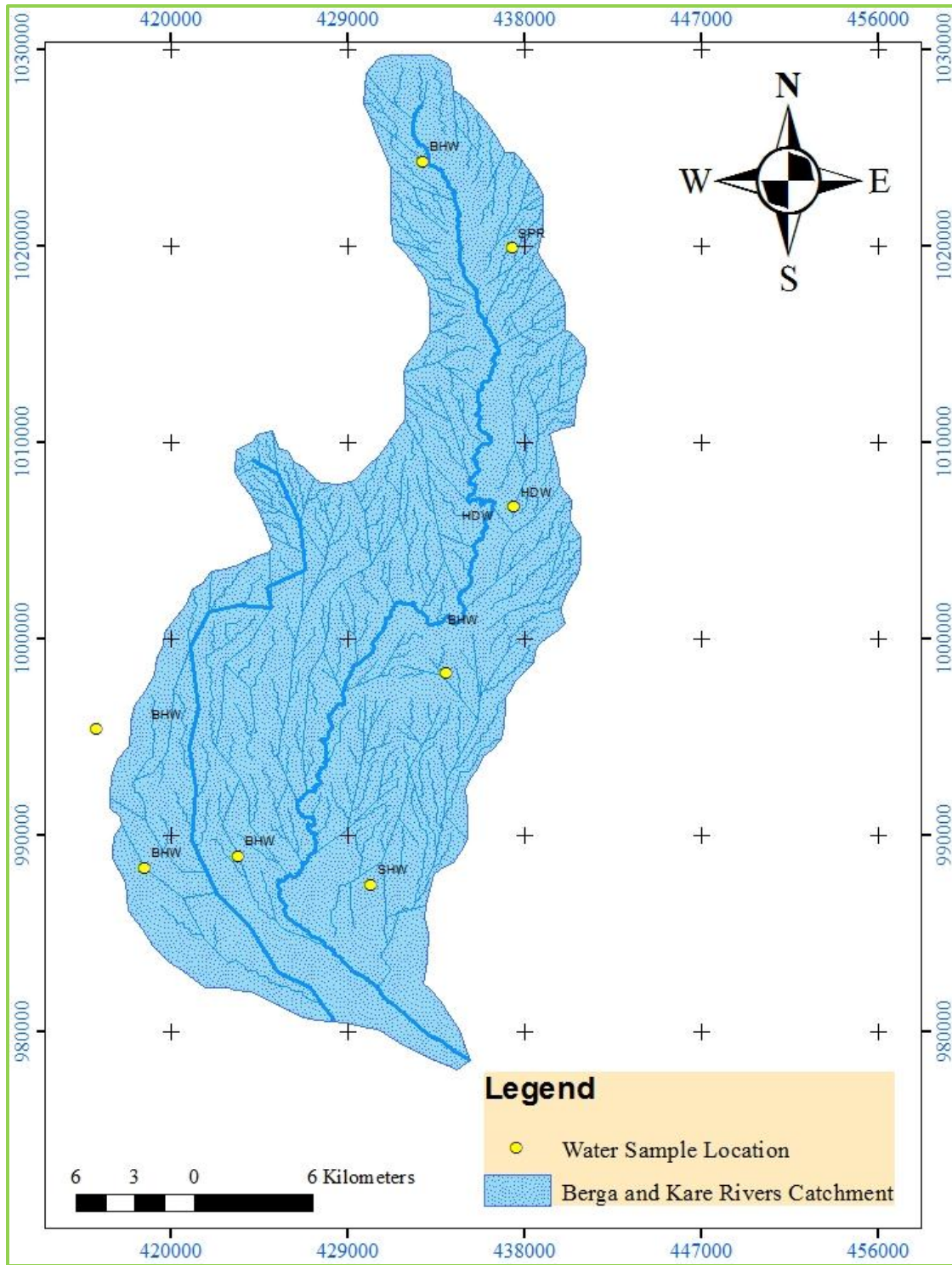


Figure 6-1 Ground water points sampling location and distribution

6.4 Organoleptic parameters

Organoleptic parameters characterize the visual values of water. They include color, odor, turbidity and taste. The existence of an objectionable situation in one of these properties of water have to be tested whether they meet some standards or not for specific water use. Except taste, other properties have been tested for the collected samples from the study area.

The presence of organic or inorganic suspended matter such as clay, silt, colloidal organic particles in water cause turbidity. Turbidity is an expression of certain light scattering and light absorbing properties of water. It has two main effects in water: because an objectionable taste or appearance to consumers, reduce the effectiveness of disinfectants by providing protection to microorganisms, WHO (1984). Its guideline value, according to WHO (1984) is 5 NTU. When samples taken from different sources in the study area compared among each other for the turbidity, it ranges from nil to 10.22 NTU. High value of turbidity is observed for Burka Gora hand dug well coordinate system (x, y and z 434550, 1025505 and 2644 respectively). This is may be due to improper scheme management problem observed during the sampling period.



Figure 6-2 Photo taken during field work sanitation problem scheme

6.5 Physicochemical parameters

The physicochemical parameters analyzed for the water samples are categorized in to two: those that have been measured both on the field and in the laboratory and those that have been only analyzed in the laboratory. For that reason the measurement of PH, Temperature (T), total dissolved solids (TDS) and Electrical conductivity (EC) are made both at the field and laboratory.

6.6 P^H

P^H is a measure of the hydrogen ion concentration of the water. The P^H of water indicates whether the water is acid or alkaline. Drinking water with a P^H of between 6.5 and 8.5 is generally considered satisfactory.

The PH value of the samples in the study area ranges from 6.27 to 8.7. The lower values measured borehole for Ejere water supply (7.06) and the higher value is sample from borehole drilled for Ilu sefara water supply (8.47). The P^H values of the water samples analyzed in the laboratory and measured on the field are mostly related with the WHO standard in the study area.

6.7 Temperature

Water temperature is an important property that determines water suitability for human use, industrial applications and aquatic ecosystem functioning. Water temperature can affect the dissolved oxygen content, an important water characteristic that strongly affects many aquatic organisms. The temperature of water is controlled primarily by climate.

A number of parameters such as turbidity, color, odor, etc. are affected by temperature directly or indirectly. Temperature also affects electrical conductivity, the rate of chemical reaction as well as the concentration of the reactants and the products, and solubility of gases in the water.

In the study area the water temperature of the samples ranges from 17c^o to 24.9c^o on the field. In general, the temperatures of the water samples show progressive increase from North to south in the direction of flow paths. This increase of temperature indicates the regional flow system in the North to south.

6.8 Total Dissolved Solids (TDS) and Electrical Conductivity (EC)

The term TDS describes all solids (usually mineral salts) that are dissolved in water. The TDS is usually measured in mg/l. Water naturally contains a number of different dissolved inorganic constituents. The major cations are calcium, magnesium, sodium and potassium: the major anions are chloride, sulfate, carbonate, and bicarbonate. These major constituents constitute the bulk of the mineral matter contributing to total dissolved solids (Fetter, 1994).

The presence of these chemical constituents gives the water ability to conduct electricity.

Thus, the electrical conductivity (EC) of water is an indirect measure of its dissolved constituents. In practice, EC is often expressed in terms of mill Siemens (ms) and micro Siemens. The TDS and the EC are in a close connection. The more salts are dissolved in the water; the higher is the value of the electric conductivity. EC does not give specific information

about the chemical species present in water, but it gives a determination of TDS, which is an acceptable indicator for water quality.

Table 6-1 Water classification based on TDS values (Tenalem Ayenew and Tamiru Alemayehu, 2001)

class	TDS (mg/l)
Fresh	0-1,000
Brackish	1000-10,000
Saline	10,000-100,000
Brine	>100,000

Table 6-2 Water classification of Berga and Kare river catchment based on TDS value

Water sample Id	TDS (mg/l) value	EC value	Water type
BHW1	211.3	325	Fresh
BHW2	288	436	Fresh
BHW3	490	781	Fresh
BHW4	354	557	Fresh
BHW5	572	945	Fresh
SPR	149.3	253	Fresh
HDW1	82.6	140	Fresh
HDW2	167.6	284	Fresh
SHW	381.7	647	Fresh

All water samples collected from the study area have a TDS value of less than 1000mg/L. Hence, they are all fresh water even though they show a progress increase along the flow path, north to south direction.

6.9 Major cations and anions

The major cations and anions that have been analyzed for the collected samples are calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, and chloride. Naturally, the total ionic concentration of cations is equal to the total ionic concentration of anions. This character which is termed as electrical neutrality is used as a check on the accuracy of chemical analysis (Tenalem Ayenew and Tamiru Alemayehu, 2001).

Table 6-3 measured values of major ions water samples from different sources (in mg/l)

Water source	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	CO ₃ ²⁻	CL ⁻	SO ₄ ²⁻
BHW1	44.1	5.52	22.0	1.2	112.5	33.6	5.4	0.12
BHW2	63.6	15.3	12.8	2.5	286.9	Nil	5.15	0.29
BHW3	12	4.8	140	12.8	368.93	Nil	48.27	5.92
BHW4	10.4	4.8	129	3.1	256.2	Nil	53.11	11.9
BHW5	9.12	7.3	216	4.9	491.17	21.12	41.86	13.4
HDW1	43.28	9.72	8.7	1.11	97.6	Nil	6.4	Nil
HDW2	20.84	3.89	4.6	1.4	73.2	Nil	1.2	Nil
SPR	36.87	7.78	10.6	1.9	146.4	Nil	2	Nil
SHW	80.16	13.62	57	4.3	366	Nil	20.79	Nil

6.9.1 Cation

In the majority of the samples the dominant cation is calcium. The concentration varies from 9.12 mg/L up to 80.16 mg/L from north to south along the flow line. The higher value of calcium is observed for sample taken from south of the study area at Bacho plain (SHW).

And the lower value is observed for sample taken from Borehole at the central of the study.

The higher calcium can be derived from the weathering of the plagioclase feldspar and pyroxene mineral groups that are the rock forming minerals of basalt. Sodium is the second highest cation in some shallow aquifer samples, concentration varies from 4.6mg/L to 57mg/L it is the highest cation in well depth from 250m-450m with concentration varies from 140mg/L to 216mg/L at the south of the study area upper Bacho plain; it is also increase along the flow line.

Another major cation is magnesium. Its value varies from 3.89mg/L to 13.62mg/L along the flow line from north to south direction.

From this ion concentration variation along the flow direction north to south, it indicates that the northern part of the study area is the recharge zone and the southern part is the discharge zone of the study area.

6.9.2 Anions

The predominant major anions in all the analyzed samples are bicarbonate. It varies from 73.2mg/L handdug well (HDW2) to 368.93 mg/L for Addis Alem town (BHW3) Most bicarbonate ions in ground water are derived from the carbon dioxide from the atmosphere, carbon dioxide in the soil, and the solution of the carbonated rocks, The high bicarbonate content in (BHW3) could be from the carbon dioxide in the soil and the shallow wells and springs in the area have more or less similar bicarbonate content.

Chloride contents are significant Decrease from recharge area to discharge area and sulfate and carbonate are lower than objectionable amount.

