ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SCIENCE

WATER RESOURCES POTENTIAL EVALUATION OF BERESSA RIVER CATCHMENT, IN NORTH SHOWA, AMHARA REGION

By
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A thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment for the Degree of Master of Science in Hydrogeology

JUNE, 2005
ADDIS ABABA

DECLARATION

I, the undersigned, declare that my thesis being entitled in my original work has not presented for a degree in any other university. Sources of relevant materials taken from books and articles have been duly acknowledged.

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ABSTRACT

Water resource potential evaluation is carried out on Beressa river catchment which is located about 130 km from Addis Ababa on the way to Dessie. The study area covers 336 km^2 and having average elevation ranges from 2100m to 3675 m above mean sea level. The area has 13-16 ^{0}c average annual temperature, 1120 mm annual rainfall and temperate (weyna daga) to cool (kur) climate. It is located in the Ethiopian highland plateau adjoining the western escarpment of the rift valley and the area is within Jema river basin which is one of the main tributaries of Blue Nile River.

By analyzing the available meteorological data, open water evaporation and potential evapotranspiration is calculated using penman combined method and the results are 1336mm and 1180mm respectively. The actual evapotranspiration of the catchment is calculated using Thornthwait and Mather soil water balance model and the annual AET is 731mm. From the computed water balance, the amount of water infiltrated to subsurface is 122.46 mm.

The local geology of the study area is Tertiary volcanic rocks which are lower basalt, rhyolitic ignimbrite, upper basalt and residual silty clay soil patches along the river valleys. These rock units are weathered, fractured and jointed.

Based on groundwater circulation and storage controlling factors of the area that is degree of weathering, fracturing, faulting of the geological formation, topographic nature, recharge and discharge condition of the area; the hydrogeological map is produced classifying thearea into 3 similar hydrostratigraphic units having high, medium and low-very groundwater potential zone. From available pumping test data the high groundwater potential zone has 5-15 l/sec yield, 10-332 m^2/d transmissivity and 0.3-7.8 m/d hydraulic-conductivity and where as the medium groundwater potential zone has 1- 4 l/sec yield, 1.5-2..22 m^2/d transmissivity and 0.04-0.045 m/d hydraulic-conductivity.

Physical parameters measurements, chemical and bacteriological laboratory analysis of water samples were conducted to study the water quality and the pollution of water resources of the catchmrnt. Accordingly, almost all sampled water show fresh water (TDS =55-307 mg/l), soft to moderately hard, $CaHCO_3$ and Ca-Na- HCO_3 water types. But two boreholes and one spring water sampled from water schemes located in the town show hard water and Ca-

HCO_3-Cl, Ca-Na-HCO_3-Cl and Ca–Cl-HCO_3 type water. These three water sources have 46-55 mg/l nitrate and 46-63 mg/l chloride ions concentration. The source of these ions in these three water samples might be due to contamination from disposal of the town municipal solid and liquid wastes released to open land surface. From 10 water samples microbiological test, 6 water samples were polluted by coliform bacteria due to waste disposal and poor sanitary protection.

the final out put of supplying potable water. As that of water supply needs chemical, physical and bacteriological analysis, irrigation water also needs hydrochemical analysis for different major ions especially for sodium, calcium, magnesium, boron, nitrate, chloride, phosphorus etc. Water used for industrial input also needs water quality standards according to the type of industries. After analyzing, the result will guide whether the water is allowable for irrigation or not

The communities living in Beresa river catchments use surface and groundwater for domestic and agricultural purposes. Some development activities like using hand dug wells, springs, boreholes for water supply, spring and river water for small scale irrigation are common in the study area. Debre Birhan town is also located within this area. Its water supply depends mainly on groundwater resource extracted from Beressa and Dalecha well fields.

Even though the water demands for different development activities within the catchment have been increasing; surface and groundwater potential of the catchments is not studied in detail. Utilization of surface and groundwater without basic understanding of the hydrogeological setting; surface and groundwater potential of an area may lead to irreversible problems, various environmental impacts and other socio-economic problems. Therefore this study tries to address the hydrogeological set up of the catchment and evaluate mainly groundwater resource based on available hydrometeorological and hydrogeological data by applying conventional method so as to come out with reliable results.

1.2 OBJECIVE OF THE STUDY

1.2.1 General Objective*:* To study the hydrogeology of Beressa river catchments with particular emphasis on groundwater resource evaluation and aquifer characterization.

1.2.2 Specific objectives

- To evaluate the components of hydrologic cycle in the catchments to estimate the water balance
- To study surface and ground water interaction within the catchment.
- To study the hydrochemistry of the catchments from quality and pollution point of view.
- To produce hydrogeological maps of the catchments at the scale of 1: 50,000.
- To delineate groundwater potential zone for future development.
- To suggest possible measures for sustainable utilization of the surface water and groundwater resources

1.3 METHODOLOGY

To achieve these objectives the following different activities have been carried out.

1 Literature, report and maps review. Concerning this area, no specific literatures are published except some geological publication describing the general geology of volcanic rocks in western highland and rift valley. Abbay Basin master plan studies carried out by BCEOM (1999) concerning soil type, land use/land cover, geology and hydrogeology is reviewed and important ideas and data were taken and incorporated in concerned chapters of this work. Water supply investigation reports and well data were reviewed and important information's like well log, pumping test data were analyzed and included in this work.

2 River discharge and meteorological records were collected from Ministry of Water Resource and National Meteorological Agency respectively. The data were analyzed and used to compute open water evaporation, potential evapotranspiration, actual evapotranspiration and finally water balance of the area is calculated

3 Base on topographic map of 1:50,000 scale, base map was prepared to use for hydrogeological mapping.

4 Aerial photo interpretation was carried out to produce geological map at the scale of 1: 50,000.

5 The field work was performed in the month of August, 2004 and February-March, 2005. During the first field work, understanding the general over view of the area, inventory of some water points, water sampling for physical parameter measurement and chemical analysis had been accomplished. In the second field work, using systematic geo-traverse; detailed geological and hydrogeological mapping, geophysical survey, additional water sampling for physical parameter measurement and chemical analysis, spring discharge measurement and the over all data collected at office and field level were refined and checked.

6 Water sample chemical laboratory analysis was done in Ethiopia geological survey and Addis Ababa Water Supply Authority laboratories and the result is analyzed using Aquachem software and interpreted according to hydrogeological condition of the environment.

7 The pumping test data were analyzed using Aquitest software and the result used to characterize the aquifer

8 The geophysical survey data were analyzed using excel, surfer, and Resix^{plus} soft ware, interpreted according to geological and hydrogeological condition of the area and the result is used to characterize the aquifer with other hydrogeological data.

9 The hard copy of geological and hydrogeological maps prepared at the field digitized using AutoCad map and arcviev software to produce soft copies.

CHAPTER TWO
GENERAL OVER VIEW OF THE STUDY AREA

2.1 Location

The study area is located in Amhara Regional State, North Showa administrative zone, around Debre Birhan town (**Beressa** river catchment). It is about 130 km from Addis Ababa on the way to Dessie. Beressa river catchment is about 336 km^2 area (i.e. **3**3600 hectare). The average elevation of the catchments area ranges from 2100m to 3675 m above mean sea level and bounded within 39°,27',20" E to 39°,44',14" E longitude and 9°,33',50" N to 9°,44',38" N latitude.

2.2 Climate

The climate of any area mostly dependent on altitude. The area has 13-16^{o}c and 1120mm average temperature and precipitation respectively. According to Tesfaye Chernet, (1993), Tenalem Ayenew and Tamru Alemayehu (2001) the climate of Beressa river catchment ranges from temprate (weyna daga) to cool (kur).

3.3 Physiography and Drainage

The geomorphology of an area depends on the general geology and climatic condition of that particular area. Beressa river catchment is situated in the Ethiopian highland plateau adjoining the western escarpment of the rift valley and the up stream of the catchment area is the water divide of Abbay and Awash river basins.

The general topography of the catchments is undulating hills and valley. It gradually decreases in elevation to the north and north-west. Numerous narrow and shallow river valleys originated from mountain ranges and merge subsequently and form Beressa perennial river. Dalecha (intermittent) river is among the main tributary of Beressa river. Beressa river flow to Jemma river and which is one of the main tributaries of Blue Nile River.

Small valleys originated from ridges and hills form dense dendritic drainage pattern in the area. These small valleys and streams are controlled by inferred and main faults, joints, fractures or a combination of them. The topography of the area is the main expression of the north-westerly oriented drainage

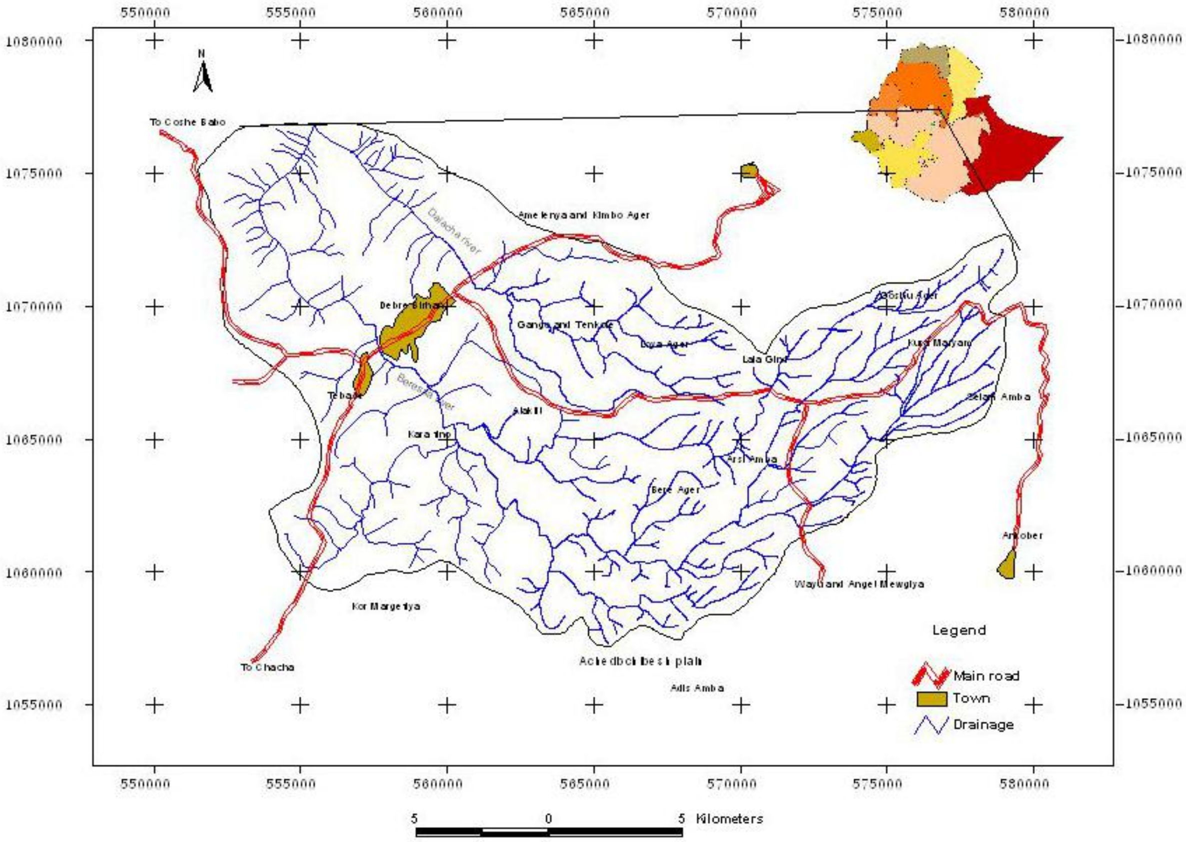


Figure 2.1. The location and drainage map of Beressa river catchment

2.4 Soil, land use and land cover

2.4.1. Soil

Soil characteristics of an area depends on land escape, geology (parent material), the type of land use practice and agricultural activities. From field observations and according to Abbay basin land resource development master plan study (BCEOM, 1999), the dominant soil type of the study area is classified in to four:

a) **Fractured rock with boulders and cobles**: It is formed at high relief hill side slopes and highly susceptible to erosion. This soil unit is characterized by steep cliffs and hills. It is highly drained soil.

b) **Silty sand with rock fragment**: This soil unit is characterized by brown residual soil having an average of 30-50 cm thickness with ignimbrite and basaltic origin rock fragments. It is formed mainly on dominantly cultivated land of the study area. The bed rock is basalt and ignimbrite. There is also none mapable small hills steep land with none developed soil and open bed rock along the river valley. Because of thin soil thickness, the precipitated moisture drained immediately.

c) **Alluvial and residual silty clay soil**: This soil is developed along flat land river channels. The soil has up to 4 m thickness as observed from well logging. It has brown color. Small irrigated marshy and grazing land on this soil unit.

Table 2.1 Soil type and aerial coverage in Beressa river catchments.

No	Soil type	Area overage(km^2)	Weighted area (%)
1	Fractured rock with big boulders and cobles	53.6	15.9
2	Silty sand with rock fragment	271	80.6
3	Alluvial residual silty clay	7.2	2.1
4	Town	4.2	1.4

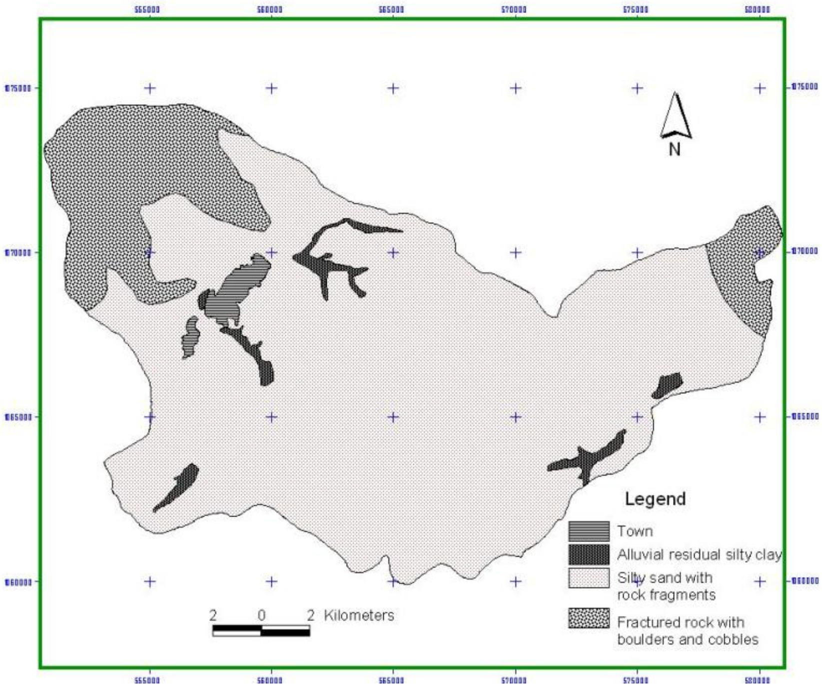


Figure 2.2 Soil map of Beressa river catchments

2.4.2 Land use and land cover

The land use and land cover of an area depends on climatic factors, land escape, agro ecology, land use practice and agricultural activities of the area. Accordingly, the land use of the study area mainly classified in to cultivation, pasture, grazing and plantation.The plantation species in the area is "Eucalyptus" tree (Nech bahirzaf) and rarely "Yeferenji Tid", some shrubs and bushes. The area has very poor indigenous plant species.