6.10 Other chemical parameters

Hardness might be considered to be the soap consuming property of water. Most of the effects observed with soap results from the presence of calcium and magnesium, thus hardness is usually expressed in terms of calcium carbonate and may be divided in to two types:- carbonate and non-carbonate. Carbonate hardness includes the portion of calcium (Ca) and magnesium (Mg) ions that combines with bicarbonate and the small amount of carbonate present. This hardness is called temporary hardness because it can be removed by boiling, which precipitates Ca and Mg carbonates and sulphate minerals. Non-carbonate hardness is the difference between total hardness and carbonate hardness. It is caused by the combination of calcium and magnesium ions with sulphate, chloride and nitrate ions (Tenalem Ayenew and Tamiru Alemayehu, 2001).

Total hardness (TH) is given by:-

$$TH=2.5Ca+4.1Mg$$

Hardness classification of water (Durfur and Becker, 1964; cited in Tenalem Ayenew and Tamiru Alemayehu, 2001)

Table 6-4 water hardness classification

CaCO ₃ , Hardness in mg/L	Water type
0-60	Soft
61-120	Moderate hard
121-180	Hard
>180	Very hard

Table 6-5 Berga and Kare River catchment hardness classification of water

Water source	CaCO ₃ , hardness	Water type
BHW1	133	Hard
BHW2	222.6	Very hard
BHW3	50	Soft
BHW4	46	Soft
BHW5	53.2	Soft
HDW1	148.1	Moderate hard
HDW2	68.1	Moderate hard
SPR	124.1	Hard
SHW	256.2	Very hard

The water hardness of the study area is range from soft to very hard; the shallow ground water is moderate to very hard while the deep ground water is hard to soft.

The chemical behavior of water in the catchment is totally fresh and mainly hard to very hard. The analysis shows that there is no recognized hydro chemical behavior difference from upper to lower catchment and among different water sources. This is because the infiltrated water leaves the recharge area with short time to discharge area due to undulated nature of the land and relatively higher permeability of the geologic formation.

6.11 Chemical behavior of water samples

The study of water chemistry gives important indication on geologic history of the enclosing rock, the velocity and direction of movement and the presence of hidden ore bodies. Two of the fundamental controls on water chemistry in drainage basins are the type of geologic material that are present and the length of time that water is in contact with those materials (Tenalem Ayenew and Tamiru Alemayehu, 2001). The study area is dominated by high land topography and tertiary volcanic rocks affected by high rain fall. Weathering and dissolution of these volcanic rocks (basalt, ignimbrite, and rhyolite/trachyte) releases elements in to water. The concentration in meq/l of major cations and anions from different water points analyzed in the area are plotted in the piper diagram. From the diagram five kind of water can be identified: CaHCO_3 , $\text{Ca-Na-CO}_2\text{-HCO}_3$, Ca-Na-HCO_3 , Na-HCO_3 and $\text{Na-HCO}_3\text{-CL}$ are dominate the area from shallow and deep ground water sample analyzed.

- ❖ CaHCO_3 water type in the study area: This water types are represent the shallow ground water in northern part of the study area geologically exposed Tarmabaler basalt changes from basalt and scoraceous basalt unit which contributes recharge into the upper aquifer of the study area. Spring (SPR), hand dug well (HDW1, HDW2), and borehole (BHW2) locate in the recharge area of the study area behaves CaHCO_3 water type which are originating from the basaltic aquifer and characterized by this water type.
- ❖ Ca-Na-HCO_3 water type: The deep well in the northern Ilu safera (BHW1) and the shallow well (SHP) in the southern part of the study area (Amaro) in bacho plain belong to this water type. The reason may be the active irregular of meteoric water to the aquifer system from the Encine highland area through local faults and scoria cones to the northern deep well and relatively residual time to the southern shallow well because it has high TD relatively (318.7mg/l).

- ❖ Na-HCO₃ water type: such water types belongs to all deep well in the southern part of the study area and upper part of bacho plain with in well depth interval between 350-450m. This well (BHW3, BHW4, BHW5) have aquifer system generally basalt and scoraceous basalts with intercalations of clay and paleosole layers. The Na increment at the outflow of Ca with little change in TDS reflects the dominance of cation exchange process which could be ascertained by the presence of the intercalated clay.

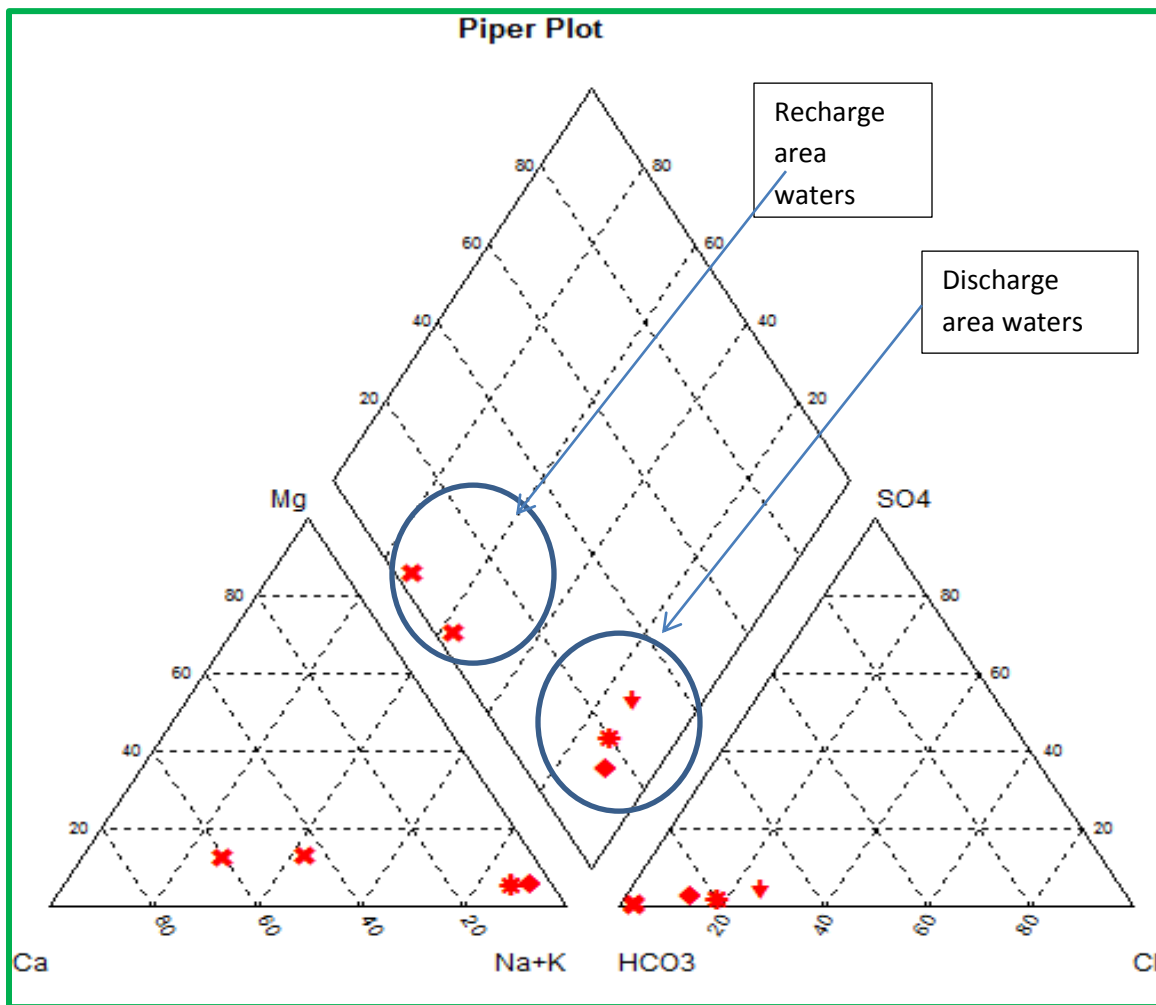


Figure 6-3 Piers diagram water type classification

6.12 Water Quality Assessment

Water quality guideline is established to protect the health of users and thus eliminate adverse effect or reduce to a minimum of water constituents harmful to health and wellbeing of the users. A guideline value represents the level or concentration of constituents that ensure visually pleasing water that does not result in any significant risk to the consumers. In this context quality refers to fitness for purpose. Water guide line for drinking purpose is established taking into consideration the socioeconomic status, availabilities of alternative water resources, geographical location (Climate condition) and nutritional condition of the people (Fetter, 1994).

One of the main objectives of hydro chemical characterization of waters of the study area is to evaluate the quality of the water resources. Therefore, in the assessment of water quality, it needs to identify the purpose for which the quality is referred to. Accordingly, water quality for drinking is different from that for irrigation and industry. The quality of water in Berga and Kare Rivers catchment is assessed for two principal purposes: drinking and agriculture.

6.13 Drinking water quality

Water qualities for purpose mentioned above are evaluated with comparison to the Standards.

Drinking water quality guidelines provide a base for decision-making:

- Approval of new water supply sources
- Watershed protection
- Disinfection of treatment plants, detection of sources of pollution
- Regulation of chemical substances
- Cleaning of water storage facilities

In this particular water quality assessment WHO and EU water quality standards has been used for comparison purpose with the water quality of the study area.

Table 6-6 Drinking water quality standard (source WHO, 2004 and EU water quality standard)

Constituents	WHO	EU	Study area
PH	7	7	6.27 to 8.7
Color (TU)	15	20	clear
TDS (mg/l)	1000	500	82.6 to 945
Total alkalinity as CaCO ₃ ,(mg/l)	500	-	60 to 437.8
Total Hardness as CaCO ₃ ,(mg/	300	-	46 to 256
Na (mg/l)	200	150	4.6 to 216
K(mg/l)	10	-	1.1 to 12.8
Ca(mg/l)	100	-	9.12 to 80.16
Mg(mg/l)	30	-	3.89 to 15.3
Cl(mg/l)	250	25	1.2 to 53.11
SO ₄ (mg/l)	250	250	Nil to 13.4
F(mg/l)	2.5	-	0.3 to 1.9
No ₃ (mg/l)	50	50	0.01 to 6.6
Mn(mg/l)	0.1	0.05	-
Fe(mg/l)	0.3	0.2	0.03 to 0.59

From the above table ground water in the study area has constituents within the range of WHO and EU water quality standards. Thus the area has fresh ground water that is very favorable for drinking purpose that could be used directly without the need for chemical purification.

6.14 Agricultural water quality

Water quality, soil type and cropping practice play a role in successful irrigation. Good water quality permits maximum yield consistent with proper soil and water management. Water quality problems in irrigation include salinity and toxicity. Excessive salinity occurs when there is an accumulation of salts in top soils. Sodium has a far reaching effect on soils (Tenalem Ayenew and Tamiru Alemayehu, 2001).

The type and concentration of salts depend on the geologic environment, the source and movement of groundwater. Weathering of primary minerals is the direct source of all soluble salts in groundwater. Sodium in the water originates from weathering of feldspars (albite), clay minerals and solution of evaporates (halite & mirabilite) (Boonstra, 1997). Groundwater salinity varies with the type and texture of sediments, solubility of minerals and contact time.

Of particular consequence is the ratio of sodium to calcium and magnesium. When sodium-rich water is applied to soil, some of the sodium is taken up by clay; the clay gives up calcium and magnesium in exchange. This reaction, called Base Exchange, alters the physical characteristics of soil and can even lead to growth retardation. Clay that takes up sodium becomes sticky and smooth when wet and has low permeability. When dry, the clay shrinks in to hard that is difficult to cultivate. Even worse, high concentrations of sodium salts can produce alkali soils in which little or no vegetation can grow. On the other hand, when the same clay carries excess calcium or magnesium ions, it tills easily and has good permeability.

If irrigation water contains calcium and magnesium ions sufficient to equal or exceed the sodium ions, enough calcium and magnesium is retained on clay particles to maintain good permeability. These waters serve well for irrigation, even though the total mineral content may be quite high. The importance of sodium led to the adoption of a method to measure the effect of sodium ions. In 1954 the United States Salinity Laboratory proposed that the sodium effect be calculated by the sodium adsorption ratio (SAR method). The SAR is calculated from the following equation:

$$SAR = \frac{Na}{\sqrt{(Ca+Ma)/2}}$$

Where sodium calcium, and magnesium are in mill equivalents per liter from the water analysis.

Table 6-7 Water classification based on SAR (Tenalem Ayenew and Tamiru Alemayehu, 2001)

Water type	Alkali hazard (SAR)
Excellent	Up to- 10
Good	10-18
Medium	18-26
Bad	>26
Very bad	

In order to evaluate water quality for irrigation from sodium hazard point of view for the study area, the parameters have been measured and calculated as shown in table 6.7.

Accordingly, all water samples show low sodium hazard, and they are almost all below 10 except BHW5 (Na-HCO₃ water type) bores having SAR equal to 24.6, which is a medium quality of irrigation water type. The quality varies from excellent to medium depend on SAR value.

Table 6-8 Irrigation water type classification

parameter	Sample code								
	BHW1	BHW2	BHW3	BHW4	BHW5	HDW1	HDW2	SHW	SPR
EC ($\mu\text{s}/\text{cm}$)	325	436	781	553	945	140	284	647	253
SAR	0.82	0.37	8.5	8.08	24.56	0.32	0.25	1.56	0.41
Water type	Exc.	Exc.	Exc.	Exc.	Medium	Exc.	Exc.	Exc.	Exc

From the irrigation point view the area is promotable both from deep ground water and shallow ground water without any treatment. But very few ground water supply irrigation schemes in the area now a day. The local peoples use traditional irrigation schemes from river in small scale. This small scale tradition irrigation from river also not covers all community in the area. It is scatter distribution in the catchment. In generally the area is not practiced irrigation schemes in well even if the area has a good ground water quality and quantity.

Chapter seven Ground water Management practice

7.1 Description of the study Woreda

The Berga and Kare River catchment is located in oromia region state administrative, west showa zone. There are two woredas that constitute in the study area: Ejere and Ada Berga woredas.

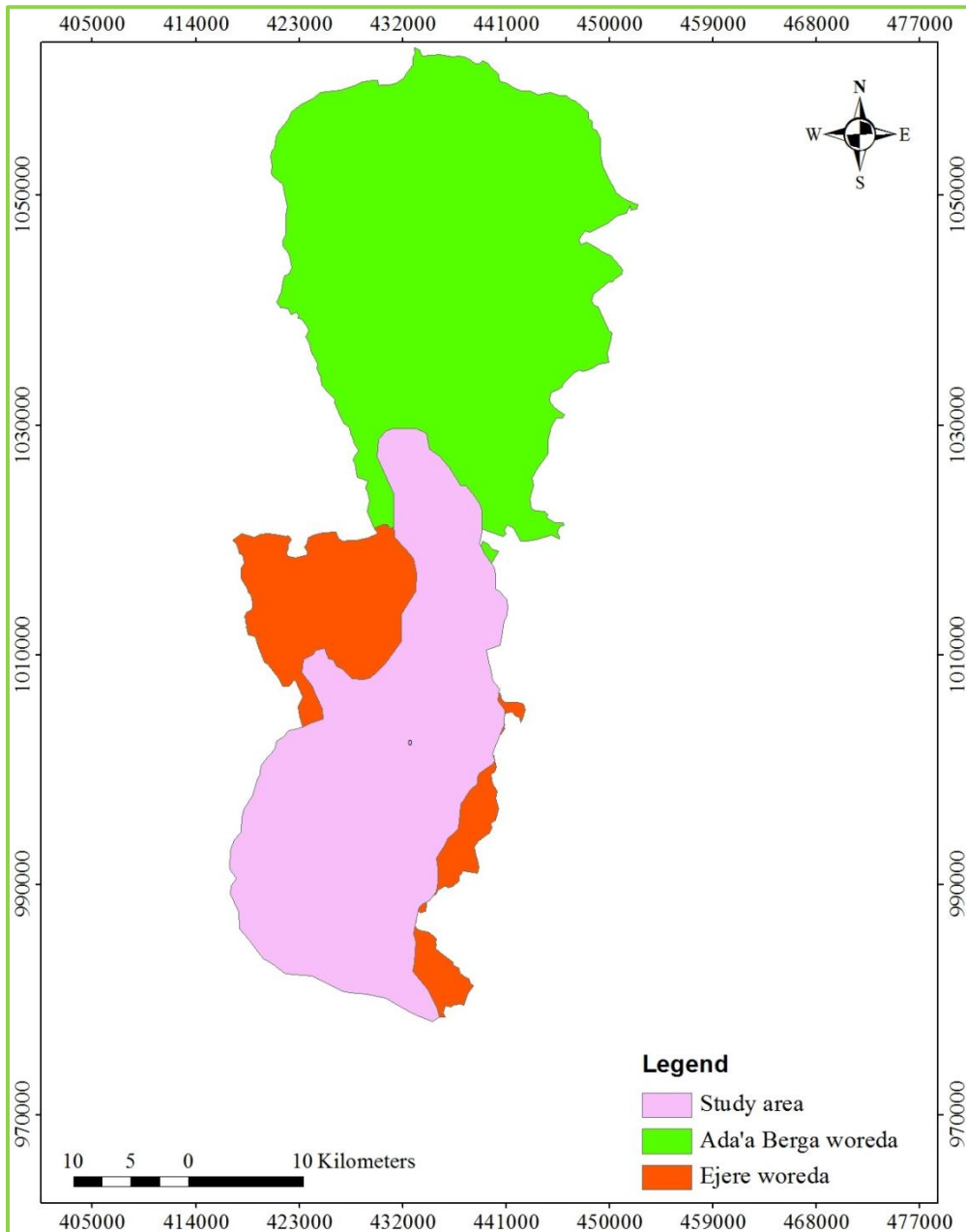


Figure7-1 woreda Location in Berga and kare catchment

7.2 Population and Demographic characteristic

According to Finance and development office of the two woredas (2012/13) estimate of population density census data from two woredas the total population is 223,098

Table 7-1 Population by sex by woredas

No	Woredas	Population 2012/13	male	female
1	Ejere	108,922	55,400	53,522
2	Ada'a Berga	114,176	57,360	56,816
Total		223,098	112,760	110,338

7.3 Socio-economic characteristics of the area

Agriculture is the mainstay of the study area economy, and it is highly dependent on rainfall. The agriculture sector in the study area dependent on traditional farming practices using backward technology, mainly by ox-plough that prevailed for thousands year without any modification. High rain fall variability and draught makes the largest part of the study area to be more vulnerable to food insecurity problems. In the study area the agriculture sub-sector is not significantly benefiting from the technologies and practices of water management and irrigation that could improve productivity and reduce vulnerability to climate variability. A small scale and traditional irrigation practice exist in scatter distribution in the catchment using surface water and ground water by agriflowera industry.

Industry in the study area is not well developed. In the urban areas are only few small scale industries and their significance in terms of economic development is very limited.

7.4 Major Findings of the Study

The house hold survey was conducted in the constitute woredas which can characterize the study area, and also representative Peasant associations (PA) were selected by woreda water office to implement household water economy analysis.

The survey may have lack of representativeness, except this limitation the overall survey findings are believed to be good and provide vital information to meet the proposed objectives.

Table 7-2 House hold interviewed

Name of woredas	Peasant association (PA)	Total house hold interviewed
Ada'a Berga	Sire Berga	23
	Maru chobot	19
	Hilu Haga	25
Ejere Woreda	Amaro	17
	Lite Mado	26
	Bolonga	13
	Worerso	16
Ejere Woreda	Kimoye	24
	Daka Bora	27

According to the household survey, the average house hold family size is about 5.2 persons. Man to women sex ratio is calculated approximately to be 1:1. Out of the total population interviewed, 13% illiterates, 7.8% Read and Write, 47.3% grade 1-8, 26.3% grade 9-10 and 5.6% are above grade 10. The community in all peasant association is from Oromo nation and they follow Protestant, Ethiopian Orthodox & a few follow wakefana.

7.5 Existing Water sources Availability

Ground water is an important source of water supply in the study area. According to the information obtained from the respondents and observation during field survey, groundwater is the major and the most reliable source of drinking water in the area. 98% of the respondents use ground water as the main source of domestic water supply. The remaining 2% uses unprotected springs. According to information gathered, the study areas have got access to safe water supply almost from ground water and unprotected spring. Except technical filter of the hand pump in ruler area and fluctuation of hydropower in the urban area there is no significant scarcity of water supply in the catchment.

According to information obtained from the respondents and physical observed during field survey, the ruler community access domestic water supply from ground with hand dug well and shallow well drilled by machine fitted hand pump of different size and type.

7.6 Groundwater use

Table 7-3 Ground water use

Ground water	Groundwater withdrawals, in percent
Domestic	97
Agriculture	3
Industry	2

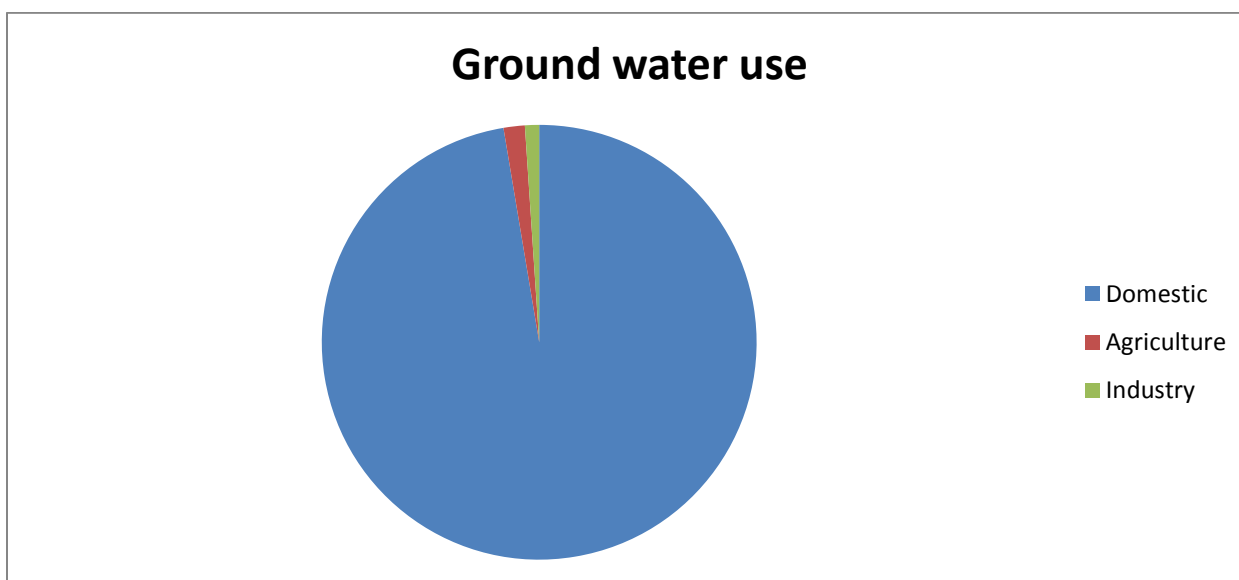


Figure 7-2 Groundwater use pattern in the study area

7.7 Water Supply Schemes

There are about 242 water points in the catchment; out of this 26 are nonfunctional. The boreholes cover (4.5%), hand dug wells (49.6%), shallow well (23%) springs on spot (11.1%), (treadle pump (7.9%) and rope and washer pump (3.7%) in the study area. Hand dug wells shallow well and springs constitute 84% of the total water supply sources in the study area. In urban areas most of the water sources are boreholes (4.5%), while in rural areas hand dug wells and springs are the main sources.