The magnitude and variety of the vegetation covers of an area is an indicator of the physical environment and the degree of human interference. Vegetation gives an excellent soil cover from erosion, provide protection by its roots and forms thick litter on land surface. It also increases the infiltration capacity of the soil, reduce surface run off and ensure continuous base flow or groundwater potential.

The main plantation area is Wofwasha state forest at the upper catchments of the study area. There is also patch of barren land which needs special land use treatment. The major cereals grown in the area are wheat, barley, beans, peas, etc and some vegetables like cabbage, potato etc.

Table 2.2 Land use /land cover and aerial coverage of Beressa river catchments

No	Type of land use and land cover	Area coverage (km^2)	Weighted (%)
1	Dominantly cultivated agricultural area	251.3	74.8
2	Moderately cultivated agro- pastoral area	43.6	13.0
3	Grass land sylvo-pastoral area	27.8	8.3
4	Plantation sylvicultural area	9.0	2.7
5	Town	4.2	1.2
	Total	335.9	100.00

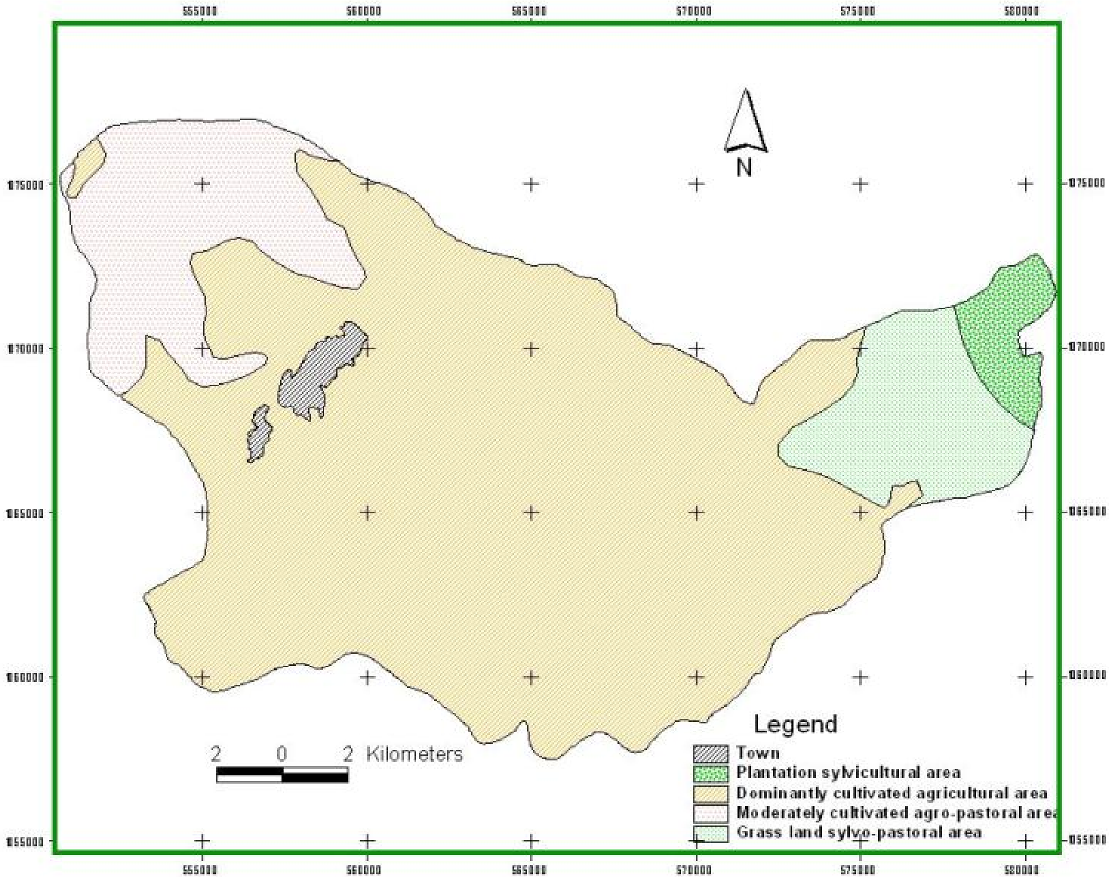


Figure 2.3 Land use / land cover map of Beressa river catchments

CHAPTER THREE
HYDROMETEOROLOGY

3.1 General

Hydrometeorology is the branch of study which links both hydrology and meteorology (Shaw, 1988). Hydrometeorological data are required to determine the water balance of a basin for developing and managing its water resources. The most useful hydrometeorological elements are precipitation, evaporation, evapotranspiration, solar radiation (sunshine hours), air temperature, humidity, soil moisture, water levels (surface and underground), stream discharge, water quality (Raghunath, 1987).

In this work, the main objective of analyzing hydrometeorological data is to compute evaporation, evapotranspiration, soil moisture and the results of the analysis further used in calculation of the water balance of the study area.

3.2. Precipitation analysis.

The physiography and topography of the drainage basin, together with the vegetation, influence the relationship between precipitation over the basin and the water drained from it. The creation and distribution of precipitation is heavily influenced by the presence of the mountain ranges and other topographic features (Fetter, 1994). Precipitation is the most commonly measured meteorological data. Accordingly there are five meteorological stations within and around the study area (Table. 3.1)

Table 3.1 Meteorological stations within and around Beressa river catchments.

No	Stations	Location (UTM)		Altitude (m) a.m.s.l.	Annual Rainfall (mm)	Recording periods(years)
		Latitude	Longitude			
1	Debre Birhan	556250	1068300	2780 m	882.7	1969-2003 1*
2	Chacha	549500	1053650	2770 m	865.4	1987-2003 3*
3	Mendida	534000	1067250	2800 m	932.7	1955-2003 2*
4	Gudoberet	574500	1083300	3100 m	1150.9	1987-2003 2*
5	Ankober	580400	1060400	2970 m	1677	1969-2003 3*

1* Records of rainfall, temperature, relative humidity, wind speed and sunshine hours.

2* Records of rainfall and temperature. 3* Records of rainfall only.

3.2.1 Determination of aerial depth of rainfall.

A rainfall measurement is a point observation and may not be use as a representative value for the area under consideration (say for a basin). There for, the point measurement have to be averaged over the area (Tenalem Ayenew and Tamiru Alemayehu, 2001). There are three different methods to determine the average depth of rainfall over the study area, i.e. arithmetic mean, theissen polygon and isohyetal methods.

3.2.1.1 **An arithmetic mean**: This method is reliable when the topography is flat; the rain gauge stations are closely and evenly spaced.

It is computed as the arithmetic mean of the amount rainfall measured stations enclosed within the study area only. Therefore, Debre birhan station is located within the study area and it is the only station uses for arithmetic mean aerial depth rainfall determination and the result is 882.7.5mm.

3.2.1.2 **Theissen polygon method:** this method provides for none uniform distribution of rain gauge by determining a weighted factors for each gauge. Eventhough, five stations are considered to construct the theissen polygon, only three (Debre birhan, Ankober and Chacha) stations are used for computing weighted annual rainfall and the result is 1119.29mm (Table3.2 and Fig 3.1).

Table 3.2. Theissen polygon method to calculate the annual rainfall of Beressa river catchment

Ser.no	Stations	Mean annual rain fall (mm)	Area of influence (km^2)	Weighted Area (%)	Weighted rainfall (mm)
1	Debre birhan	882.70	233.71	69.59	614.27
2	Ankober	1677.00	100.07	29.80	499.74
3	Chacha	865.40	2.03	0.61	5.28
Total			335.81	100.00	1119.29

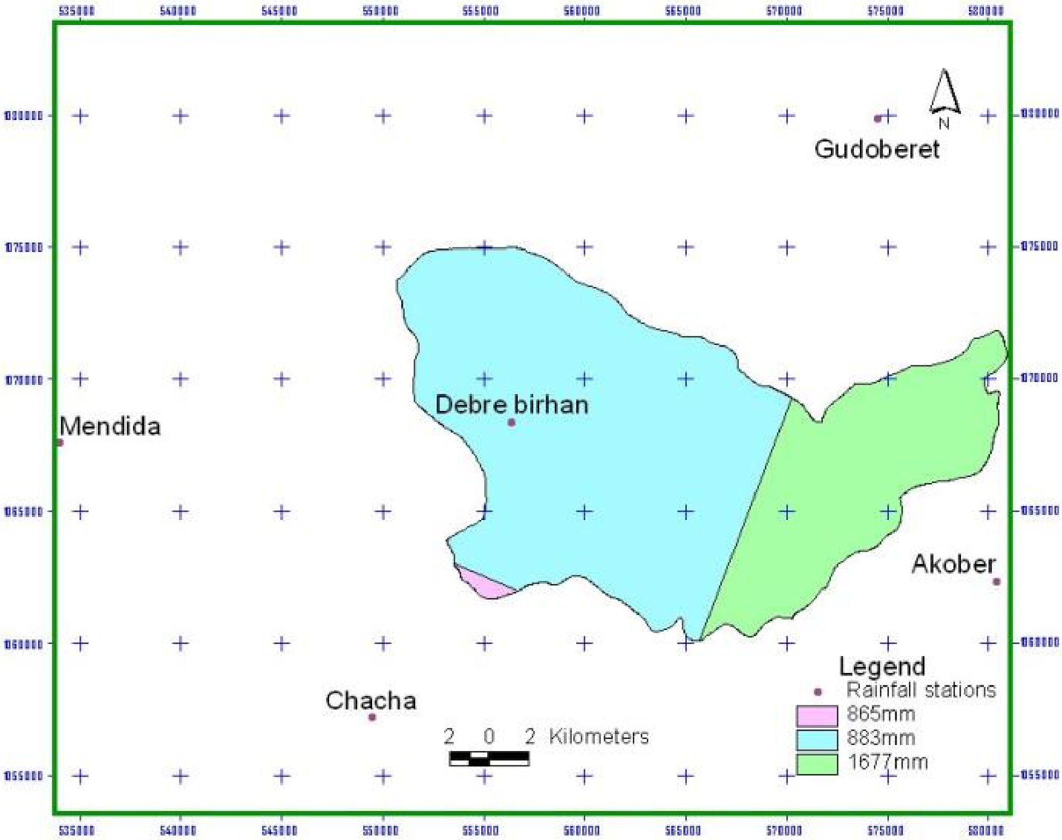


Figure 3.1 Theissen Polygon map

3.2.1.3 **Isohyetal method**: this method makes use of joining points of equal rainfall value and then measures their inter-isohyetal area. The annual rainfall of Beressa river catchment computed by isohyetal method is 1120.66 (Table 3.3 and Fig 3.2).

The calculation of mean annual rainfall computed by arithmetic mean method underestimate the value. The cause may be due to uneven distribution of stations or undulated nature of the topography or both. Where as the result of mean annual rainfall computed by theissen polygon and isohyetal methods 1119.29mm and 1120.66mm respectively have equal value. This indicates that the topography has no effect on rainfall. Therefore, it is logical to take 1120mm (the average value of theissen polygon and isohyetal method) as the mean annual rainfall of the studied catchment area.

Table 3.3. Isohyetal method of calculating annual rainfall in Beressa river catchment.

Ser. No.	Isohyetal range (mm)	Average isohyetal (mm)	Net enclosed area (km^2)	Weighted area (%)	Weighted rainfall (mm)
1	< 950	900	118.08	35.16	316.43
2	950-1050	1000	42.26	12.58	125.83
3	1050-1150	1100	35.48	10.56	116.21
4	1150-1250	1200	33.10	9.86	118.27
5	1250-1350	1300	35.67	10.62	138.07
6	1350-1450	1400	42.67	12.71	177.88
7	1450--1550	1500	26.75	7.97	119.47
8	>1550	1575	1.83	0.54	8.50
Total					1120.66

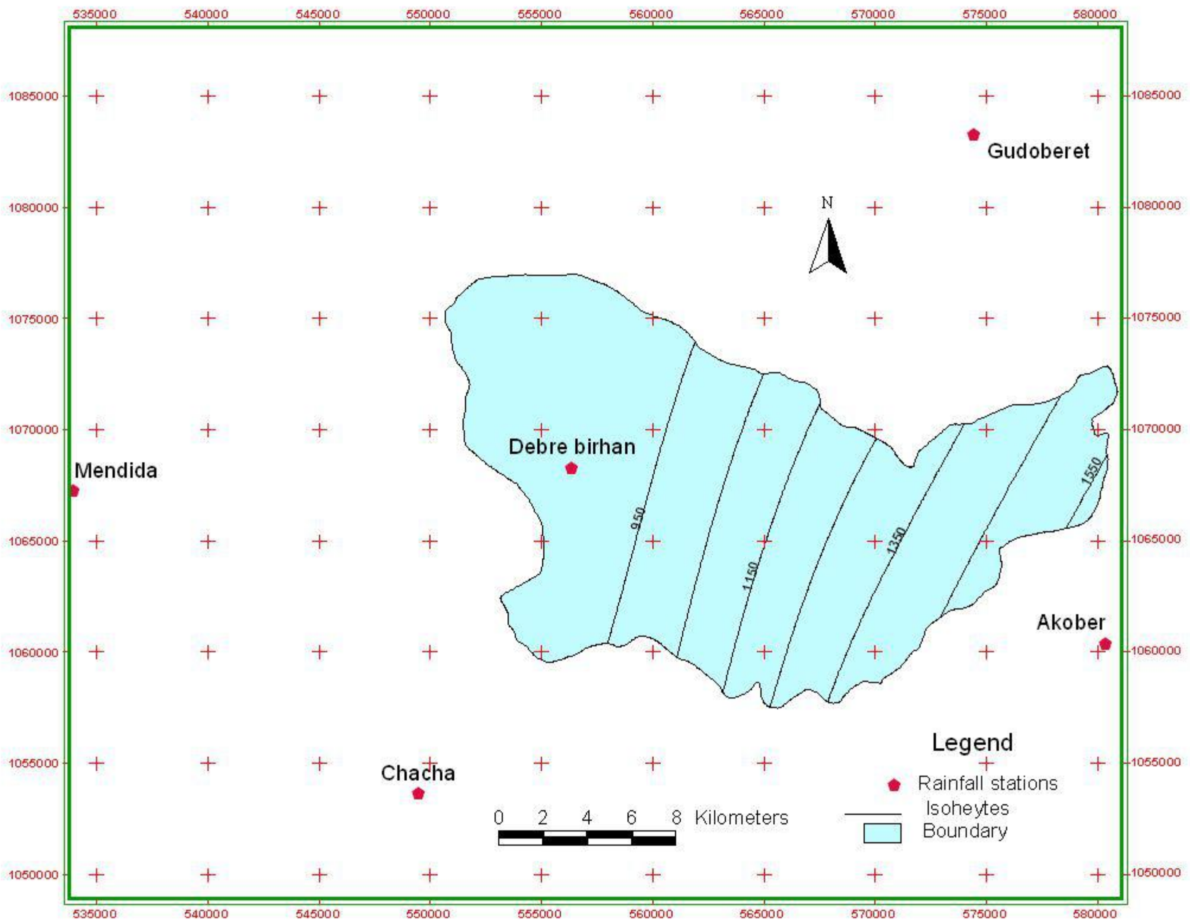


Figure 3.2 Isohyetal map

3.2.2 Characteristics of rain fall

The amount of rain fall increases when altitude increases. Its amount and frequency are greater on the wind ward side of the orography or mountain barriers (Tenalem Ayenew and Tamiru Alemayehu, 2001). As it is indicated in table 3.1, the annual rain fall increase with altitude. Even though, the altitude of Akober station is lower than Gudoberet station, its annual rainfall higher than Gudoberet and other stations due to the wind ward side of the orography or mountain barriers.