Table 7-4 Type of Water sources in the study area

Source	Function	Non function	Total
Deep well	9	2	11
Shallow Well	55	1	56
Hand dug well	103	17	120
Spring on spot	21	6	27
Rope and washer	9	-	9
Treadle pump	19	-	19
Total	216	26	242

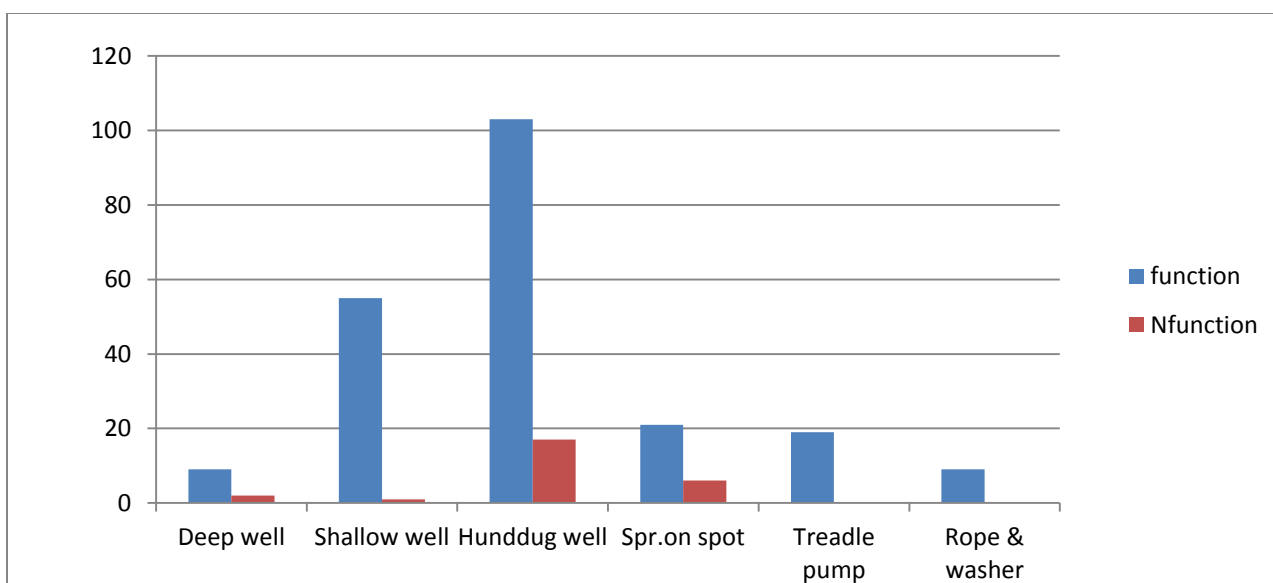


Figure 7-3 Status of Rural Water Supply Schemes by scheme

The water supply coverage of the study area is medium in the catchment, it is around 60% in average (Source: Ada'a Berga and Ejere Woreda Water sectors).

7.8 Rural Water Supply Schemes

Rural water supply schemes in the study area are characterized by: the schemes are widely distributed following the scatter of the settlement of population. Almost all each village have water supply scheme specially the Amaro village peasant associations accessed the Treadle pump at household level in their compound at bacho plain area southern part of the study area. The widely water supply scheme in the area of the catchment is handdug wells, shallow wells from shallow ground water which covers 72.7% of the total scheme in the catchment.

There are 216 functional and 26 nonfunctional water supply schemes in the rural community of the study area. Functional and nonfunctional schemes constitute 89.3% and 10.7% of the total

water supply schemes available in the rural areas of the study area. It can be seen from the table 7.3 that a significant number of the water supply schemes are out order. This is a serious problem to be taken in to consideration concerning the water supply coverage of the area. The causes of failure in water supply schemes are: construction problem, poor management of the constructed schemes, and lack of awareness at community level.



Figure 7-4 poorly manage scheme

7.9 Water Lifting Technologies

Demand for water lifting technologies in the study area for domestic is high and in a small area for industrial use is exist in area of Kimoye village by supra flower P.L.C. Appropriate water lifting technologies can reduce waste and release more water for the sectors

7.9.1 Hand pumps

Hand pumps are familiar and widely used for water supply purpose. These pumps are used pumping water from shallow ground level, which generally vary from few meters to not more than 50 meters deep. Hand pumps use different operating principles but are commonly classified in accordance with the depth from which particular pumps draw water, namely: low, intermediate and high lift respectively. The Widely used hand pumps in the study area are, Afridev and Indian mark II.

The Afridev hand pump has a lifting capacity up to 45 meters and a pumping rate capacity of 0.38l/s (adequate) for low lift, 0.19 l/s (good) for medium and 0.14 l/s (good) for high lift conditions. All the down-hole components consist of stainless steel rods and PVC riser pipes, which are resistance to corrosion.

7.9.2 Indian mark II

Afridev pump becomes unsuitable above 45 meters depth and a higher capacity hand pump must be selected. The recommended type of hand pump for use in such kind of well is the modified version of Indian mark II. In the study area all the hand dug wells manual holed down are fitted with Afridev hand pump while shallow well greater than 45 water depth is fitted with Indian mark II



Figure 7-5 hand pump type Indian mark II Afridev pump

7.9.3 Motorized pumps

There are several types of motorized pump sets that use fossil fuel or hydropower: mostly gasoline or diesel. Where the depth of bore hole or location of a spring do not allow the use of hand pumps or gravity flow respectively then it will be necessary to use motorized pumps for lifting the water to the convenient point. There are generally two types: surface and submersible types. The submersible motorized pump in the study area fitted with the deep ground water bore holes. For water supply purpose in Addis Alem town, Olenkom town, Ilu sefara village, Gabe jimata village and Ehad gabia village the pump is fitted to bore hole of different water level depth.

The surface motorized pump in the study area used to lift the surface water from river for irrigation in a few villages. No motorized surface pump fitted to pump ground water in the catchment.



Figure 7-6 Gaba jimata water supply deep ground water fitted with submersible pump

7.9.4 Rope and washer pump

Rope and washer pumps are a simple and affordable technology few people in the study area practice this technology for water lifting to domestic purpose. The pump is designed to lift water from a depth of up to 40 meters for drinking water purposes. According to Ejere woreda water sector report there are only nine Rope and washer pumps are fitted to lift up the ground water but there is no such a pump in Ada'a Berga woreda.

7.9.5 Treadle pump

The treadle pump is a low lift, high-capacity, human-powered pump. The pump can lift from shallow ground water wells up to 14 depths. The treadle pump has an important advantage over motorized pumps for small irrigation land of agricultural at household level. It is considerably less expensive to purchase and operate, needing no fuel and limited maintenance.

In the study area, Treadle pump is used in the household level to left shallow ground water for domestic purpose. The peasant association in Amaro and wereso, upper bacho plain southern part of the study area use this technology at household level.



Figure 7-7 Treadle pump used to lift shallow ground water for domestic purpose at Amaro village

7.10 Sustainability of Water Supply Systems

For a scheme to be sustainable good operation and maintenance must be fulfilling. In addition the presence of community management and water committee are crucial for a scheme to be sustainable for longer service.

Generally a scheme is sustainable if:

- ❖ repair is done on time,
- ❖ the scheme caretakers are trained,
- ❖ spare parts are available,
- ❖ community management is in place, and
- ❖ There is water committee.

7.11 Women's Capacity and Role in water use

Water supply scheme failures largely affect women, because they are most often collectors, users and managers of water in the household. In such cases, participation of women in both

development and management activities is crucial for sustainability of the scheme. In study area according to the respondent survey indicates, in the community women and girls are main water fetchers. Collecting water is not only physically stressful but also time consuming.



Figure 7-8 Human roles in water us

Women could play a major role in taking care of water supply schemes. Their participation in rural water supply schemes can reduce sustainability problems. Women are usually believed to be competent at managing finance. In some cases women are influential in deciding the location of water sources and water points. In general there appears to be no pronounced barrier or resistances to women participation in rural water supply during site location .Women are not fairly represented in water committees. According to oromia water, mine and energy bureau water committee establishing rule out of the seven committee members two and above should be women but according to the respondent, in same place they did not know what water committee mean and in other place they are simple a member, they did not engaged decision.

More attention should be given for women’s involvement in rural water supply schemes committees, there are some places in the study area that still believe that women should not be involved in such activities.

7.12 Fetching Distance

Information gathered from the respondents indicates that, the house hold members travel medium to short distance to collect water from the available water resources. The information

attained from community members, show that more than 80% of the households are located less than 1 kilometer far from the water sources similarly, less than 20% of the households walk for more than 1 kilometer to reach at the water sources. According to information gathered from community members and officials of the woreda, in some areas, people particularly those use unprotected spring specially women and children who are socially water fetchers, travel up to 3 km distance in the dry season.

Chapter eight Conclusion and Recommendation

8.1 Conclusion

- ✚ Indirect investigations from hydrography, Nature of springs, type of vegetation cover, degree of fracturing of the rocks, in addition to direct data on boreholes, geologic logs, pumping tests, hydrochemistry, etc. reveal that the subsurface water resource assessment of the study area are enormous.
- ✚ Due to undulated topographic nature of the area and high permeability of geologic formation, the infiltrated rain water has shorter residence time at recharge area.
- ✚ Regional groundwater flow system of the area is controlled by the structural and lithostratigraphic set up of the area and the main aquifer type is weathered and fractured basalt, behaves confined type at Kimoye well field and unconfined type at a relatively shallow depth.
- ✚ So far, there is no industry that can pollute both surface and ground water in the catchment, except bacterial pollution of some hand dug wells at Kerbo (HDW2) Village.
- ✚ The amount of recharge estimated over the catchment by hydrograph base flow separation software is 27.8% of the mean annual rainfall of the catchment.

8.2 Recommendation

- ✚ As most of aquifers of the catchments are confined, cone of depression may extends fast. Therefore careful well site locations are essential to minimize the likely occurrence of this interference.
- ✚ In order to understand and evaluate the aquifer behavior and groundwater potential zone precisely, additional boreholes, with evenly distribution and fully penetration should drilled in the catchment.

- ✚ Fast land cover change is occurring in converting most of the grass and shrub areas to traditional Agricultural farm. This activity reduces the amount of infiltration. Therefore, attention has to be given to water resource protection of the area.

- ✚ In order to keep continuous drinking water supply, the scheme management activity should practice in the catchment.

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Annex-1 Climatological data

Element: Monthly rain fall in mm

Region: Oromia

Station: Addis Alem

Years	Months											
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
1969	8.4	39.1	32.2	160.2	141.2	204	217.1	273.3	112.7	11.3	6.9	72.1
1970	0	3.5	80.1	76.1	88.9	156.7	222.3	145.9	124.4	38.5	0.6	15.3
1971	20.8	1.5	33.3	73.1	16.2	85.5	216.2	232.9	101.8	53.2	23.5	0
1972	3	87.3	72.6	180	49	148.7	293.3	397.7	160.5	30.5	8	0
1973	0	131	18	0.5	39	179.5	257	377	184.5	13	0	0
1974	106	63	175	185	57	200	429	353	156	21	15	0
1975	41.5	89	124	44	74.5	149.5	397.5	307	198	51	0	1.5
1976	3	0	57	79	173	226.5	233	303.5	183.5	27.5	16.5	23
1977	28	71.5	60.8	152.5	70.8	116.2	215.5	260.5	156.5	1.5	17.5	0
1978	0	25	132.8	11.1	110.5	97	241.2	281.6	150.6	2	0	0
1979	0	8.2	25.5	121	52	150.9	274.9	288.6	182.9	35.1	0	0
1980	20.5	4.1	50.8	54.5	89.5	96.8	266.1	295.9	104.2	17.8	19.3	2.5
1981	61.3	28.5	98	22	115.6	134	241.5	223.5	176.2	206	186.1	9
1982	7	56	49.5	39.5	41	163.5	315.1	231.2	232.1	75.5	2	25.5
1983	71.4	100	94.5	69	61	137	277	296	184.5	22	0	38
1984	33	45	62	69	69	168	215	236	138.4	1.7	8.1	0
1985	0	87.5	141	98.2	75.6	88	245.6	267	267	12	9	47
1986	52	49	42.5	65.5	70.9	65.5	228	256	59	64	112	40
1987	2.5	0	32	12	138	157.6	157.4	150.5	109.5	3	8.1	8
1988	10	0	8	59.2	50	98.1	170	168.5	86.9	61.1	12	0
1989	2.5	64.3	105	89	148	138	193	179	121	16	3	4.5
1990	78	44.4	106	52	127	89	129	122	88	13	0	5.5
1991	11	35.5	9	55	13.9	117	182	242	127	21	0	0
1992	32	61	28	104	38.9	126.2	250.2	256	210	10.5	0	24
1993	9.6	131.6	55	55.8	105.1	111.5	187.6	342.8	196	13	0	7
1994	0	79.8	102.6	43.9	16.8	144.6	370.4	350.8	193.6	0	0	24.1
1995	41	50.7	72.4	85.5	33.7	75.1	323.1	385.4	234.3	36.3	5.4	8.2
1996	10.2	12.5	14.4	116.8	88.9	168.6	359.7	367.3	168.1	44.3	0	0
1997	0	39.5	47.1	144.9	94.5	245.1	393.5	352.3	136.8	6.4	0	15.6
1998	0	7.9	129.5	70.1	160.4	163.2	371.9	326.6	123	6.2	0	2.2
1999	23.5	0	17.6	65.9	23.7	88.1	243.1	164.1	86.1	58.8	82.2	0.5
2000	53.2	86.5	107.4	67.3	101.1	198.1	289.5	251	154	53.9	13.9	0
2001	29.5	3.3	28.6	13.5	72.6	197.5	255	299.8	46.8	125.6	0	0

2002	0	0	12.5	103.1	135.4	168.1	266.6	238.1	186.8	28.4	17.4	29.2
2003	0	0	169.4	28.2	124.3	233.9	309.7	265	43.3	21.4	0	0
2004	48.6	83.8	77.8	26.4	35	174.5	333.1	275.3	38.8	0	0	34.9
2005	24.8	19.8	173.2	96.2	2.1	49.5	156	224.4	87.7	0	8.8	22.2
2006	0.0	0	12.5	4.2	16.7	168.1	266.6	238.2	186.8	33.6	17.4	29.2
2007	0.0	0	169.4	28.2	23.8	233.9	309.7	265	43.3	21.4	0	0
2008	51.6	84.1	77.8	26.4	35	174.5	333.1	264.6	38.8	0	0	62.4
2009	0.0	65.8	109.6	84.1	0	173.1	226	232.1	165.3	11	6.6	4
2010	17.5	27.6	70.5	140.6	62.9	143.1	190.4	212.5	172.5	33.6	1.3	0
2011	14.2	15.2	148.2	45.1	96.9	90.4	325.5	224	99	21.9	12.7	0
2012	0.0	83.5	101	61.1	83.2	148.9	334.3	265.4	135.5		0	9.8
2013	12.1	59.3	120.1	94.9	123.4	170.1	237.3	204.3	75	23.1	0	0

Element: Monthly rain fall in mm

Region: Oromia

Station: Echini

Years	Months											
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1989	4.5	127.4	101.1	107.2	94.7	115.9	147.5	85.7	123.5	3.3	3.5	3.5
1991	60.9	0.1	95.1	87	233.2	218.1	294.6	387.6	270.9	5	112.9	0
1992	28.1	95.2	0	135.6	102.7	253.6	469.3	493.1	174.8	46.5	57.7	35.3
1993	141.9	14.6	0	0	23.6	185	381.2	250.9	44.7	123.9	21.9	27.2
1994	0	19.3	45.6	32.9	58	167.3	257	204.5	177.7	13.2	5.7	102.1
1995	28	15.8	0	84.1	54.4	173.4	330.8	269.7	115.9	41	9.5	0
1996	10.4	2.4	155.8	190.5	35.4	72.1	366	221.2	52.4	0	0	0
1997	0	14.6	75.8	45.2	108.2	93.1	248	294.4	104.7	105.9	105.6	10.5
1998	8.5	52	71	97.8	253.6	119.1	312.7	338.9	140.6	27.6	45.7	4.3
1999	3.6	24.3	234	95.2	164.4	124	161	207.7	68.5	17.6	0	0
2000	38.9	105	14.4	81.3	19.2	163.4	254.4	254.4	358	121.1	54.9	0
2001	48.4	46	103	24.9	26.1	116.2	316.8	265.1	108.9	43.5	8.4	29.8
2002	57.3	48.2	64.7	143.5	75.5	150.8	207.6	267.1	142.6	69.2	50.4	7
2003	1.9	53	31.6	200.6	79.3	146.3	270.3	235.7	269.6	70	1.5	5.7
2004	6.8	8.1	100.9	34.2	70.4	231.2	330.3	222.7	148.7	12.7	11.6	0
2005	82.9	21.8	168.6	93.8	99	191.7	310.5	341.3	122.2	21.9	37.1	3.8
2006	49.3	0	25.6	100	89	123.3	306.1	218.1	98.7	151.2	101.4	16.1
2007	46	19.4	66.2	18.4	119.5	195	348.2	304.4	170	113	13	0
2008	16.7	9.3	22.6	22.5	41	90.4	274.7	319.1	88.8	136.5	1.3	1.8
2009	0	0	26.1	182.2	77.7	122.8	346.3	263.1	111.9	55.8	62.5	4.5
2010	9.9	38.5	195	48.4	126.1	171.1	308.9	207	121.2	38.5	3.4	8.6

2011	62.8	5.5	121.1	32	20.6	163.1	222	305.1	154.2	0	0	53.2
2012	61.1	95.1	140.1	235.2	9.1	174.3	308.2	320.9	158.2	10.1	14.5	29.6
2013	41.1	25.3	29.9	71.2	0	136.5	253.5	296	196.4	37.7	1.7	63.9

Element: Monthly rain fall in mm

Region: oromia

Station: Holeta

Years	Months											
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
1986	17	41.3	50.1	0	70.9	84.6	152.1	107.6	184.3	29.9	45.8	31.7
1987	45.3	21.2	81	88	62.1	163.7	241	232.3	110.9	25.8	1.2	0
1988	0	22.5	117.7	111.7	34.9	56.1	366.5	258.1	188.8	3.6	0.5	15.4
1989	43.4	58.7	84.7	120.3	53.7	84.9	250.9	284.5	124.6	42.2	46.7	30.3
1990	19.9	49.4	120.4	126.3	219.1	87.5	241.2	284.1	101.9	23.8	3.9	22.7
1991	0	0	41.8	8.5	141.6	178.5	260.5	221.8	106.1	0	0.6	13.1
1992	15.2	0	47.7	62.1	48.5	45.6	257.3	281.9	105.1	21.1	4.1	0
1993	0	51.2	88	139.1	89	157.9	243.9	279.4	144	11.9	0	0
1994	2.4	77.3	112.1	82.4	137	86.5	182.1	261.8	112.9	19	1.4	27.4
1995	62.6	8.5	96.1	58.4	55.4	183.8	249.8	226.6	120.7	5.3	1.4	2.3
1996	0	84.6	41.9	123.8	81.3	91.6	197.1	262.7	82.1	15.5	0	34
1997	0	2.3	86.2	45.9	29.8	107.3	216.4	203.3	149.7	0	34.8	0
1998	18.2	83.6	3.8	127	60.3	103.1	218.1	276.1	214.3	27.4	0	0
1999	57.4	34.8	58.8	95	34.6	115.4	190.9	312.6	112.1	36.3	0.6	7.8
2000	23.9	74.8	118	21.3	115.4	89.9	232.1	229	112.5	2.6	0.3	5.8
2001	0.5	162.5	34.8	96.4	55.5	131.8	262.4	338.2	155.5	0	0	0.9
2002	7.1	86.9	78	69.8	8.3	74.9	240.7	279.3	117.5	3	0.3	21.6
2003	10.3	78.7	7.8	90.1	21.1	107.4	291.6	283.9	239.9	31.9	0	0.2
2004	15.3	0	21.1	95.4	13.5	131	233.5	193.2	42.5	53.5	23.6	2.1
2005	54.6	42.3	25.7	65.7	80.4	141.5	342.1	238.1	168.3	67.4	0.8	0
2006	76.3	4.6	34	16.6	50.6	98.9	272.8	306.8	88.9	65.4	0	0
2007	0	0	12.5	123.8	52	89.9	187.1	260.6	120.7	9.5	38.9	30.4
2008	7.9	10.6	130.7	48.6	100.6	175.5	301.6	162.1	103.2	24.2	0	0.1
2009	72.6	25.7	56.8	37.1	48.9	123.2	273.1	194	77.4	0	0	15.7
2010	17.5	11.3	33.3	84.2	13.6	117.1	194	237.2	101.4	10	0	8.4
2011	12.7	0.8	42.5	155.1	27	121.4	204	226.6	119.7	3.6	0.7	0
2012	22	4.5	61.7	49.1	94.4	81.8	253.9	187.5	130.7	31.5	3.8	0
2013	21.1	74.8	118	21.3	37.2	89.9	232.1	229	172.5	2.6	0.3	5.8