To compare monthly distribution of rainfall and to identify dry and rainy season; rainfall coefficient should be employed. The rainfall coefficient is calculated by dividing mean monthly rainfall to one twelve of the annual mean rainfall (Daniel Gemechu, 1977).According to Daneil Gemechu (1977) classification displayed on Table 3.4 and 3.5, the study area has two rainfall regime (bimodal rainfall characteristics). During the month of March and April the area got small rain (bulg season) while July, August and September months got more than 60% annul rainfall or big rain (kiremt season).

Table3.4 Classification scheme of monthly rain fall values (Source: Daniel Gemechu, 1977)

Designation	**Rainfall coefficient**
Dry month	less than 0.6
Rainy month	0.6 and above
Small rains	0.6 to0.9
Big rains	1.0 and over
Moderate concentration	1.0 to1.9
High concentration	2.0 to2.9
Very high concentration	3.0 and above

Table 3.5 Monthly average, rainfall coefficient and classification of rainfall of Beressa river catchments.

Methods	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec.	Total
Theissen	31.43	32.63	78.8	72.1	54.20	59.91	286.90	293.45	111.46	50.4	27.48	19.3	1118.3
Isohyetal	31.5	32.7	79	72.3	54.32	60.05	287.56	294.13	111.72	50.5	27.54	19.3	1120.6
Combined average	31.47	32.7	78.9	72.2	54.26	59.98	287.23	293.79	111.59	50.5	27.51	19.29	1119.4
%contribution	2.81	2.92	7.05	6.45	4.85	5.36	25.66	26.25	9.99	4.50	2.42	1.72	
Rainfall coefficient	0.34	0.35	0.85	0.77	0.58	0.64	3.08	3.15	1.20	0.54	0.29	0.21	
Designation	dry	dry	rain	rain	dry	rainy	rainy	rainy	rainy	dry	dry	dry	

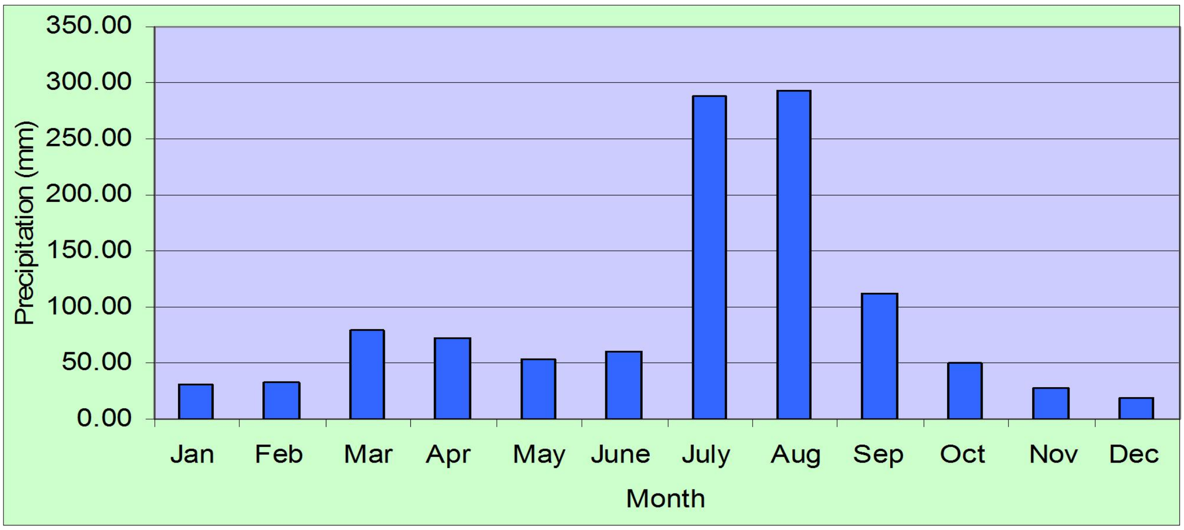


Figure 3.3 Monthly rainfall distributions of Beressa river catchments

3.3 Temperature

Air and water temperature are dependent on solar radiation and has direct influence on evaporation. It governs the rate at which water molecules leave the surface and enter the over lying air.

From five meteorological stations used for this work, only three stations (Bebre birhan, Godoberet and Mendida) have records of monthly maximum and minimum temperature. The least minimum and the most maximum air temperature is recorded in the month of November and June respectively (Table 3.6).

Table 3.6 Monthly maximum mean and minimum mean temperature variability of the three stations.

Station.		Jan.	Feb	Mar	Apr.	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bebre birhan	Max.	19.51	20.32	20.66	20.61	21.49	21.86	18.67	18.25	18.63	18.6	18.73	18.99
	Min.	4.28	5.51	7.61	7.62	7.21	7.23	8.75	8.72	7.15	3.48	2.26	3.37
	Ave.	11.89	12.91	14.13	14.11	14.35	14.54	13.71	13.48	12.89	11.0	10.52	11.18
Godo beret	Max.	17.76	18.04	17.99	17.73	18.42	18.82	16.94	16.83	16.33	15.8	16.18	16.67
	Min.	7.8	8.09	8.50	8.75	9.09	9.00	8.28	8.34	8.45	7.3	7.26	7.47
	Ave	12.78	13.07	13.25	13.24	13.73	13.91	12.61	12.58	12.39	11.6	11.72	12.07
Mendi da	Max.	21.75	22.35	22.14	22.08	22.51	22.56	18.74	18.76	19.49	19.6	20.82	20.76
	Min.	7.28	7.82	8.55	9.46	9.71	9.61	9.29	9.36	8.86	7.77	6.30	6.36
	Ave.	14.52	15.08	15.35	15.77	16.11	16.09	14.01	14.06	14.17	13.7	13.56	13.58

Table 3.7 Monthly mean temperature of the three stations.

Station.	Jan.	Feb	Mar	Apr.	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Debre birahan	11.89	12.91	14.13	14.11	14.35	14.54	13.71	13.48	12.89	11.03	10.52	11.18
Godoberet	12.78	13.07	13.25	13.24	13.73	13.91	12.61	12.58	12.39	11.56	11.72	12.07
Mendida	14.52	15.08	15.35	15.77	16.11	16.09	14.01	14.06	14.17	13.70	13.56	13.58
Average	13.06	15.08	15.35	15.77	16.11	16.09	14.01	14.06	14.17	13.70	13.56	13.58

3.4 Relative humidity

Relative humidity is the relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature, ed/ea , and represents as a percentage (Shaw, 1988).

$$RH = 100\,ed/ea \qquad (3.1)$$

Where RH is relative humidity

ed is actual vapor pressure.

ea is saturated vapor pressure

As air humidity increases, its ability to absorb water vapor decreases and the evaporation rates slow down. For evaporation to take place there must be a difference in humidity (Tenalem Ayenew and Tamiru Alemayehu, 2001).

From available data of five stations used for this work, only Debre birhan station has relative humidity records

Table 3.8 Monthly mean relative humidity of Debre birhan statio n.

Station	Jan.	Feb	Mar	Apr.	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
600	83.62	82.55	84.52	86	84.4	86.55	93.42	94.05	92.52	90.56	84.34	80.56
1200	55.62	54.89	56.86	58.09	49.9	49.44	75.63	79.16	68.76	58.74	56.81	56.49
1800	64.76	57.55	60.67	61.05	53.52	52.71	75.42	79.71	70.86	64.72	61.69	62.75
Average	68	65	67.35	68.38	62.61	62.57	81.49	84.31	77.38	71.34	67.63	66.60

3.5 Wind speed

The horizontal component of the air movement parallel to the earth's surface is generally referred to as wind while the vertical components are referred to as the air current or turbulence (Jayarami, 1996). The movement of the air and moisture transfer depends on the speed and turbulence. Evaporation has a direct relation with the wind speed and turbulence (Tenalem Ayenew and Tamiru Alemayehu, 2001). Wind speed and air temperature removes water vapor molecules from the air in contact with the water holding surface and enable evaporation to proceed at maximum rate governing with the existing ration, temperature and humidity conditions. Wind speed varies with height above the ground.

The wind speed data of the study area, i.e., at Debre birhan stations measured at 2m above the ground surface. The average wind speed value reaches maximum and minimum in the month of November and August respectively (Table 3.9)

Table 3.9 Monthly wind speed of Debre birhan station 2m above ground surface (m/s)

Station		Jan.	Feb	Mar	Apr.	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Debre birhan	Max.	3.2	3.3	3.4	3.6	4.6	3	2.2	2.1	2.3	2.2	2.6	2.9
	Min.	1.2	1.5	1.3	1.3	1.2	0.2	0.8	0.7	1	0.1	1.3	1.4
	Ave.	2.4	2.6	2.6	2.3	2.6	2.1	1.6	1.5	1.7	1.7	2.1	2.3

3.6 Sunshine hours

Sunshine hour is the time in hours of sunshine in a day. It has direct relationship with evaporation. When the day is cloudy, the sunshine hours decreases and evaporation rate also decrease with the existing other meteorological factors. As shown from the table3.10, the average sunshine hours gets maximum and minimum in the month of January and July respectively. It has direct relationship with dry and rainy season.

Table 3.10 Monthly mean sunshine hours of Debre birhan station.

Station		**Jan.**	**Feb**	**Mar**	**Apr.**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Debre birhan	Max.	10.4	11	10	10	9.9	9.6	7	8.1	7.4	10.1	10.4	10.5
	Min.	6.9	4.8	4.2	4.7	6.4	5.6	3.4	2.8	4.3	5.4	6.5	6.8
	Ave.	9.3	8.42	7.41	7.07	8.29	7.52	5.12	5.32	6.14	8.08	9.21	9.07

3.7 Methods of estimating evapotranspiration

Evaporation is the process that water molecules changes from liquid phase to vapor phase and escapes into the atmosphere. Water evaporate from land, either bare soil or soil covered with vegetation and from trees, impervious surface like roofs and roads, open water bodies and stream. Growing vegetation needs water to sustain life. Only small amount of the water needs by plant is retained in the plant structure but most of the water passes the roots to the stem or trunk and is transported into the atmosphere through the leaf part of the plant.

In the field, it is practically impossible to differentiate between evaporation and transpiration if ground is covered with vegetation. There fore, the two combined processes are termed as evapotranspiration (Wilson, 1983). The rate of evaporation varies with the color and reflective properties of the surface (albedo).

In the study are, there is no direct measured value of evaporation from open water body or pan evaporation and there is no studies that shows the evapotranspiration. Therefore, it is necessary to calculate evaporation and evapotranspiration using different conventional methods and available hydrometeorological data.

3.7.1 Penman combined methods of evaporation (E_O) estimation

The physical principles to calculate evaporation are the mass transfer method and the energy budget method. The basic equations are modified and rearranged to use meteorological constants and measurements of variables made regularly at climatological stations (Shaw, 1988).

A simplified energy balance equation:

$$H = Eo + Q \qquad (3.2)$$

Where H is the available heat.

Eo is the energy for evaporation or rate of evaporation.

Q is energy for heating air.

$$\Delta = \frac{ea - ed}{Ta - Td} \qquad (3.3)$$

$$Ea = f(u)(ea - ed) \qquad (3.4$$

$$Eo = f(u)(es - ed) \qquad (3.5)$$

then, $Q = \gamma f(u)\left[\left(\frac{es - ed}{\Delta}\right) - \left(\frac{ea - ed}{\Delta}\right)\right]$

$$Q = \gamma\, Eo/\Delta + \gamma\, Ea/\Delta \qquad (3.6)$$

Where Δ is the slope of the curve of saturated vapor pressure plotted against temperature.

ed is actual vapor pressure at dew point temperature (Td)

ea is saturated vapor pressure at air temperature (Ta)

$ea - ed$ is the saturation deficit

es is saturation vapour pressure of the air at the water surface (mm of mercury)

$f(u)$ is a function of wind speed

Ta is easily measured and ea is also obtained from table against Ta

ed is calculated from equation 3.1

Substituting for Q in the energy balance equation (3.2), then Eo could be derived to be

$$Eo = \frac{\frac{\Delta}{\gamma} H + Ea}{\frac{\Delta}{\gamma} + 1} \qquad (3.7)$$

Equation 3.7 is the basic Penman formula for open water evaporation. It requires the value of H and Ea as well as Δ.

More often, H is calculated from incoming radiation (RI) and out going radiation (Ro) determined from the sunshine records, temperature and humidity using

$$H = RI(1 - r) - Ro \qquad (3.8)$$

Where r is the albedo and equals 0.05 for water.

RI is a function of the solar radiation (Ra) which is fixed by altitude and season modulated by a function of ratio, n/N, of measured to maximum possible sunshine duration, for r =0.05, gives

$$RI(1 - r) = 0.95 Ra fa(n/N) \qquad (3.9)$$

Penman used $fa(n/N) = (0.16 + 0.62\, n/N)$ for latitude south of $54^{1/2}$

$$Ro = \sigma T_a^4 \left(0.56 - 0.09\sqrt{ea}\right)\left(.0.1 + 0.90\, n/N\right) \quad (3.10)$$

Where σT_a^4 is the theoretical blank body radiation at Ta

n is bright sunshine hours over the some period.

N is mean daily duration of maximum possible sunshine hours

Ra is solar radiation

N and Ra expressed in mm/day and taken from standard meteorological tables, for this Work, N and Ra is taken from Shaw, (1988) at 10^{o} north latitude.

Then H in equation 3.7 is obtained from value found via equation 3.9 an3.10 inserted into equation 3.8

$$Ea = 0.35\left(0.5 + u_2/100\right)\left(ea - ed\right) \quad (3.11)$$

Where u_2 is mean wind speed at 2m above the ground surface.

Knowing open water evaporation of the study area is important for dam design in the area and surrounding for irrigation, hydropower and water supply purpose. Accordingly, annual open water evaporation rate within the catchments is calculated to be 1336 mm (Table 3.11)

Month	Temp (°c)	e_a (mm/day)	RH (%)	e_d (mm/d)	U_2 (mile/d)	Tk (°k)	n (hr/d)	N (hr/d)	n/N	fa(n/N)	R_a (mm/d)	$R_I(1-r)$ (mm/d)	σTa^4 mm/d	R_a mm/d	H	Ea mm/d	Δ/γ	E_o mm/m
Jan	13.06	11.28	0.68	7.67	128.80	286.10	9.30	11.6	0.802	0.66	12.80	8.03	13.06	3.83	4.70	3.26	1.52	127.89
Feb	13.69	11.75	0.65	7.64	144.36	286.70	8.42	11.8	0.714	0.60	13.90	7.92	13.17	3.04	4.88	2.79	1.57	113.87
March	14.24	12.18	0.67	8.20	139.53	287.20	7.41	12.0	0.617	0.54	14.80	7.59	13.26	2.63	4.96	2.64	1.62	126.31
April	14.37	12.28	0.68	8.40	125.04	287.40	7.08	12.3	0.576	0.52	15.20	7.51	13.30	2.46	5.05	2.38	1.64	121.16
May	14.73	12.57	0.63	7.87	139.53	287.70	8.29	12.6	0.658	0.57	15.00	8.12	13.36	2.84	5.28	3.12	1.67	138.60
Jun	14.85	12.67	0.63	7.93	114.84	287.90	7.52	12.7	0.592	0.53	14.80	7.45	13.40	2.60	4.85	2.73	1.68	121.77
July	13.44	11.56	0.81	9.42	85.86	286.40	5.12	12.6	0.406	0.41	14.90	5.80	13.12	1.73	4.07	1.02	1.54	88.95
Aug	13.37	11.51	0.84	9.70	78.79	286.40	5.32	12.4	0.429	0.42	15.00	5.99	13.12	1.78	4.21	0.82	1.54	89.14
Sept	13.15	11.34	0.77	8.77	91.22	286.20	6.14	12.1	0.507	0.47	14.80	6.61	13.08	2.13	4.48	1.27	1.52	96.19
Oct	12.10	10.59	0.71	7.55	92.30	285.100	8.09	11.8	0.685	0.58	14.20	7.15	12.88	2.89	4.26	1.51	1.43	96.97
Nov	11.93	10.47	0.67	7.08	112.70	284.90	9.21	11.6	0.794	0.65	13.10	8.09	12.85	3.35	4.74	1.93	1.41	107.22
Dec	12.28	10.72	0.66	7.14	125.04	285.30	9.08	11.5	0.789	0.65	12.50	7.72	12.92	3.34	4.38	2.19	1.45	108.07
Total																		1336.14

Table 3.11 Evaporation from open water body using penman combined method for Beressa river catchment

Where e_a = saturation vapour pressure (mmHg)
e_d = actual vapour pressure (mmHg)
RH = relative humidity (%)
N = maximum possible sunshine hours determined by latitude and season (10^o N latitude is taken from standard tables for the study).
U_2 = wind speed (mile/day)
n = daily mean bright sunshine hour (hr/day)
fa = a function of sun shine hour
Ra = solar radiation which depends on latitude and season (10^o N latitude is for the study area) taken from standard tables
R_1 = incoming solar radiation (mm/day),
r = albedo (reflection coefficient for incident radiation = 0.05 for water)
σ = Stephan-Boltzman constant ($5.67 \times 10^{-8} \times Wm^{-2} T^{-4}$),
T = air temperature (^{o}c) ,
TK= temperature in Kelvin
Ro = out going solar radiation (mm/day),
H = available heat (mm/day),
Ea = energy for evaporation (mm/day)
σT^4 = theoretical black body radiation (mm/day)
Δ = slop of saturation vapour pressure plotted against temperature
γ = hygrometric constant (0.27mmHg/^{o}c),
Eo = open water evaporation (mm/month)

3.7.2 Estimation of potential evapotranspiration (PET)

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

Though, there are different potential evapotranspiration calculating method , as resulted from experience, Penman combined method used to allow for the condition under which evaporation and transpiration takes place from vegetated surface (MAFF,1967 in Shaw, 1988):

$$PET = \frac{\frac{\Delta}{\gamma} Ht + Eat}{\frac{\Delta}{\gamma} + 1} \qquad (3.12)$$

Where subscript t signifies inclusion of transpiration effects.

$Ht = RI(1 - r) - Ro$ where r is the albedo of the vegetation covers of the catchment and 0.23 is taken for Beressa river catchment.

$$Ht = 0.77RI - Ro \qquad (3.13\ )$$

Eat very similar to Ea in equation 3.11 except the coefficient 0.5 is being replaced by 1 to allow for the extra roughness in wind speed function (Shaw, 1988).

$$Eat = 0.35(1 + u_2/100)(ea - ed) \qquad (3.14)$$

$$RI(1 - r) = o.77 Rafa(n/N) \qquad (3.15)$$

$fa(n/N) = (0.16 + 0.62\, n/N)$ for latitude south of $54^{1/2}$ (3.16)

$$Ro = \sigma T_a^4 (0.47 - 0.075\sqrt{ea})(.0.17 + 0.83\, n/N) \qquad (3.17)$$

As it is displayed in table 3.12, annual potential evapotranspiration rate of Beressa river catchments is 1180 mm. It is calculated using Penman combined method. Lower monthly potential evapotranspiration is occurred in the months of July and Augest (74.10 mm and 72.05 mm respectively) because of high humidity in the atmosphere, lower wind speed and lower daily sunshine hours due to cloudiness (Tab. 3,8, 3.9 and 3.10).

Month	Temp (°c)	e_a (mm/day)	RH (%)	E_d (mm/d)	U_2 (mile/d)	Tk (°k)	n (hr/d)	N (hr/d)	n/N	fa(n/N)	R_a mm/d	$R_I(1-r)$ (mm/d)	σTa^4 mm/d	R_o mm/d	H_T	E_{at} mm/d	Δ/γ	PET mm/m.
Jan	13.06	11.28	0.68	7.67	128.80	286.10	9.30	11.6	0.802	0.66	12.80	6.50	13.06	3.00	3.50	2.89	1.52	100.99
Feb	13.69	11.75	0.65	7.64	144.36	286.70	8.42	11.8	0.714	0.60	13.90	6.40	13.17	2.76	3.64	3.51	1.57	100.50
Mar	14.24	12.18	0.67	8.20	139.53	287.20	7.41	12.0	0.617	0.54	14.80	6.20	13.26	2.41	3.79	3.34	1.62	112.16
Apr	14.37	12.28	0.68	8.40	125.04	287.40	7.08	12.3	0.576	0.52	15.20	6.10	13.30	2.27	3.83	3.83	1.64	114.90
May	14.73	12.57	0.63	7.87	139.53	287.70	8.29	12.6	0.658	0.57	15.00	6.60	13.36	2.60	4.00	3.94	1.67	123.30
Jun	14.85	12.67	0.63	7.93	114.84	287.90	7.52	12.7	0.592	0.53	14.80	6.60	13.40	2.40	4.20	3.56	1.68	118.83
July	13.44	11.56	0.81	9.42	85.86	286.40	5.12	12.6	0.406	0.41	14.90	4.70	13.12	1.66	3.04	1.39	1.54	74.10
Aug	13.37	11.51	0.84	9.70	78.79	286.40	5.32	12.4	0.429	0.42	15.00	4.80	13.12	1.70	3.10	1.13	1.54	72.05
Sept	13.15	11.34	0.77	8.77	91.22	286.20	6.14	12.1	0.507	0.47	14.80	5.40	13.08	2.0	3.40	1.72	1.52	82.00
Oct	12.10	10.59	0.71	7.55	92.30	285.100	8.09	11.8	0.685	0.58	14.20	6.30	12.88	2.63	3.67	2.05	1.43	93.10
Nov	11.93	10.47	0.67	7.08	112.70	284.90	9.21	11.6	0.794	0.65	13.10	6.50	12.85	3.02	3.48	2.52	1.41	92.45
Dec	12.28	10.72	0.66	7.14	125.04	285.30	9.08	11.5	0.789	0.65	12.50	6.30	12.92	3.01	3.29	2.82	1.45	96.04
Total																		1180.42

Table 3.12 Calculated potential evapotranspiration of Beressa river catchments using Penman modified method

3.7.3 Estimation of actual evapotranspiration (AET).

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

Actual evapotranspiration is the amount of evaporation that occurs under field conditions. If there is abundant moisture in the soil, the actual evapotranspiration rate is equal to potential evapotranspiration. When the moisture content in the soil limited and vegetation unable to abstract enough water from the soil, then actual evapotranspiration become less than the potential evapotranspiration. Thus the relationship between AET and PET depends upon the soil moisture content.

If there is no rain to replenish the water supply, the soil moisture gradually become depleted by the demands of the vegetation to produce a soil moisture deficit (D). As soil moisture deficit increases, the AET become increasingly less than PET. The value of soil moisture deficit and AET vary with soil type and vegetation (Shaw, 1988).Accordingly, the study area has been classified into three major groups of soil type with their vegetation cover. Based on these categories and meteorological data the actual evapotranspiration of the basin is calculated using Thornthwait and Mather soil water balance model (Table.3.13, 3.14,and 3.15).

Inputs of this model consist of monthly rainfall (P_m) and monthly potential evapotranpiration (PET_m) (Dingman, 1994). The soil-water storage capacity of the region is represented by a single value S_{max} and an initial value of soil moisture by S_o.

According to Alley (1984), cited Dingman (1994), if for a given month $P_m > PET_m$, the value of the soil moisture at the end of that month, S_m, is found as

$$S_m = \min[((Pm - PET) + S_{m-1} + S_{m-1})] \quad 3.18)$$

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

$$S_m = S_{m-1} \exp\left[-\frac{PET_m - P_m}{S_{\max}}\right] \quad (3.19)$$

The monthly actual evapotranspiration (AET) is then found as

$$AET_m = PET_m \text{ if } P_m > PET_m \tag{3.20}$$

Otherwise $$AET_m = P_m + S_{m-1} - S_m \tag{3.21}$$

Where S_m is soil moisture of the month m

$S_{\max}$ is maximum soil moisture capacity of the soil

S_{m-1} is soil moisture in previous month

Finally, as it is computed from three soil type and the corresponding land use land cover units, annual actual evapotranspiration (AET) loss from the catchments is about 730.98 mm, i.e., 65.3 % of the annual mean rainfall (Table 3.13 and 3.17). The annual surplus water in the soil is 388.38 mm occurred in the month of July, August and September.

Item	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
AET	36.63	35.70	79.97	73.28	55.49	60.70	74.10	72.05	82.00	81.28	49.32	30.46	730.98
S	0	0	0	0	0	0	137.23	221.55	29.29	0	0	0	388.38
D	64.36	64.80	31.44	41.62	67.81	58.13	0.00	0.00	0.00	11.82	43.13	65.58	448.69

Table 3.13 Monthly actual evapotranspiration (AET) of Beressa river catchments summarized from table 3.14, 3.15 , 3.16 and 3.17

No	Items	Jan.	Feb	Mar.	Apr.	May	June	July	Aug	Sep	Oct.	Nov.	Dec.	Total
1	P	31.47	32.67	78.91	72.22	54.26	59.98	287.23	293.79	111.59	50.45	27.51	19.29	1119.37
2	PET	100.99	100.50	112.16	114.90	123.3	118.83	74.10	72.05	82.00	93.10	92.45	96.04	1180.42
3	P-PET	-69.52	-67.83	-33.25	-42.68	-69.04	-58.85	213.13	221.74	29.59	-42.65	-64.94	-76.75	
4	Acc.pot WL	-253.86	-321.69	-354.94	-397.62	-466.66	-525.51	-	-	-	-42.65	-107.59	-184.34	
5	Sm	0.31	0.08	0.04	0.02	0.01	0.003	50	50	50	21.31	5.81	1.25	
6	ΔSm	-0.94	-0..23	-0.04	-0.02	-0.01	-0.01	-50	0	0	-28.69	-15.5	-4.56	
7	AET	32.41	32.90	78.95	72.24	54.27	59.98	74.10	72.05	82.00	79.14	43.01	23.85	704.9
8	D	68.58	67.60	32.21	42.66	69.03	58.85	0	0	0	13.96	49.44	72.19	474.52
9	S	0	0	0	0	0	0	163.13	221.74	29.59				414.46

Table 3.14 Monthly actual evapotranspiration of Beressa river catchments for fine sand covered with wheat, barley, beans, peas and 125 mm maximum available water capacity root depth.

No	Items	Jan.	Feb	Mar.	Apr.	May	June	July	Aug	Sep	Oct.	Nov.	Dec.	Total
1	P	31.47	32.67	78.91	72.22	54.26	59.98	287.23	293.79	111.59	50.45	27.51	19.29	1119.37
2	PET	100.99	100.50	112.16	114.90	123.3	118.83	74.10	72.05	82.00	93.10	92.45	96.04	1180.42
3	P-PET	-69.52	-67.83	-33.25	-42.68	-69.04	-58.85	213.13	221.74	29.59	-42.65	-64.94	-76.75	
4	Acc.pot WL	-251.86	-319.69	-352.94	-395.62	-464.66	-523.51	-	-	-	-42.65	-107.59	-182.34	
5	Sm	27.65	17.58	14.08	10.60	6.70	4.53	150	150	150	113.00	73.29	43.94	
6	ΔSm	-16.30	-10.06	-3.50	-3.48	-3.90	-2.17	145.47	0	0	-37.00	-39.71	-29.35	
7	AET	47.77	42.73	82.41	75.70	58.16	62.15	74.10	72.05	82.00	87.45	67.22	48.64	800.38
8	D	53.22	57.77	29.75	39.20	65.14	56.68	0	0	0	5.65	25.23	47.40	380.04
9	S	0	0	0	0	0	0	67.66	221.74	29.59	0	0	0	318.99

Table 3.15 Monthly actual evapotranspiration of Beressa river catchments for fine sand soil covered with Eucalyptus trees, shrubs, bushes and 150 mm maximum available water capacity root depth.

Table 3.16 Monthly actual evapotranspiration of Beressa river catchments for fine sand soil covered with matured forest and 250 mm maximum available water capacity root depth.