Element: Monthly rain fall in mm

Region: oromia

Station: Olenkom

Years	Months											No v	Dec
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov		
1984	3	5.8	52.6	76.4	13.6	122. 7	279. 9	327.4	118. 2	1.2	0	39. 2	
1985	25. 4	47.2	129. 8	31.8	30.6	0	173	251	113	0.6	0	21. 1	
1986	0	23.3	48.2	14	56.8	114. 3	217	220.8	77.8	102. 1	1.1	11. 3	
1987	69. 6	3.4	0	30.3	101. 8	129. 9	214. 5	217	105. 8	48.9	0	35. 5	
1988	0	0	135. 7	102. 1	147. 4	220. 1	427. 7	316.7	114. 7	0	15. 5	0	
1989	25. 4	136. 2	38.6	413. 6	338. 4	216. 1	525. 8	1089	295. 6	52.4	0	0	
1990	2.6	24.4	109. 6	28.8	22	101. 9	207. 6	243.5	120. 5	16.3	0	0	
1991	0	157. 9	18.6	115. 8	33.5	74.3	245. 6	220.5	139. 2	23.8	4.2	0	
1992	3.3	203. 9	102. 2	355. 5	19.4	109. 8	305. 1	550.4	213. 3	19	0	2.1	
1993	0.4	92.5	49.6	72.2	6.1	65.4	227. 9	236.6	114. 2	5.8	0	17. 6	
1994	0	149. 6	74.5	79.1	30.4	101. 7	251. 1	210.6	81.3	11.8	0	0	
1995	0	53.1	140. 3	3.1	34.7	96.9	221. 9	261.8	129. 3	1.8	0	18. 3	
1996	43. 7	60.1	61.3	87.1	76.4	124. 3	122. 8	235.4	89.5	56.3	4.6	1.5	
1997	5.1	100. 3	0	149. 9	100. 1	92.9	234. 7	288.8	97.3	22	0	2.5	
1998	0	0	33.7	36.8	28.4	197. 8	185. 4	241.6	128. 8	0	13. 3	0	
1999	53. 3	2.3	99.8	95	71.9	113. 2	219. 3	208.3	72.5	3.6	1.9	0	
2000	89. 8	52.4	29.7	70.6	68.2	135. 7	310. 2	232.1	87.2	64.4	0	0	
2001	29. 3	21.1	80.6	153. 7	48	158	229. 8	267.4	84.3	0	0.2	9.6	
2002	3.4	33.7	58.4	143. 3	0	88.1	218. 1	318.6	150	36.8	0	7.9	
2003	3.2	161. 1	60.4	144. 5	25.2	48.3	204. 2	413.4	143	46.1	2.1	0	
2004	11. 7	52.1	11.6	168. 3	91.5	157. 2	209. 5	291.5	190. 1	24.1	0	0	

2005	0	81.3	73.3	140.3	95.9	78.2	165.1	256.9	97	0	0	28.6
2006	20.5	5.8	126.2	95.4	128.1	289.7	346.3	312.7	211.4	0.2	0.4	0
2007	29.1	0	22.1	66.8	44.8	128	257	160.7	94.7	58.6	15.3	0
2008	66.6	40	43.8	99.8	197.7	153.4	270.7	236.8	173.4	139.4	0	0
2009	4.4	0	35	17.8	30.5	104.6	294	270.5	62.8	127.1	0	0
2010	0	0	17.6	109.7	95.2	102.1	192.9	221.9	157.5	19.6	7.5	0
2011	0	10.3	165.3	14.8	106.7	163	274.4	179.1	107.3	10.6	0	0
2012	30.6	25.9	79.4	36.6	49.6	109	213.9	233.6	72.6	0.5	0	32.8
2013	4.8	34.1	48.9	121.9	33	128	226.4	238.4	130.2	4.6	0	33.3

Element: Temperature Max

Region: oromia

Station: Addis Alem

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	26	28.2	27.5	27.5	25.2	23.9	21.6	21.3	20.3	19.8	24.1	25.6
2001	24	25.5	24.7	23.6	23.9	23.3	21.9	21.7	23.5	24.4	24.3	24.4
2001	24	25.5	24.7	23.6	23.9	23.3	21.9	21.7	23.5	24.4	24.3	24.4
2002	25	24.8	24.9	26.9	28.2	26	23.1	21.8	23.4	24.2	24.9	23.9
2003	25	24.6	26.2	26.1	27.8	23.3	20.7	20.8	22.3	25.6	26.1	25.7
2004	27	26.4	27.1	25.2	27	23.8	21.3	21.5	22.3	23.8	24.8	25.6
2005	25	27.8	26.5	25.2	24.5	23.7	21.3	22.1	22.8	24.8	23.5	25.4
2006	26	26.6	25.2	24.5	25	24.2	21.8	20.2	21.9	24.3	24.6	24.2
2007	25	25.1	26.2	24	25.4	22.9	21.2	20.4	22.5	24.4	24.8	24.4
2008	26	26.5	26.5	27.3	25.5	22.5	21.4	20.5	22.7	23.1	25.3	24.3
2009	24	25.8	26.7	26.5	26.9	21.9	21.3	22.5	22.3	24.1	25.1	24.4
2010	24	26.1	26.4	25.9	26.3	27.7	25.6	22.5	21.8	24.6	21.8	25.2
2011	25	27.5	25.6	27.7	26.7	27.7	22.6	22.5	22.7	24.6	21.8	24.9
2012	25	25.9	25.7	25.8	25.1	23.9	21.4	21.5	22.4	25.7	25.5	25
2013	26	28.2	27.4	27.5	25.1	23.9	21.6	21.3	22.1	25.6	26.3	24

Element: Temperature Min

Region; oromia

Station; Addis Alem

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	8.4	9.2	10.2	10.4	11.6	9.6	11	9.7	10.2	11.3	6.4	5.2
2001	4.5	5.2	7.3	7.5	7.5	9.4	9.5	9.5	9.7	7.8	5.7	4.7
2002	5.7	6.3	7	6.9	7.6	9.3	9.3	10.3	8.6	7.7	5.6	5.5
2003	7	7.3	7.3	8.6	9.6	9.2	9.9	9.5	7.6	6.4	6.1	8.7
2004	5.7	7.3	9.3	9.2	9.7	9.5	9.8	10.6	11.1	12.7	15.1	15.5
2005	13.5	12.6	13.8	12.8	14.9	12	9.8	10.5	12.8	12.4	13.1	10.5
2006	11.3	14.1	13.7	12.8	13.5	11.9	10.2	11.3	12.9	12.3	8.2	2
2007	5.8	10.3	10.7	11.7	10.6	10.6	11.2	11.1	10.3	12.6	7.7	7.8
2008	8.6	10.2	10.1	11	10.9	10.7	11.3	11.1	10.5	7.1	6.4	4.9
2009	7.6	7.8	8.8	10.6	11.4	11.2	10.1	10.8	10.3	8.8	7.6	9.2
2010	8.3	8.3	9.2	11.2	10.6	14.7	13.9	10.9	7	7.7	7	8.5
2011	8.4	9.2	10.2	10.4	11.6	13.5	11	10.5	8.6	6.9	8.1	8.6
2012	7.8	10.6	10.1	10.7	12	10.5	11.3	11.2	10.4	7.7	6.7	6.7
2013	6.9	7.6	10.2	11.3	10.9	11	9.8	10.5	11.6	9.2	7.8	8.2

Element: Temperature Max

Region: Oromia

Station: Holeta

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993	19.8	21.6	22.5	20.6	22.5	21.7	18.6	17.9	19.3	19.5	24.1	25.6
1994	18.8	21.1	20.6	20.5	22.2	21.8	18.5	17.8	18.4	19.3	24.3	24.4
1995	8.2	21.7	22	21.1	21.7	20.9	18.9	18	18.7	19.3	24.3	24.4
1996	19.2	20.3	22.2	21.5	21.5	20.6	19	18.1	19.1	19.4	24.9	23.9
1997	19.3	21.3	20.4	22.1	21.8	23.1	19.1	18.3	18.4	19.4	26.1	25.7
1998	19.7	20.8	22	21.6	22.8	23.4	18.7	18.3	19.5	18.7	24.8	25.6
1999	20.1	21.7	22	21.9	21.3	22.6	18.7	18.5	19.7	19.3	23.5	25.4
2000	19.9	19.9	19.5	20.3	20.7	21.7	18.7	18.5	18.7	19.5	24.6	24.2
2001	25.2	8.7	11	24.1	22.3	22.4	20.1	20.3	21.5	23.2	24.8	24.4
2002	26.7	28.1	26.8	25.9	26.4	23.1	21.3	21.2	22.9	25.8	25.3	24.3
2003	26.3	26.8	27.2	27.1	25.4	23.7	21.3	21.9	23.9	26.7	25.1	24.4
2004	25.9	27.8	29.3	27.1	26.1	23.6	21.4	21.4	22.5	24.2	21.8	25.2
2005	26.5	27.9	25.9	28.4	26.2	22.5	21.1	21.2	23.5	25.2	21.8	24.9
2006	26.6	27.9	29.4	28.4	28.2	26.3	22.3	21.8	23.8	24.9	25.5	25
2007	26.8	27.7	29.6	28.2	25.9	23.2	20.9	21.1	23.4	25.1	26.3	24
2008	26.9	28	27.1	28	27.8	23.6	22.4	21.7	23.6	26.3	24.8	25.1
2009	27.2	28.7	28.1	26.7	28.8	24.1	20.6	21.3	22.4	25.4	25.9	26.5
2010	26.1	27.7	29.2	27.8	27	23.1	21.5	21.4	22.3	25	24.1	25.8
2011	26.9	26.4	28.3	28.4	26	23.4	21.3	22.1	23.1	25.3	24.3	26.1
2012	26.6	27.2	27.8	26.5	27.8	23.1	21.4	21.9	22.7	25.6	25.4	27.5

2013	27.4	28.5	27.3	28.9	26.8	23.5	22.2	21.5	22.8	25.9	25.4	25.9
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Element: Temperature Min

Region: Oromia

Station: Holeta

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993	8.1	8.7	11	11.5	11.6	10.8	10.5	10.5	10.2	9.1	8.4	5.2
1994	8	7.2	9.4	10.5	11.8	10.6	10.6	10.5	10.1	8.5	4.5	4.7
1995	7.6	9.7	10.3	11	11.9	11	10.7	10.5	10.2	9.6	5.7	5.5
1996	8	7.3	9.2	10.4	11.5	10.7	10	10.3	10.3	8.2	7	8.7
1997	6.7	8.2	9.7	11.4	11.5	11.3	10.6	10.5	10.1	7.9	5.7	15.5
1998	7.5	9.2	11	10.7	11	11.4	10.7	10.7	10.2	8.8	13.5	10.5
1999	6.5	8.7	11	10.2	11	11.2	10.2	10.7	10.8	9.2	11.3	2
2000	7.1	9.4	9.2	9.9	10.4	11.3	10.5	12.4	10.2	9	5.8	7.8
2001	9.2	14.3	13.8	15.1	13	12.6	12.1	13.2	11.5	11.8	8.6	4.9
2002	13	15	15	14.9	14.7	13.7	13.1	13.4	12.5	13.1	7.6	9.2
2003	13	14.3	15	14.4	12.7	13.1	12.2	12.8	11.8	13	8.3	8.5
2004	13	14.8	15.1	14	12.8	12.3	13.2	13.2	12.5	12.9	8.4	8.6
2005	14	14.1	12.8	12.5	12.6	12.7	12.9	12.9	11.6	12.7	7.8	6.7
2006	13	14.8	14.7	12.7	12.1	12.8	12.9	13.3	12.5	13	6.9	8.2
2007	13	14.6	15.3	14.5	13.3	13.5	12.9	13.2	12.5	12.3	6.4	10.3
2008	14	14.1	14.6	14.7	13.2	12.9	13.1	13	12.5	12.6	5.7	10.2
2009	14	11.5	13.1	14.3	12.7	12.3	12.4	12.7	12.6	12.3	5.6	7.8
2010	14	14.8	14.6	15.4	14.1	13.1	13.2	13.2	13.2	12.4	6.1	8.3
2011	14	28.1	14	14.2	13	12.6	13.3	13	12.3	13.3	15.1	9.2
2012	14	13.8	14.6	14.7	13.8	13.6	13.1	13.1	12.5	13	8.1	10.6
2013	13	14	15.2	14.4	13.9	13.1	12.8	12.8	12.2	12.6	6.7	7.6