No	Items	Jan.	Feb	Mar.	Apr.	May	June	July	Aug	Sep	Oct.	Nov.	Dec.	Total
1	P	31.47	32.67	78.91	72.22	54.26	59.98	287.23	293.79	111.59	50.45	27.51	19.29	1119.37
2	PET	100.99	100.50	112.16	114.90	123.3	118.83	74.10	72.05	82.00	93.10	92.45	96.04	1180.42
3	P-PET	-69.52	-67.83	-33.25	-42.68	-69.04	-58.85	213.13	221.74	29.59	-42.65	-64.94	-76.75	
4	Acc.pot WL	-251.86	-319.69	-352.94	-395.62	-464.66	-523.51	-	-	-	-42.65	-107.59	-182.34	
5	Sm	90.65	69.11	60.50	51.15	38.80	30.66	243.79	250	250	211	162.73	119.71	
6	ΔSm	-29.06	-21.54	--8.61	-9.35	-12.35	-8.14	213.13	6.21	0	-39	-48.27	-43.02	
7	AET	60.53	54.21	87.52	81.57	66.55	68.12	74.10	72.05	82.00	89.45	75.78	62.31	874.19
8	D	40.46	46.29	24.64	33.33	56.75	50.71	0	0	0	3.65	16.67	33.73	306.23
9	S	0	0	0	0	0	0	0	215.53	29.59	0	0	0	245.12

Table 3.17 Long term actual evapotranspiration (AET) of Beressa river catchments

Ser. no	Soil type	Land use/ Land covere	Aerial coverage (km^2 / %)	AET (mm)	Weighted AET (mm)	Moisture surplus (mm)	Weighted Moisture Surplus (mm)
	Silt loam	Dominantly cultivated land covered with Wheat, barley, beans, peas and open grass	252 / 75	704.9	528.67	414.46	310.85
2	Fine sand	Scattered plantation , i.e., Eucalyptus wooded plant, Shrubs, Bushes	73.9 / 22	800.38	176.08	318.99	70.18
3	Fine sand	Matured forest	10.1 / 3	874.19	26.23	245.12	7.35
Total					731		388.85

Where p = precipitation PET = Potential evapotranspiration AET = Actual evapotranspiration

Sm = Monthly soil moisture ΔSm = Monthly change of soil moisture D = Soil moisture deficit

Acc.pot.WL = Accumulated potential water loss S = Surplus moisture

3.8 Runoff

Runoff is the water which moves in defined channel or all the water that moves over the land surface in undefined channel. The runoff process is influenced by rainfall intensity and infiltration capacity of soil. The 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, then all water reaching the land surface will infiltrate. If the rainfall intensity is greater than infiltration equilibrium capacity at the beginning all the water will infiltrate, but when the infiltration capacity drops below the rainfall intensity, some of the water starts to remain on the land surface. That water which is not infiltrate, forms flows as thin sheet of across the land surface, which is called over land flow or surface runoff (Tenalem Ayenew and Tamiru Alemayehu, 2001and Fetter, 1994). In exceptional stormy rains, runoff might occur before the rainfall exceeds the infiltration capacity of soil.

The pattern of runoff volume of any catchments or basin is a function of duration of intensity and aerial distribution of rainfall and other factors such as size, shape, geology, topography, slope, land use and land cover of catchments

In the study area, there is one river gauge station on Beressa river near Debre Birhan town. The river discharge of data collected from this station by the Ministry of Water resource shows that the 87.51million cubic meter (mcm) of water leaves annually from catchments of 211 km^2. This amount of water is not surface runoff only but there is base flow component within it (Table 3.18).

3.8.1. Base flow separation method

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 method may either under estimate or over estimate the components of river discharge where as the spreadsheet program (software) could estimate reasonably by taking in to consideration the topographic characteristics of the basin. From soft ware base flow separation methods, the annual base flow and surface runoff of Beressa river catchment is 149mm and 265.93mm respectively.

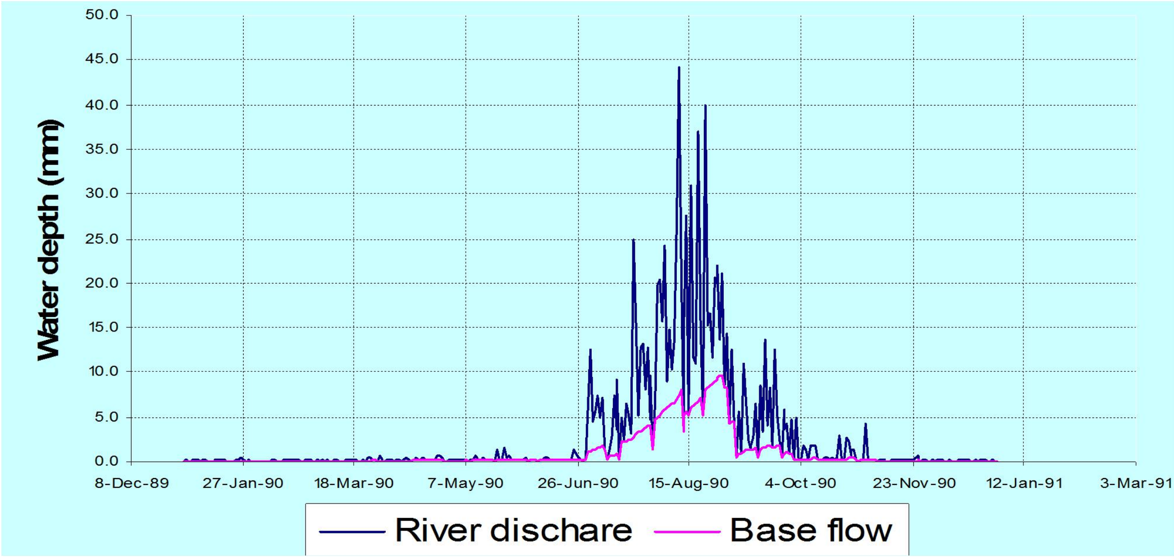


Figure 3.4 Base flow (mcm) and runoff separation from the river discharge.

Table 3.18 Amount of base flow and surface runoff (mcm) separated from Beressa river discharge

Year	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SRO(mcm)	0.16	0.12	0.22	0.34	0.49	0.8	13.4	29.82	8.19	1.85	0.54	0.15	56.11
BF(mcm)	0.19	0.16	0.01	0.27	0.39	0.46	5.98	18.9	3.93	0.66	0.26	0.18	31.4
Q(mcm)	0.35	0.28	0.23	0.61	0.88	1.26	19.4	48.72	12.1	2.5	0.81	0.33	87.51
SRO(mm)	0.78	0.56	1.04	1.61	2.33	3.77	63.7	141.3	38.8	8.75	2.57	0.71	265.93

BF = Base flow. SRO = surface runoff. Q = Total river discharge. mcm =Million cubic meter.

3.8.2 Runoff - rainfall relationship

The nature of the runoff to rainfall relationship over long periods depends primarily on the structure of the catchments area, but it can also be affected by climate of the area (Shaw, 1988). The runoff – rainfall relationship is useful to understand the geomorphologic and hydrogeological condition of the catchments because runoff depends on size, shape, geology, topography, slope, land use and land cover of catchments.

As it is shown from bar graph figure 3.18, the most maximum rainfall occurred in the months of July and August, but the maximum river discharge recorded in the month of August. From hydrogeological point of view, even though there is maximum rainfall in the month of July, most part of it infiltrate to the subsurface to saturate or up to its infiltration capacity. The catchments do not show fast response to rainfall. This means, there is time lag between high rainfall and runoff. This explains relatively higher residence time and storage of groundwater.

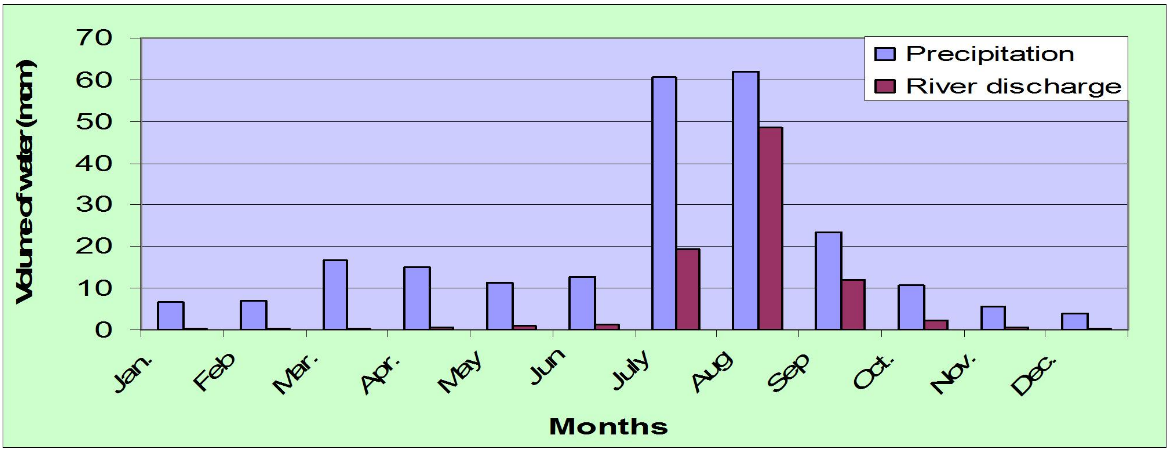


Figure 3. 5 Bar graph showing the relationship between river discharge and precipitation

CHAPTER FOUR
GEOLOGY

4.1 Regional Geology

4.1.1 General

The Ethiopian highlands were characterized and mapped as a flood basalt province and dominated by a Tertiary volcano (Mohr, 1983). As a result of the tectonic process the Ethiopia plateau (western highlands) as whole is a great horst narrowing northwards and gently dipping from eastern boarder (3000-4000 m above MSL) to western border (1000-1500m above MSL) (Marla, et. al, 1979)

4.1.2 Volcanism of the Trap series

4.1.2.1 Ashangi Basalts

The Ashangi basalt chronologically belongs to Paleocene to Eocene. It is the oldest and the first cycle of Tertiary volcanic rocks. The type of volcanism is characterized by fissural. These volcanic very often turn out to be crushed by tectonics and the large-scale erosion probably removed the upper portions (Zanettin and Justin–Visentin, 1974). This group consists predominantly alkaline basalts with inter bedded pyroclastics and rare rhyolites erupted from fissures. They are injected dololarite sills, acidic dykes, and gabro diabase intrusions. The flow ranges in total thickness from 200 to 1200m. The thickest exposed reaction occurs close to the rift escarpment suggesting that the main source was associated with the rift faults (Kazmin, 1975)

The upper part of Ashangi group is more tuffaceous and contains lacustrine deposits including lignite seams and acidic volcanic and locally over lies the older part of the group with angular unconformity (Katmin, 1975).The out crops of Ashangi basalts are restricted to the northern central part of Ethiopian plateau (Zanettin and Justin - Visentin, 1975)

4.1.2.2 Aiba basalt

The Aiba basalts were separated on Ethiopian plateau as the units comprising the second major volcanic cycle. The basalts of this formation were produced by fissural eruptions and attain a thickness of 200 to 600m meter. They are generally aphyritic compact rock, in places showing clear stratification. Their absolute age ranges from 34 to 28 m.y, placing the Oligocene (Zanettin and Justin- Visentin, 1973 cited in kazmin,1979).

Aiba basalts are flood basalts with rare tuffs. The flows are always evident with columnar jointing. The Aiba basalts pinch out southward and westward (Merla et al, 1979)

4.1.2.3 Alaji- formation

On the Ethiopian plateau the Alaji formation is represented mainly by aphyric stratoid basalts associated with rhyolites and ingnibrite and to a lesser extent with trachytes (Katmin, 1979)

According to Zanettin and Justin-Visentin,(1973 in kazmin,1979) the acidic rocks (interbedded with greater or lesser amounts of statiform basalts) of central-eastern Ethiopian plateau form a large and continuous cover extending from Amba Alaji to Debre Berhan and Mugher areas. These acidic rocks lie on the "Aiba Flood basalts" and are over laid by the "Tarmaber basalts" which are the products of a central type volcanism.

Northwest of the line joining Ambo and Fichie, on the Addis Ababa- Dessie road, the Alaji basalt is Oligocene age, from 36-34 to 28-26 m.y (Alaji- Molale), while to the southeast of this line they are lower – middle Miocene, from 26 to 16-13 m.y (Alaji-Sirro). Thus, the migration of the Alaji - type volcanism from north to south is established (Zanettin et al. 1974a, cited in kazmin, 1979).

4.1.2.4 Tarrmaber basalts

The Tarmaber basalts which are considered to be shield groups were erupted from central volcano of Hawaiian type and the formation is represented by various femic pyroxine-olivene porphyritic varieties to plagioclase porphyritc types, also contains large amounts of tuffs, scoraceous lava flows, and red paleosoils. Sometimes the lava flows fills ancient erosion channels cuts in the paleosoils are frequent (Merla et al., 1979 and kazmin, 1979).

The Tarmaber basalts occupy large area in the more elevated area of northern Ethiopian plateau (northern high lands) and escarpment (Zanettin and Justin-Visenttin, 1973 in kazmin,1979) On Ethiopian plateau the shield volcano of the Tarmaber formation become progressively younger from north to south. Central- type volcanism started in the north about 26m.y in lower Miocene (Tarmaber Guassa) .In southern part of the plateau the shield volcanoes were formed from 15-16 to 13m.y in middle- Miocene(Tarmabler Meghezez) (Zanettin et al., 1974).

4.1.3 The Rift Series

After the formation of the escarpment of south-western Afar and of the proto-Ethiopian rift, fissural volcanism become confined to the rifts. At the foot of the escarpment the titled and eroded lavas of the preceding stage were covered unconformably by transitional flood basalt (Fursa basalts; 12-10 m.y. ago). Later, a long strip of the escarpment was up lifted in Karakore area, forming a horst of separated from the Ethiopian plateau by the marginal graben of the Borkena river and about the same time, a great fault running E-W via the Cassam river, Addis Ababa and Ambo, cut across the escarpment. Then fissural basalts accompanied by emission of rhyolites continuously. South of the Ambo-Cassam river fault, ignimbrite volcanic were emitted (Balchi rhyolite; 8-2 m.y. ago) that buried the southern most part of the Miocene escarpment. Many well known Ethiopian volcanic cones, such as Wochacha, Yerer, Zuquala etc are belong to Balchi formation and locally central volcanism was followed (Bishoftu basalts 1.5 m.y old.) (Zanettin and Justin –Visentin, 1978)

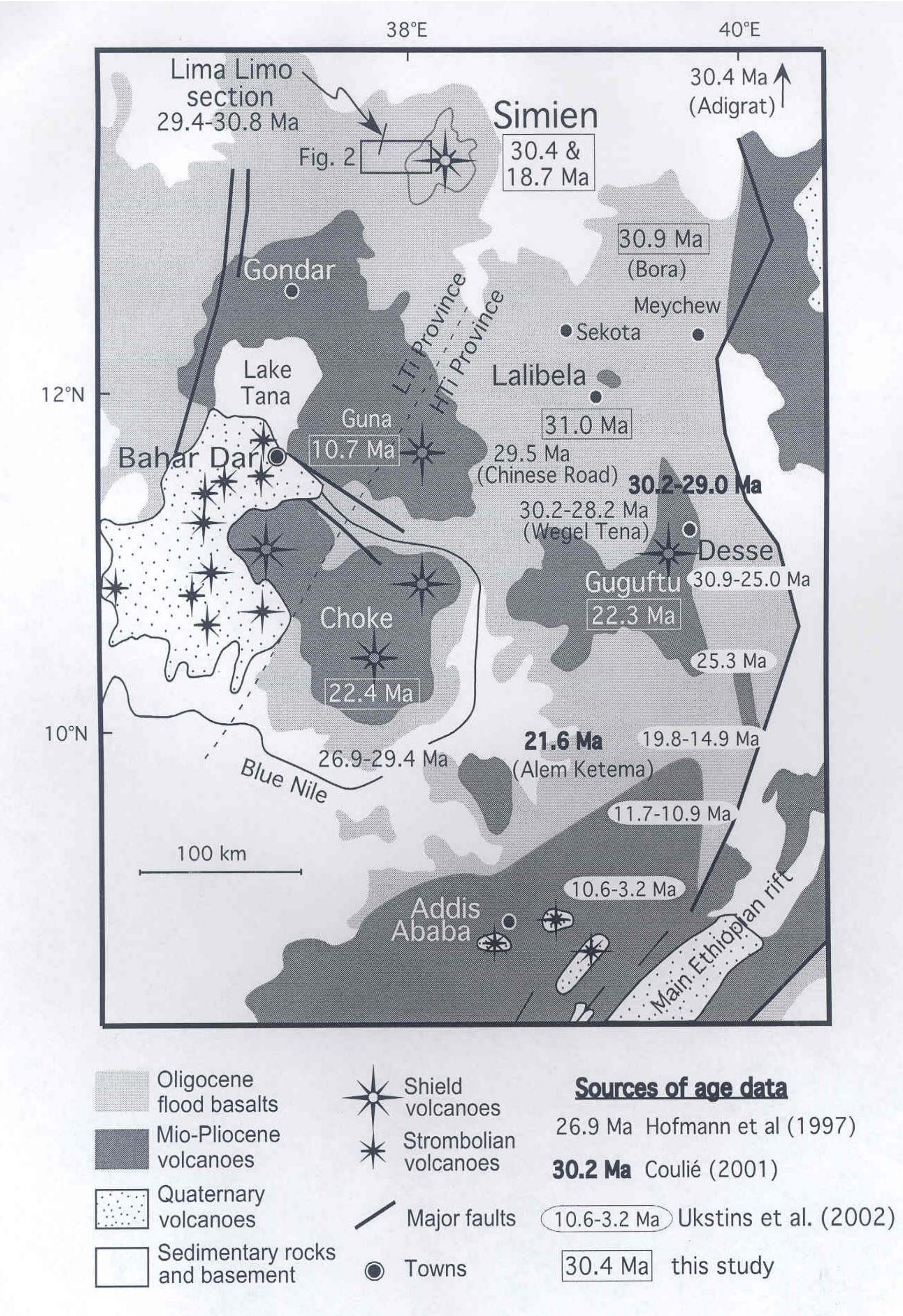


Figure 4.1. Map of the northern part of Ethiopian plateau showing volcanic province (Source: kiffer et al., 2004).

4.2.1 Local Geology

4. 2.1 **General**

Considering the previous work, it is not possible to get large scale geological maps which show the geology of Beressa river catchments except 1:250,000 scale, sheet Nc37-11 which had been done by BCEOM-French Engineering Consultants, (1998), during Abbay River Basin integrated development master plan project. This map mainly adopted from Ethiopia and Somalia 1:2,000,000 scale geological map prepared by Merla et. al. (1979) and other publication like Zanettin and Justtin-Visentin (1974) supported with satellite image and minimum field visit (BCEOM, 1999). The map has certain limitation to indicate the local geology of the study area.

According to Zanettin and Justin-Visentin (1974), in the central eastern Ethiopian plateau, extending from Amba-Alaji to Debrebirhan and Muger area, the acidic rocks lie on the "Aiba flood basalt" and overlaid by the "Tarmaber basalt" which is the product of central type volcanism.

4.2.2 Lithologic units

. From aerial photograph interpretation and intensive field geological mapping of the study area, 4 main lithologic units are identified and mapped with the scale of 1:50000 (Fig.4.2). Accordingly the following 4 lithologic units are outcropped from lower (Beresa river gorge) to upper limit (Wef Washa Mountain).

1 Lower basalt
2 Ignimbrite, rhyolite, tuff
3 Upper basalt
4 Alluvial and residual silt clay soil

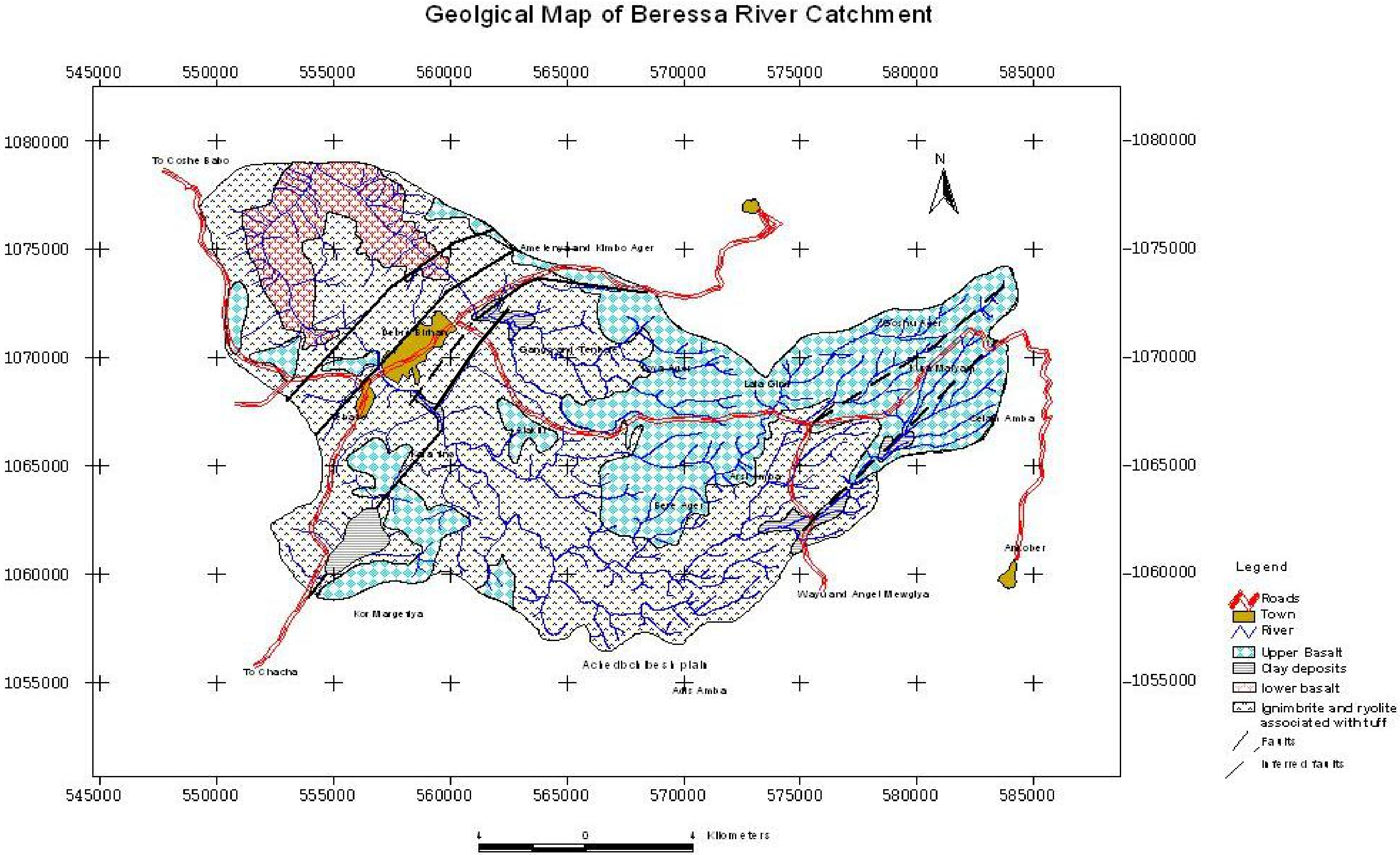


Figure 4.2 Geological map of Beresssa river catchment

4.2.2.1 Lower basalt (LB)

The lower most part of the lithologic unit of the study area is characterized by basalt. This formation is located in the Beresa and Dalecha river gorge forming steep cliffs at northern part of the investigated area. It has up to 600 m thickeners. The successive flow of this formation deeply eroded by the rivers determining steep cliffs alternating with shoulder shaped gentle slope. This rock unit is highly jointed and fractured by minor local faults (Plate 4.1). It has dark grey colour and aphanitic texture. This rock is very similar with Aiba basalt described in the regional geology (Section 2.1.2.2)

Plate 4.1. Fractured and jointed lower basalt located in Beressa river gorge.

4.2.2.2 Rhyolitic ignimbrite and tuffs (IRT)

On the top of the lower basaltic unit silicic volcanic products of ignimbrite, rhyolite and tuff have been out cropped in the area as the second major volcanic rock units. The ignimbrite, rhyolite rock units are joined, fractured and weathered (plate 4.2).The coarser grain ignimbrite rock contains phenocrysts of quartz and feldspars. The fresh rocks have got light grey, light greenish and white colour. These rock unites are similar with Alaji formation described in regional geology (section 2.1.2.3)

Plate 4. 2 Weathered, fractured and jointed Rhyolitic ignimbrite at Keba area

Plate 4.3 Quarry site of rhyolitic ignimbrite at Wushawshigne.

4.2.2.3 Upper basalt (UB)

The third main volcanic unit overlay on the top of ignimbrite rhyolite and tuff is Basalt. There are paleosoil in between different flows. Its thickness varies locally. This rock unit is highly weathered and fractured. It has aphanatic and porphyritic texture. The main phenocrysts are plagioclase feldspars. This rock covers the upper and middle catchments of the study area. Its textural feature very similar with Tarmaber basalt described in this chapter section 4.1.2.4.

Plate 4.4 Spheroidally weathered upper basalt at Tora Mest area

4.2.2.4 Alluvial and residual silt clay soil

Due to highly undulated topographic nature of the area, most of the stream and river beds out crops rock units. On the gentle slope of the hills, there is a wide area of cultivated land having brown clay and silt residual soil with an average depth of 0.50m overlaying on ignimbrite, rhyolite and basaltic bed rock. This thin thickness residual soil unit mapped according to the bed rock lithologic type. But there are some soil patch mapped as soil unit which covers relatively wide area along flat rivers and small valley coarse.

The soil thickness varies locally and reaches up to 4m thickness in some places. This soil has mostly brown colour.

Plate 4.5. Alluvial and residual silty clay soil along river valley at Tora Mesk area.

4.2.3 Geological Structure

As indicated on the geological map (Fig 4.2) there are clears major and inferred faults having NE- SW trend. These faults have the same orientation with major faults forming the western escarpment of the rift valley adjacent to the study area.

Major faults are seen NE and SW of Debre Berhan town. The town is situated on the horst like NE- SW elongated ridge. Different set of joints are observable along the stream bed and cliff forming lower basalt and ignimbrite rocks.

CHAPTER FIVE
HYDROGEOPHYSICS

5.1. INTRODUCTION

Hydrogeophysics is a branch of geophysics that deals with the problem of hydrogeology. The most common hydrogeological problems are

- the location of interface between different layers,
- location and direction of fractures and faults,
- determination of depth, lateral extent and thickness of the aquifer
- mapping of buried river channels,
- determination of salinity in ground water (TDS)

In groundwater exploration, geo-electrical (resistivity survey) method is the most widely used method to study and solve the hydrogeological problems.

5.2. ELECTRICAL RESISTIVITY SURVEY

Electrical resistivity surveying is based on the principle that the distribution of electrical potential in the ground around a current carrying electrode depends on the electrical resistivity and distribution of the surrounding soils and rocks The usual practice in the fields is to apply direct electrical current by means of two electrodes (AB) implanted in the ground and to measure potential difference between two additional electrodes (MN) that do not carry current.

5.2.1 ELECTRODE LAYOUT IN RESISTIVITY SURVEYS

In this work, more attention is given to vertical electrical sounding (VES) and electrical profiling methods for depth investigation and lateral variation respectively. The selection of particular electrode array depends according to the needed information, the local condition of the terrain, capability of the instrument, the ease of interpretation of the array data, etc. Even though, different electrode array are available, only Schlumberger and Wenner electrode array is used in this work.

From the measured apparent resistivity data, it is possible to estimate the electrical parameters of subsurface geological formations which are based on established physical laws. The physical principle underlying the resistivity method is embodied in ohm's law.

Apparent resistivity is determined using observed values of potential difference (ΔV) created by current flow (I).

The relation between these parameters is expressed by ohm's law (Reynolds, 1997).

$$R = \frac{V}{I} \tag{5.1}$$

Where R is resistance the formation that the current pass in (ohms)

V is potential difference across formation (volt)

I I is current passing through formation (ampere)

The apparent resistivity of ground section is related to the resistance (R) through geometric factors which specify a current path length and cross-sectional area through which the current flows

$$R = p\frac{L}{A} \tag{5.2}$$

Where p is electrical resistivity or electrical specific resistance (ohm-m).

L is the length of the material through which the current flows

A is cross-sectional area through which the current flows

5.2.1.1. Schlumberger array

Schlumberger array is mostly used for quantitative interpretation in vertical electrical sounding (VES). When compared with Wenner array, it offers the important advantage of being less sensitive to unknown lateral inhomogeneties because the potential electrodes (M and N) remain in fixed position during a large number of successive increases of current electrode. In field operation, the Schlumberger array is faster and easier than Wenner array because in Wenner array all four electrodes move between successive measurements and need more time and labour.

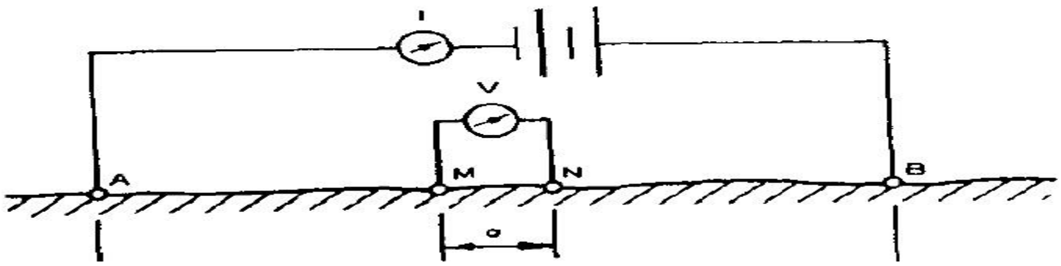


Figure 5.1 Current and potential electrode arrangements in Schlumberger array

$$p_a = K\frac{\Delta U_{MN}}{I} \qquad (5.3)$$

Where K is geometric factor

$$K = \frac{2\Pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}}$$

and AB should be at least five times greater than MN.