Element: Temperature Max

Region: oromia

Station: Echini

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	20.6	24.2	23.8	23.2	21.3	19	17.5	16.9	19	18.5	18.7	19.5
1988	20.5	23.1	22.1	22.3	20.5	19	17.2	16.9	18.1	18.1	18.9	19.6
1989	19.6	21.5	19.3	21.2	20.4	18	16.6	16.1	18.5	19.2	20	21
1990	19.6	21.8	19.9	21	22.3	20	18.8	17.3	17.7	18.7	19.5	20.6
1991	18.3	20.5	19.8	19.7	21.3	21	19.6	19.2	18.7	18.3	18.3	18.5
1992	19.1	19.5	20.3	19.8	19.7	21	19.4	18.9	18.4	18.5	19.8	19.4

1993	20	19.7	21	19.1	19.7	20	19.1	17.7	18.2	18.3	19	19.1
1994	20	19.6	21.4	19.1	20.2	18	15.9	16.6	17.7	18.2	19.7	19.3
1995	21.4	20	21.4	20.3	19.3	19	16	17	17.2	19	19.5	19.4
1996	21.3	20.3	20.7	20.4	20	19	17.1	17.1	17.8	19.2	19.3	19.3
1997	21.6	22	20.5	21.4	21.1	20	17.9	17.5	18.4	19.3	19.7	19.2
1998	21.6	24.1	23.8	23.2	21.3	19	17.5	16.9	18.7	19.2	19.5	20.1
1999	21.9	23.6	25	23.8	21.4	20	17.8	17.6	19.1	19.9	19.2	20.6
2000	20.9	23.8	23.2	24.5	24	24	21.4	21.5	21.4	23.8	23.6	23.1
2001	21.2	23.4	24.8	21.9	22.7	21	18.1	17.2	18.7	19.8	19.6	20.2
2002	22.4	23.1	21.4	23.3	22.1	19	18.1	17.9	19.4	20.7	20.3	21.7
2003	23.1	23	24.3	22.9	23.2	20	17.4	17.5	18.5	19.6	20.4	20.9
2004	9.7	25	24.9	25.5	23	21	17.4	17	19.1	19.4	20.3	21
2005	22.8	24.2	23.5	23.4	25.7	21	17.6	17.8	18.9	20.8	21.6	21.7
2006	22.2	23.8	23	23.9	25.1	21	17.2	18.3	19.5	20.7	22.1	21.5
2007	22.6	23.9	23.4	23.3	22.3	21	17.7	18.6	19.4	20.6	20.8	21.4
2008	21.7	24.2	23.4	22.9	22.7	21	18.3	17.7	18.7	20.7	20.2	20.3
2009	23.7	24.1	23.8	22.4	24.2	20	18.2	17.8	18.8	20.6	21	20.6
2010	22.1	25.1	25.1	23.9	24.6	21	17.9	18	18.8	20.8	21.2	20.8
2011	23.5	23.4	24.3	24.2	24.8	22	17.6	18.2	19.6	20.4	21.7	20.9
2012	22.7	24.3	23.1	24.3	22.6	21	18.8	18.6	19.7	21.5	21.1	21.5
2013	21.2	23.5	21.4	21.9	20.2	18	15.9	16.6	17.7	18.2	19.8	19.3

Element: Temperature Min

Region: oromia

Station: Echini

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	10.4	11	10.7	11.7	11.2	11.3	10.3	10.4	10.5	10.1	10.2	10.1
1988	10.5	11.8	12.4	12.5	12.4	11.2	11	10.7	10.6	10.2	10.3	9.9
1989	10.3	10.1	11.2	11.4	11.6	9.8	9	9.1	9.3	8.9	8.9	9.5
1990	10.4	11.4	11.4	11.9	11.8	10.2	10.2	10.8	10.1	9.8	9.6	9.9
1991	10.6	11.3	12.9	12.6	12	10.8	10.2	10.5	10.9	10.9	10.2	10.8
1992	10.7	11.4	11.3	11.7	13.2	9.9	9.6	10.1	9.8	9.7	9.4	9.2
1993	10.8	11.6	11.2	11.6	12.7	10.4	9.9	9.8	9.7	10.2	9.9	10.3
1994	11.1	11.1	12.2	11.6	12.1	11	10.2	10	10.4	10.2	10	10.4
1995	10.9	12.2	12.1	12.4	12.2	10.8	10.9	10.8	10.7	10.8	10.3	10.4
1996	6.2	3.5	7.7	12.3	12.2	11.3	10.7	10.7	10.6	10.3	10.1	9.6
1997	3	11.1	11.8	12	12.5	10.6	10.3	10.1	9.7	9.9	10	10.2
1998	10.2	12.1	12.5	12.7	12.5	12	11.2	11.1	11.3	10.8	10.2	11.3
1999	10.6	9.4	9	9.9	9.9	9.1	9.4	9.5	8.2	9.3	6.2	5.8
2000	6.5	8.2	8.7	9.5	9.5	8	7.4	7.4	7.2	7	6.7	6.8

2001	7.6	8.1	8.3	9	9.1	8.1	8.4	8.6	7.4	7.2	6.9	7.5
2002	7.4	9	8.7	8.8	9.5	8.2	8.3	7.6	7.7	7.1	7.1	8.1
2003	8.7	8.7	9	9.2	9.8	8.9	9.1	9.1	9	8.9	8.5	8.2
2004	8.7	9	9	9	8.9	9.5	9.5	9.7	9.1	8.6	8.9	8.9
2005	8.6	9	9.7	9.8	9.3	9	8.6	8.6	8	8.6	8.6	8.6
2006	8.3	9.2	9.9	9.7	9.6	8.9	9	8.6	8.2	8.3	8.4	8.7
2007	8.2	9.6	10	9.3	9.1	8.7	9.2	8.6	8	8.1	7.3	7.8
2008	8.2	9.3	9.9	10	9.6	8.7	8.6	8.4	8.3	7.2	7.1	7.5
2009	8.3	9.2	9.7	10.3	9.3	8.6	8.5	8.2	8	7.6	7.2	7.7
2010	8.2	9.4	9.7	10	9.6	8.3	8.2	8.1	8.5	7.8	7.1	7.6
2011		9.8	9.4	10.2		9.1	8.7	8.9	8.3	7.8	7.5	7.5
2012	7.3	8.2	9.2	9.4	9.4	8.6	8.1	8.5	8.3	7.4	7.2	7.4
2013	8.4	8.4	9	9.4	9.1	8.8	8	8.3	8.1	7.3	7.1	7.6

Element: Temperature Max

Region: oromia

Station: Olenkom

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993	27.4	30.3	30	28.8	30.6	28.7	25.2	25	25.4	26.8	27.9	26.7
1994	27.6	29.5	29.7	27.6	29.8	27.6	25.6	26.2	26	26	28.1	27.9
1995	26.6	29.8	29.5	28.2	29.3	29.3	25.4	26.1	25.7	27.5	27.3	27
1996	28.5	30.1	31	29.5	30	28	25.4	25.3	26.6	26.5	27.2	28
1997	28.7	29.2	29.7	28.9	27	27.6	24	23.2	24.7	25.4	26.4	26.9
1998	28.3	28.4	27	28.6	27.9	25.6	24.3	24	25.7	26.8	27	26.8
1999	28.4	30.6	29.8	29.5	28	27.9	24.5	25.4	26.1	27.1	27	27.1
2000	28.6	28.6	28.3	29.2	30.7	27.8	26.7	25.2	26.2	28	28.1	28
2001	29.3	28.6	30.1	31.2	29.5	27.8	25.4	25.6	26.7	28.4	26.7	25.6
2002	30.6	29.4	31	30.2	29.7	27.2	25.4	24.6	26.4	27.9	27.4	25.6
2003	32.1	28.9	28.3	28.6	29.1	28.1	25.7	24.8	26.5	27.3	27.6	26.4
2004	29.1	28.1	29.3	28.5	29.3	27.9	26.1	24.5	26.4	27.4	27.6	26.7
2005	29.4	28.8	30.4	29.6	28.5	27.1	26.5	25.1	26.2	26.6	26.2	27.5
2006	28.1	24.2	23.8	23.2	21.3	19.2	17.5	16.9	19	22.7	21.3	23.8
2007	20.5	23.5	23.5	22.6	21.4	19.5	17.2	16.9	18.1	18.1	18.9	19.6
2008	19.6	21.5	19.3	21.2	20.4	17.7	16.6	16.1	18.5	19.2	20	21
2009	19.3	21.8	19.9	21	22.3	19.8	18.8	17.3	17.7	19.2	19.3	19.8
2010	18.3	21.6	19.2	21.3	22.8	20.5	19.6	19.2	18.7	18.3	18.3	18.5
2011	19.5	19.5	20.5	24.5	19.7	19.6	19.8	18.2	17.5	18.2	18.6	18.4
2012	20	24.2	21	22.3	19.7	19.5	19.1	17.7	17.2	18.2	19	19.1
2013	21.2	23.5	21.4	21.9	20.2	18.1	15.9	16.6	17.7	18.2	19.8	19.3

Element: Temperature Min

Region: oromia

Station: Olenkom

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993	7.1	4.7	8.1	10.3	11.4	9.7	11.1	11	9.5	4.9	3	1.5
1994	7.9	6.8	10.7	8.5	11.6	11.4	11.3	12.3	9.5	7.1	3.6	1.5
1995	6.1	7.3	9.8	12.4	11.1	10.6	11.6	11.2	9.8	6.1	5.1	8.7

1996	8.7	9.6	10.4	12.6	8.8	9.4	10.6	11.5	11.6	4.9	5.8	4.6
1997	8.2	7.1	8.3	11.6	9.8	11.2	11.6	11	9.7	6.7	4.7	7.2
1998	7.6	7.9	11.2	10.4	11.6	10.5	11.3	11.7	11.3	7.3	5.3	3.5
1999	10	10.4	11.6	10.1	11.2	10.8	11.5	11.6	10.4	8.6	7.7	8.6
2000	9.1	10.2	9.3	10.2	11.2	11	11.7	11.8	10.3	8.9	6.1	5.3
2001	7.7	7.2	7.4	9.2	11.2	11.9	11	11.3	10.7	6.9	6	4.2
2002	8.2	7.6	10.3	11.4	12.3	12.4	11.3	11.8	10.9	7.2	7.1	4.9
2003	6.4	12.7	11.2	13	13.5	12.6	12	12.5	11.8	7.6	7	5.1
2004	5.3	0.5	10.5	12.7	13.5	12.4	9.2	12	9.8	7.2	6.7	6.3
2005	5.7	8.5	8.6	11.3	10.5	9.2	8.4	8.5	8.6	7.3	6.8	6.7
2006	6.5	8.2	8.3	10.8	9.8	7.9	7.4	7.4	7.2	7	6.7	6.8
2007	7.6	8.1	8.3	9	9.1	8.1	8.4	8.6	7.4	7.2	6.9	7.5
2008	7.4	9	8.7	8.8	9.5	8.2	8.3	7.6	7.7	7.1	7.1	8.1
2009	8.7	8.7	9	9.2	9.8	8.9	9.1	9.1	9	8.9	8.5	8.2
2010	8.7	9	9	9	8.9	9.5	9.5	9.7	9.1	8.6	8.9	8.9
2011	8.3	9	9.7	9.8	9.3	9	8.6	8.6	8	8.2	8.6	8.4
2012	8.3	9.2	9.3	9.1	9.6	8.9	8.7	8	8.3	8.1	8.4	8
2013	8.2	9.1	10	9.3	9.1	8.7	9.2	8.6	8.4	8.6	7.3	7.8