.5.2.1.2. **Wenner Array**

Mostly Wenner array is used to investigate lateral changes in apparent resistivity reflecting lateral anomalous features. This array consists of four electrodes in line separated by equal intervals denoted by "a". (Fig 5.3)

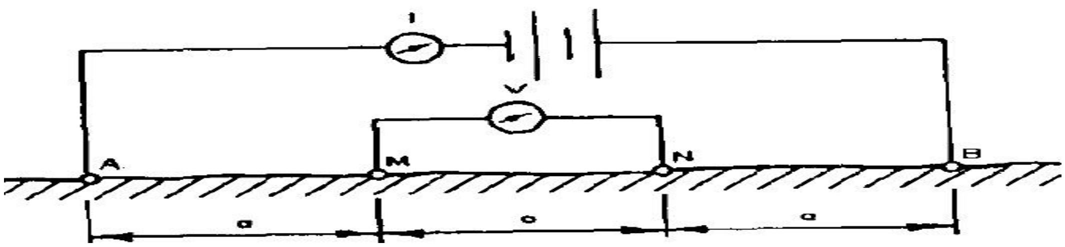


Figure 5.2 Current and potential electrode arrangements in Wenner array.

$$p_a = K\frac{\Delta U_{MN}}{I} = 2\Pi a\frac{\Delta U_{MN}}{I} \qquad (5.4)$$

Where K is geometric factor

$K = 2\Pi a$ and $a = AM = MN = NB$

5.2.2 Data acquisition and processing

The main objectives of electrical resistivity survey in this work are:

1. To know the depth of aquifer
2. To identify the main fracture of the fault zone
3. To understand whether or not there is aquifer transfer between adjacent sub-catchments (Dalecha and Beressa well fields).

Within these contexts, electrical resistivity data was gathered using OYO instrument. The VES survey was conducted using Schlumberger array by expanding the current electrodes to the maximum spacing of AB/2 = 420 meter. The VES data are first interpreted manually using two layers master and auxiliary curves. Then the raw data was entered manually into RESIX^{PLUS} software package. With the RESIX^{PLUS}, the software models were produced and compared with manually interpreted data. Then some adjustments were conducted to reduce the errors as much as possible and to know the resistivity and thickness of each layers (Annex 5). With processed data two geo-electrical sections was produced using the aligned vertical electrical soundings (VES) considering their separation (Fig. 5.6 and 5.7)

Based on VES apparent resistivity values, two pseudosections were produced using surfer software for qualitative interpretation. These pseudosections profiling contours show the lateral and vertical variations of electrical properties within subsurface (Fig. 5.6 and 5.7)

Three profiling data was gathered using Wenner electrode configuration with electrode spacing
a = 60 meter at Dalecha well fields. Each profiling survey covers 1350m distance and 22 readings. The separation distance between each profile is 650m. With the data produced by Wenner array, three profiling graph (Fig. 5.8) and one profiling contour map (Fig.5.9) were produced using Microsoft excel and surfer software respectively.

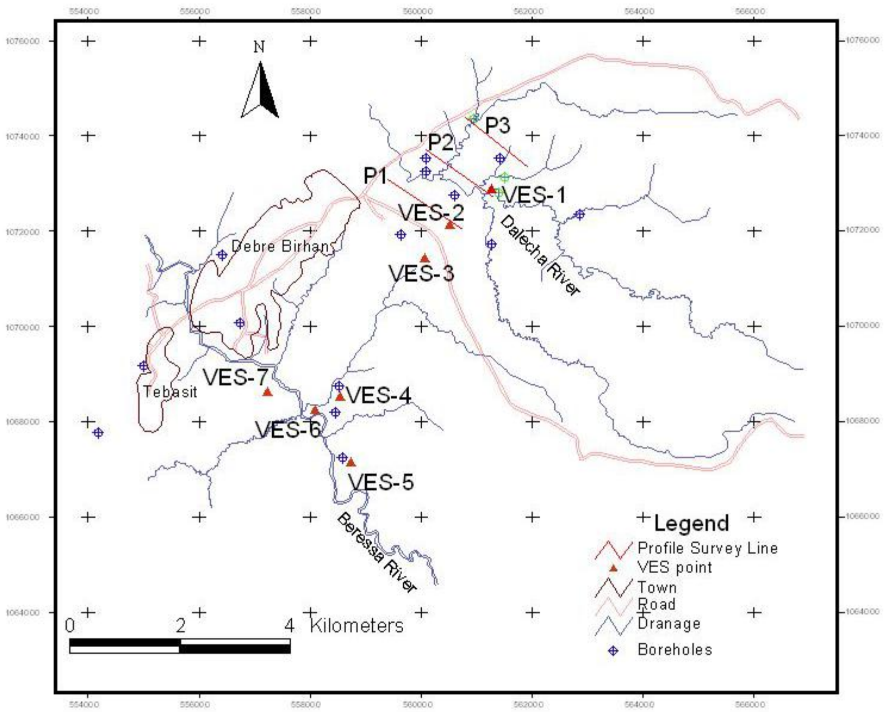
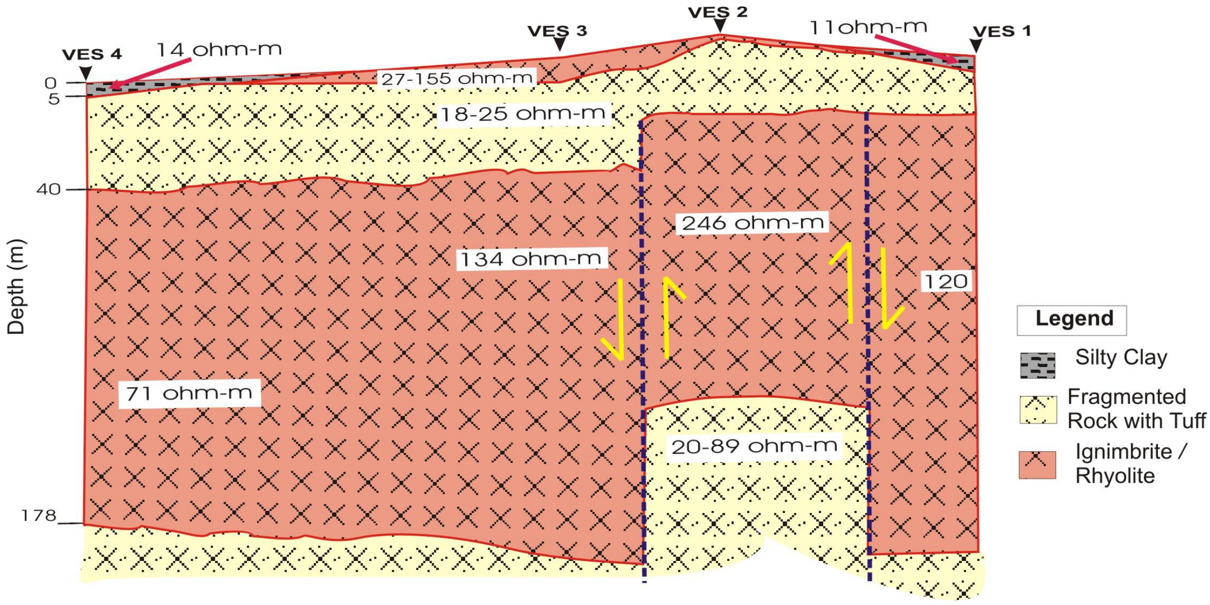


Figure 5.3 Locations of VES and Profile stations



a). Geo-electrical section of VES1, 2, 3, 4

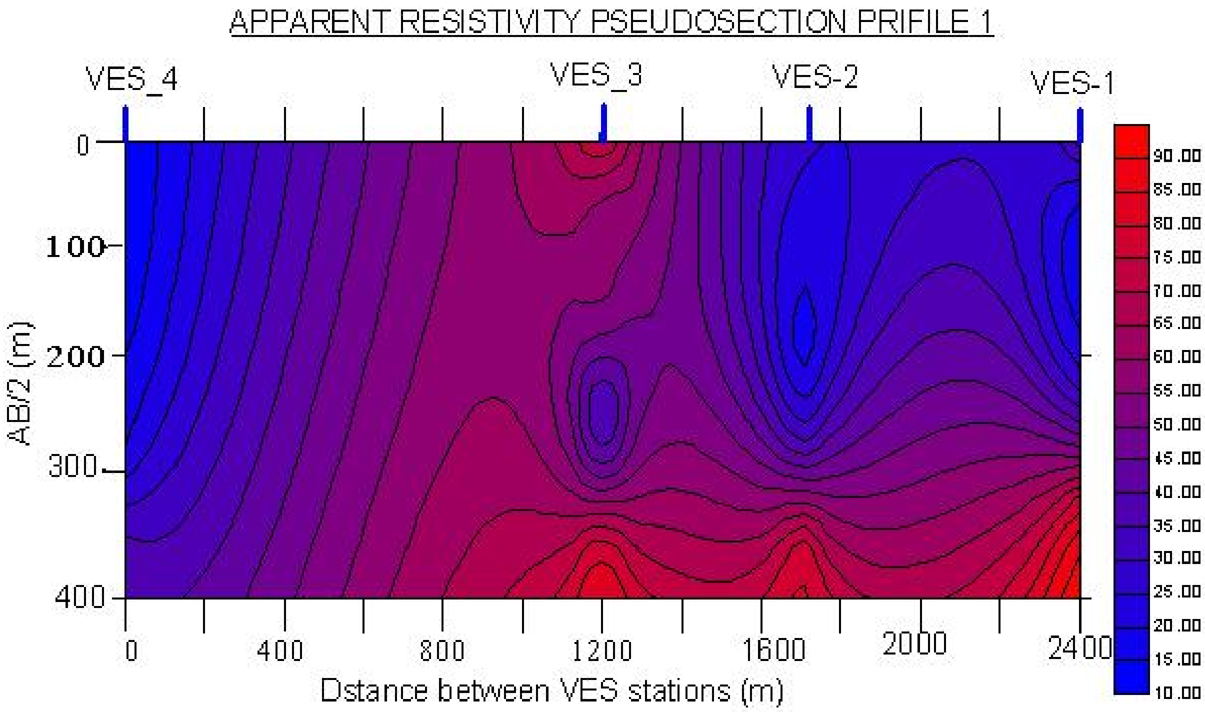
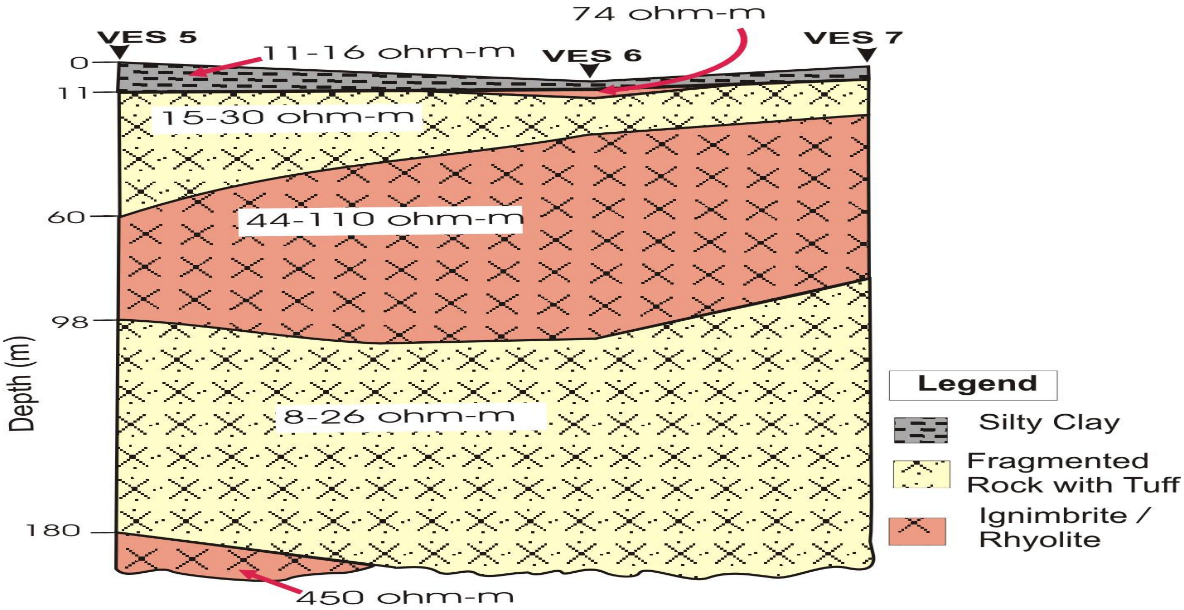


Figure 5.6 Geo-electrical sections and apparent resistivity pseudosections of VES1, 2, 3, 4 data



b) Geo-electrical of VES5, 6, 7

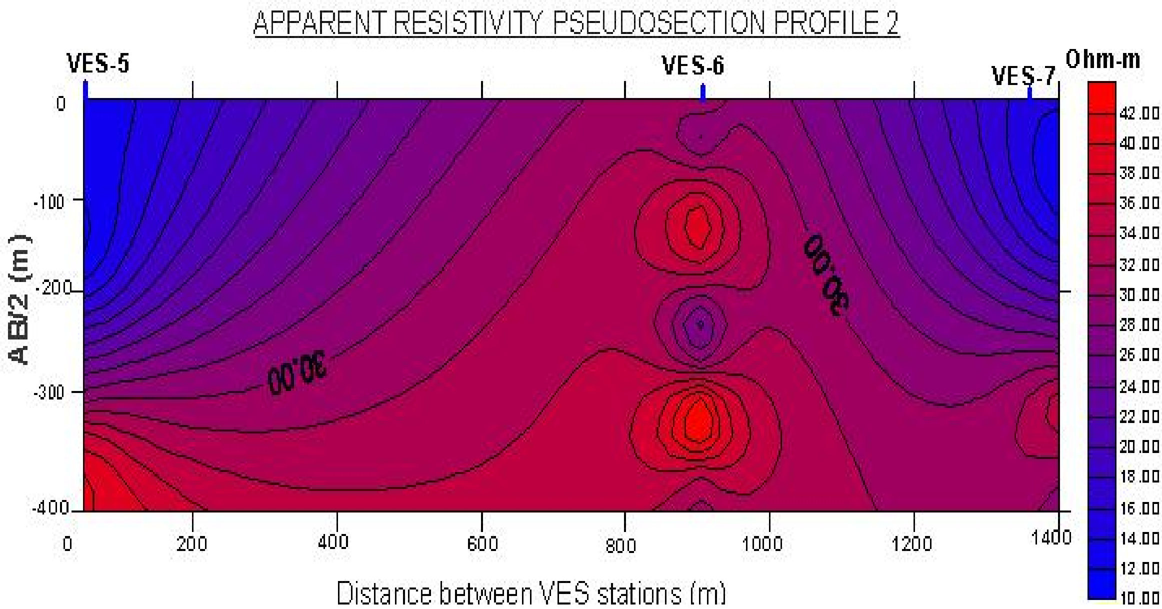


Figure 5.7 Geo-electrical sections apparent resistivity pseudosections VES5, 6, 7