Element: Sunshine

Region: oromia

Station: Holeta

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	6.8	5.9	4.3	5.7	7.9	6.5	2.9	3.5	4	8.6	9.9	9.2
1987	7.8	6.6	8.1	6.7	5.8	3.8	3	5	5.2	7.2	7.3	8.6
1988	8.2	8	6.9	6.9	6	7	4.6	2.4	4.1	7	8.9	9.1
1989	9.8	10	8.8	8.7	5.8	5.2	3.4	4	3.5	9.9	9.3	9.5
1990	9	8.4	7.8	5.4	6.3	5.5	2.4	3.3	5.4	8.3	9.4	8.9
1991	9.3	6.3	7.2	5.6	7.7	4.4	4.1	3.6	6	8.5	9.8	9.2

1992	8.9	4.9	5.7	7.5	6	5.9	4.1	3.6	5.8	7.9	9.4	9.4
1993	8.1	7.3	9.2	6.6	8.1	5.3	1.5	3.3	4.3	7.8	10.2	10
1994	8.6	8.2	6.8	5.9	8.5	5.9	2.8	3.6	4.7	7.8	9.5	7
1995	9.5	5.5	7.5	6.9	7.4	5.8	3.3	3.2	4.5	8.7	8.5	9.8
1996	8.8	7.6	7.2	8.1	8	5.4	2.6	3.4	5.3	8.4	9.2	8.4
1997	6.5	6.4	7.6	7.1	7.5	5.6	3.1	1.7	4.5	6.8	7.9	8.4
1998	7.9	6.4	9.2	5.4	6.9	5.3	3.2	3.4	3.2	7.1	9.3	9.4
1999	9.8	9.3	7.2	6.5	7.4	4.3	2.5	2.8	5.5	8.8	8.7	9.8
2000	10.3	8.6	8	4.8	7.6	6.6	2.7	3.1	4.5	8.2	9.6	8.8
2001	7.1	8.9	6.7	6.4	5.9	3.9	3.2	2.8	4.4	8.6	8.5	9.2
2002	6.7	10.3	8.2	6.1	7.8	5.5	3.1	3.1	6.6	6.7	7.4	9.3
2003	8	7.3	6.8	7.1	6.1	5.4	2.4	2.4	4	5.5	9.3	10
2004	8.7	9.9	7.3	8	6.6	6.2	2.5	3.5	4.9	4.7	9.8	9.5
2005	10.2	10.2	9.6	5.9	6.7	4.9	2.8	2.3	3.9	6.4	7.9	8.9
2006	8.2	9.7	5.2	8.2	6.6	4.8	3.3	2.5	5.5	7.2	9.5	9.4
2007	7.9	9.3	7.1	8.8	7	5.8	3.4	2.8	5.8	7.8	20.3	6.9
2008	8.1	8.7	7.2	5.7	7.9	1.22	2	1.8	3.3	8.17	8.9	8.7
2009	7.3	8.2	6.8	5.3	7.4	3.6	2.5	2.7	3.8	6.3	8.7	8.3
2010	8.1	9.1	7.6	6.2	5.9	4.4	1.9	2.8	4.3	5.6	8.8	8.2

Element: Humidity

Region: oromia

Station: Holeta

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	49	46	52	52	51		71	70	65	45	41	39
1987	35	41	61	59	39	50	81	95	72	42	33	38
1988	48	61	53	67	57	67	81	86	66	70	71	65
1989	56	61	61	68	71	69	80	87	82	66	58	56
1990	49	46	47	47	63	76	81	80	73	52	55	54
1991	53	51	51	66	62	61	80	83	75	57	54	52
1992	47	60	59	66	63	77	79	79	74	57	56	52
1993	49	49	69	64	67	73	79	77	69	58	49	49
1994	50	50	38	53	41	67	81	80	77	56	42	42
1995	51	49	52	61	41	61	77	76	73	52	45	59
1996	43	65	57	56	51	69	76	79	75	50	50	41
1997	45	54	53	42	45	62	84	82	73	48	43	47
1998	57	64	51	56	51	67	79	84	75	61	50	53
1999	57	64	46	69	66	77	82	83	81	62	52	44
2000	43	50	53	66	56	63	79	81	73	52	46	48
2001	58	39	54	56	56	74	78	79	74	48	46	42
2002	54	34	43	55	42	59	77	75	64	59	59	51

2003	58	55	42	51	55	66	81	82	75	65	46	38
2004	45	33	53	39	49	62	77	78	72	68	43	48
2005	44	34	36	53	59	73	77	83	79	64	58	51
2006	55	46	61	52	65	75	80	83	74	59	49	48
2007	58	44	59	51	49	67.2	78	83	71	49	43.2	59
2008	50.2	43	46	61	46	62	81	83	81	56	51	52
2009	57	47	44	66	49	66	81	83	77	59	51	55
2010	57	45	56	47	65	68	83	80	76	62	72	47

ANNEX-2 Laboratory chemical result

Parameter	BHW1	BHW2	BHW3	BHW4	BHW5	HDW1	HDW2	SHW	SPR
Color (app)	-	-	-	-	-	-	-	-	-
Turbidity (NTU)	3.0	Trace	10.22	5.11	0.036	10.10	1.18	0.37	3.13
Total Solids 105 ⁰ C (mg/l)	-	290	508.00	404	582	174.00	114	456	200
Total Dissolved Solids, 105 ⁰ C(mg/l)	211.3	288.0	490.00	354	572.0	82.6	167.6	381.7	149
Electrical Conductivity μ s/cm) (EC)	325	436	781.00	557	945.00	284	140	647	253
pH	8.47	7.06	7.40	8.15	8.42	7.5	7.28	7.55	8.2
Ammonia (mg/l NH ₃)		0.26	2.62	0.22	0.31	Nil	0.01	0.01	0.05
Sodium (mg/l Na)	22.0	12.8	140.00	129.00	216.00	8.7	4.6	57.00	10.6
Potassium (mg/l K)	1.2	2.5	12.80	3.10	4.90	1.11	1.4	4.30	1.9
Total Hardness (mg/l CaCO ₃)	133	222.6	50.00	46	53.20	148.00	68	256	124
Calcium (mg/lCa ²⁺)	44.1	63.60	12.00	10.40	9.12	43.28	20.84	80.16	36.8
Magnesium (mg/l Mg ²⁺)	5.52	15.30	4.80	4.8	7.30	2.72	1.89	13.62	5.78
Total Iron (mg/l Fe)	0.27	0.03	0.59	0.13	0.05	0.03	0.21	0.23	0.06
Manganese (mg/l Mn)	-	Trace	-	-	-	-	-	-	-
Fluoride (mg/l F ⁻)	0.55	0.3	1.31	0.59	1.90	0.21	0.26	1.21	0.24
Chloride (mg/l Cl ⁻)	5.4	5.15	48.27	53.11	41.86	6.40	1.2	20.79	2
Nitrite (mg/l NO ₂)	0.01	-	Trace	0.01	Trace	0.02	0.01	Nil	0.02
Nitrate (mg/l NO ₃ ⁻)	17.99	6.6	0.67	1.04	1.13	8.25	4.25	Nil	6.24
Alkalinity (mg/lCaCO ₃)	148.2	235.2	302.4	210.	437.8	80.00	60	300	-

Carbonate (mg/l CO ₃ ²⁻)	33.6	Nil	Nil	Nil	21.12	Nil	Nil	Nil	Nil
Bicarbonate (mg/l HCO ₃)	112.5	286.9	368.93	256.20	491.17	97.60	73.2	366	146.
Sulphate (mg/l SO ₄ ²⁻)		0.29	5.92	11.90	13.40	Nil	Nil	Nil	Nil
Phosphate (mg/l PO ₄ ³⁻)	0.22	0.06	0.90	0.34	0.34	0.10	0.04	0.17	1.10
Total Coliform Per 100ml	-	-	-	-	-	-	-	-	-
Fecal Coliform Per 100ml	-	-	-	-	-	-	-	-	-

ANNEX-3 House holed survey questioner

Date _____

House hold survey questionnaire

Survey area: Region _____ Zone _____ Woreda: _____ Kebele _____
Village/Gote _____

Date of interview: _____ **Name of interviewer:** _____

Name of head of house hold _____ **Age** _____ **Sex** _____

Marital status of the head of the household: Single Married Divorced Widowed

Educational level of the head of household: illiterate Read and write Grade 1-8
 Grade 9-10 Grade >10

Ethnic group does your household belong: Amhara Oromo Other, specify:
.....

Religion of your household: Ethiopian Orthodox Islam Roman Catholic
 Protestant Other, specify

Respondent's Name (if different from the head): _____ **Age:** _____
Sex _____

1. What type of source do you use for domestic water supply?

- A. Surface water source
- B. Groundwater source
- C. Both sources

2. If your answer is surface water, what type of surface water is it?

A. River B. Lake C. Natural Pond D. Dam E. All

F. Other, specify_____

3. If your answer is groundwater, what type of groundwater?

A. Hand dug well B. Spring C. Borehole

D. Other, specify_____

4. What kind of water lifting device/technology do you use?

A. Hand pump B. Motor pump C. Windmill D. Bucket/rope pump

E. Other, specify_____

9. Do you believe that the source you are using for domestic water supply at present healthy/potable?

Yes

No

10. If it is not healthy, what are the specific problems?

A. Physical contaminants

B. Chemical contaminants

C. Biological contaminants

D. a&b

E. b&c

F. a&c G. all

11. Are there members of the family who are victims of dental Fluorosis?

A. Yes

B. No

12. If yes, state the number of family members affected _____

13. Is there any failed water supply scheme in your area?

A. Yes

B. No

14. Did you take any measure?

A. Yes B. No

15. If not why?

A. It is costly B. high labor demanding C. I don't know how to participate

D. other reason (specify) _____

16. What are the water supply development activities undertaken by you and your family traditionally?

A. dug wells

B. springs

C. ponds

D. Others specify_____

17. What is the extent of community participation in deciding the site and design of the water supply scheme/ projects?

- A. involved in site selection B. involved in planning
C. involved in construction D. involved in administration and management
E. others, specify_____

18. What is your participation during the water supply scheme development?

- A. Contribution of cash B. Labor C. Local construction materials D. Idea
E. Other, specify_____

19. Do you get training at a household level?

- A. Yes B. No

20. Do you get training at community level?

- A. Yes B. No

21. Do you need new water points?

- A. Yes B. No

22. Who manage the water supply scheme?

- A. Water committee B. Professionals C .Community D. Local administrators
E. Others, specify_____

23. What is the participation of women in water supply scheme management and development?

- A. Water committee and water use management B. Main fetchers C. Guards
D. Technical workers
E. Other, specify_____

24. Do you think representation of more women in the water committee is good for the society?

- A. Yes B. No

25. Do you discuss about water supply problems with your neighbors, Local authorities, or other community members?

- A. Yes B. No

26. What major natural disasters occurred in your Woreda that affects sustainability of the water supply scheme?

A. Drought

B. Flooding

C. Conflict over water resources

B. Water borne diseases

E. Presence of hazardous chemical constituents

F Other, specify_____

27. If there is water bore disease, what are the major ones? List down