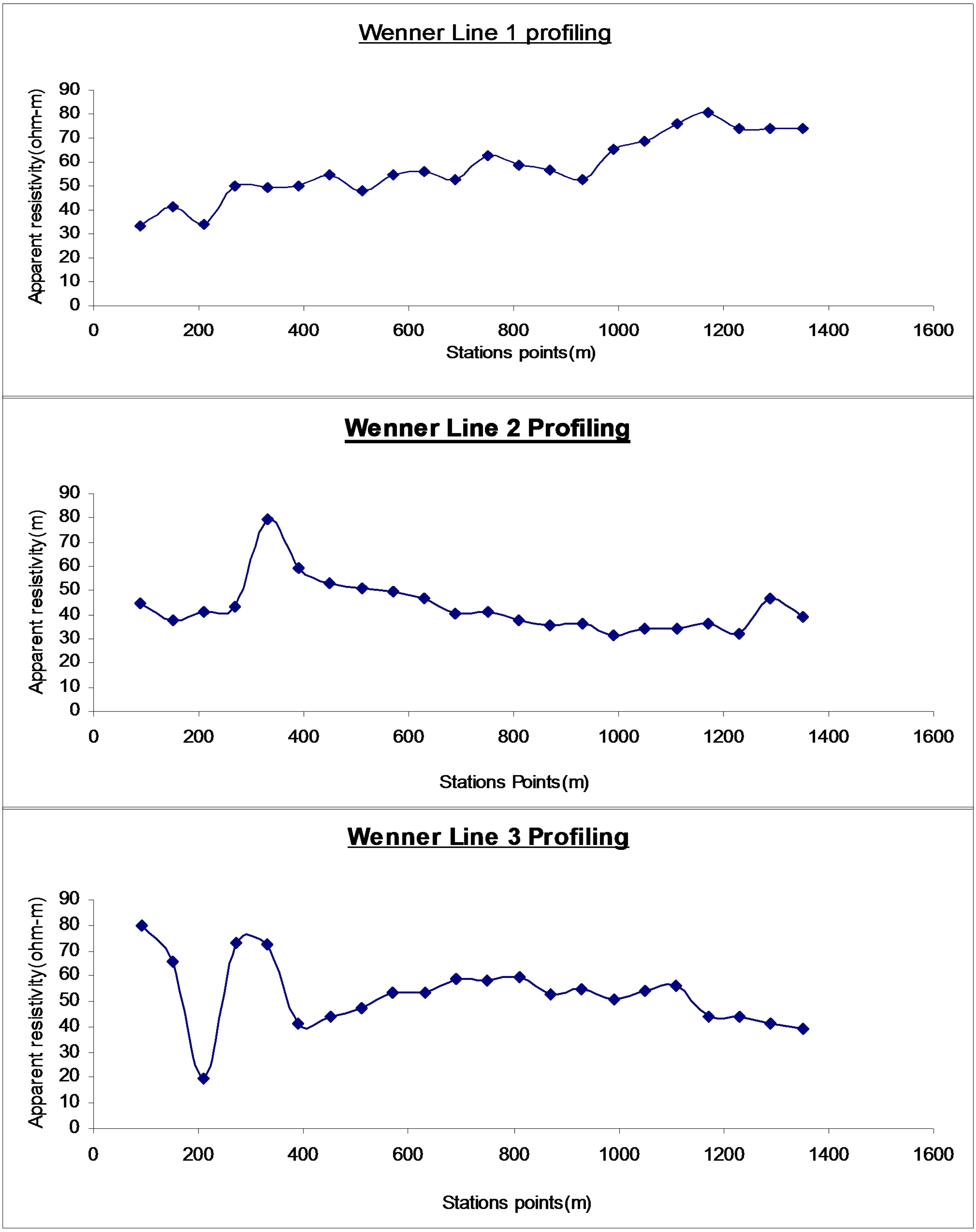


Figure 5.8. Wenner array apparent resistivity profiling graphs.

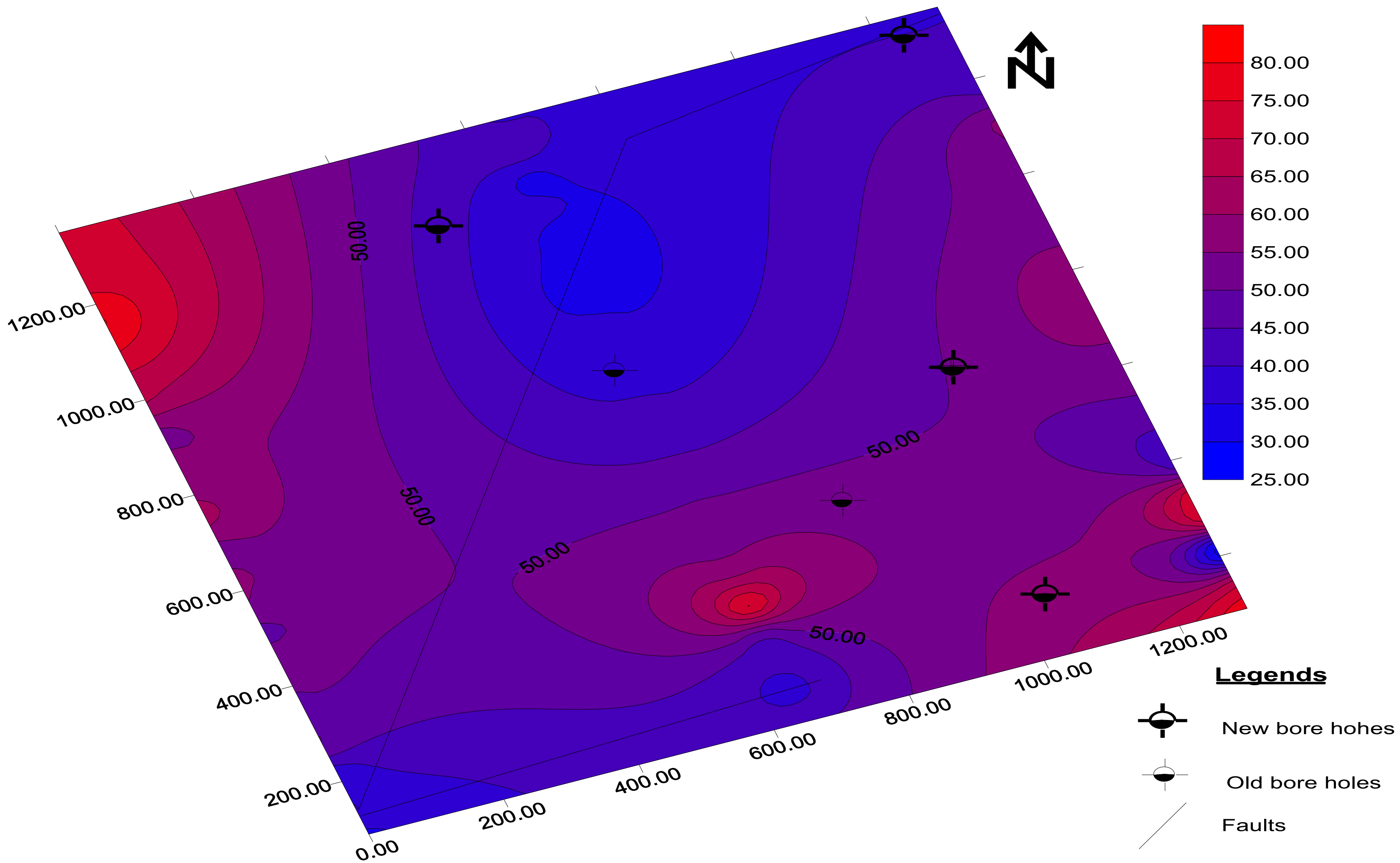


Figure 5.9 Wenner array apparent resistivity profiling contour map.

5.2.3. Result and interpretation

Two geo-electric section and apparent resistivity pseudosection profiling produced from the VESs data uses for quantitative and qualitative interpretation respectively. The profiling graphs and contours produced from Wenner array apparent resistively data are used for qualitative interpretation with the consideration of geological and hydrogeological condition of the area.

The geo- electric section produced from VES-1, VES-2, VES-3 and VES-4 as presented on figure 5.6 shows mainly four lithostratigraphic units. From top to bottom these units are:-

- Silty clay soil.
- Fragmented rock associated tuffs.
- Ignimbrite / rhyolite
- Fragmented rock associated tuffs.

The silt clay soil has resistively values 14.6 ohm-meter and 4.64 thicknesses at VES-1 and 11.39 ohm-meter resistively values and 5.28m thickness at VES-4.

Fragmented rock associated tuffs have an average resistivirty 18-25 ohms-m and 15-40 m thickness. This formation has minimum15m thickness at VES-1 and maximum 40 m thickness at VES-3. As result of borehole logging, this formation is semi-compacted and significant water bearing formation (aquifer zone) depending on rock fragment proportion. Having higher rock fragment proportion has better transmisivity and hydraulic conductivity. At VES-3, the top 10 m thickness of this formation has relatively higher resistivirty (57 ohms-m).

The third litthostratigraphic unit is ignimbrite / rhyolite has an average resistivity 71-246 ohms-m and 100- 170m thickness. The minimum resistivity value is 70 ohms-m at VES 4 and maximum resistivity value is 246 at VES-2. From borehole logging, degree of weathering and fracturing effects of this formation varies with depth. This formation is an aquifer and is its transmissivity and hydraulic conductivity values vary with degree of weathering and fracturing.

The fourth litthostratigraphic units is fragmented rock associated tuffs. This formation has an average resistivity 20-80 ohms-m and unknown thickness. The least depth of this formation is 100m at VES-2. This formation is very shallow at Beressa well field see figure 5.7 geo-electrical section produced by VES-5, VES-6 and VES-7

VES-1, VES-2, VES-3 and VES-4 were conducted along the main fault line running south west to north east. VES-1 at Dalecha well field and VES-4 at Beressa well fields; the rest VES-2 and VES-3 are conduced near water divide of these two well fields. The resistivity values at VES-2 and VES-3 has higher resistivity 246 ohms –m and 134 ohms-m respectively. As explained in this chapter section 5.2.4, aquifer transfer between adjacent sub-catchments (Dalecha and Beressa well fields) is one of the geophysical survey objectives. As observed from geo-electrical section 1 and apparent resistivity pseudosections profile1(Fig5) fragmented rock associated tuffs inclined from Dalecha well field to Beressa well fields. There for, there should be groundwater flow from Dalecha well field to Beressa well fields up to 20-40 m depth. Due to relatively higher resistivity values of ignimbrite / rhyolite at VES-2 and VES-3, there is a less probability of groundwater flow from Dalecha well field to Beressa well fields from 30m -168m depth.

As indicated in geo- electrical section figure 5.6, the fourth litthostratigraphic units is very shallow in VES-2 than the adjacent VES_1 and VES- 2 and these litthostratigraphic unit is very deep in VES-1 and VES-3 than VES-2. This condition indicates that there should be buried parallel fault on both side of VES-2 (water divide line) than being lithological flow contact.

VES-5, VES-6 and VES-7 were conducted along Beressa river on Beressa well field. Geo-electrical section produced by these data shows mainly four litthostratigraphic units except VES-5 which shows an additional highly resistive 5th litthostratigraphic units. The stratigraphic sequences of these formations from top to bottom are

- Silt clay soil with an average resistivity 11-16 ohms-m and 1.5-11m thickness
- Fragmented rock associated tuffs with an average resistivity 15-30 ohms-m and 13-48m thickness
- High to medium weathered and fractured ignimbrite / rhyolite with an average resistivity 45-110 ohms-m and 40-76 m thickness.
- Fragmented rock associated tuffs with an average resistivity 8-26 ohms-m and 82m thickness at VES-5 and unknown thickness at VES-6 and VES-7.
- Less weathered and fractured ignimbrite / rhyolite with an average resistivity of 450

ohms-m and unknown thickness. This formation is encountered at VES-5.
Except the 5th formation, the rest four formations have the same hydrostratigraphic behaviour with lithostratigraphy identified by VES-1, VES-2, VES-3 and VES-4.

Wenner array apparent resistivity profiling survey was conducted on 1260m by 1300m area at Dalecha well field. This well field is suitable to conduct apparent resistivity profiling due to its flat topography. The profiling graph and contour produced by this method could show lateral variation of formation and used for qualitative interpretation.

As it is indicated on figures 5.8 and 5.9, lower apparent resistivity profiling graph and contour vales are displayed around SSW and NNE of the area. There is a shifting of lower values from SSW to NNE of the area. When this condition compared with fault orientation on geological map of the area, there is an indication of shifting of faults from south to north.

CHAPTER SIX
HYDROGEOLOGY

6.1 Aquifer characterization

The term hydrogeology encompasses the interrelationship of the geologic material and the processes with water (Fetter, 1994). It deals with the occurrence, distribution, and movement of ground water in addition to physical and as well as chemical relationship with the surrounding environment (Sen, 1995). The work done under hydrogeological study solves economical and social problems to human concerns, i.e. ground water supply, contamination, etc.

As explained by Meinzer (1923) in Sen (1995), an aquifer is a geological formation, group of formation or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to well or spring. This water is recoverable and economically usable quantities (Fetter, 1994).

The aquifer in a given geologic media is largely a function of the degree of weathering, fracturing and faulting, the nature of the geologic material, the sediment grain size, degree of sorting and packing. Accordingly, considering all the facts together with the spring location and corresponding discharge, topographic and geomorphic position, vegetation cover and settlement patterns were used to classify the different lithostratigraphic units into similar groups of hydrostratigraphic units which show homogeneity in their hydrogeologic characteristics

Aquifer is characterized according to subsurface geological and hydrogeological conditions. The nature and distribution of an aquifer in a geological system are controlled by lithology, stratigraphy and structural features. Accordingly, the lithology of the study area is Tertiary volcanic rocks.

In this work, due to lack of evenly distributed borehole (pumping test) data, undulated and steep nature of the topography; the description and interpretation of the lithostratigraphic units are given qualitatively with their similarity in hydrostratigraphic units and having homoginity in hydrogeological characteristics such as degree of weathering, fracturing, faulting, topographic features, spring discharge and location. With these relative description and interpretation, the lithostratigraphic permeability and groundwater potential classification is given and hydrogeologicical map is produced with the scale of 1:50.000 (Fig.6.1).

As explained in section 3.3 the topography of the study area is highly undulated, rugged valleys and ridges. These conditions lead to high runoff and decrease rain water infiltration rate and each valley; ridges have their own groundwater occurrence and circulation system.

Depending on hydrometeorological and available borehole (pumping test) data analysis, degree of weathering, fracturing, faulting, topographic features, spring discharge and location; the relative lithostratigraphic permeability and groundwater potential zone of Beressa river catchments are classified as below

- High permeability and high groundwater potential zone
- Moderate permeability and medium groundwater potential zone
- High permeability and low to very low groundwater potential zone
- Moderate permeability and low to very low groundwater potential zone

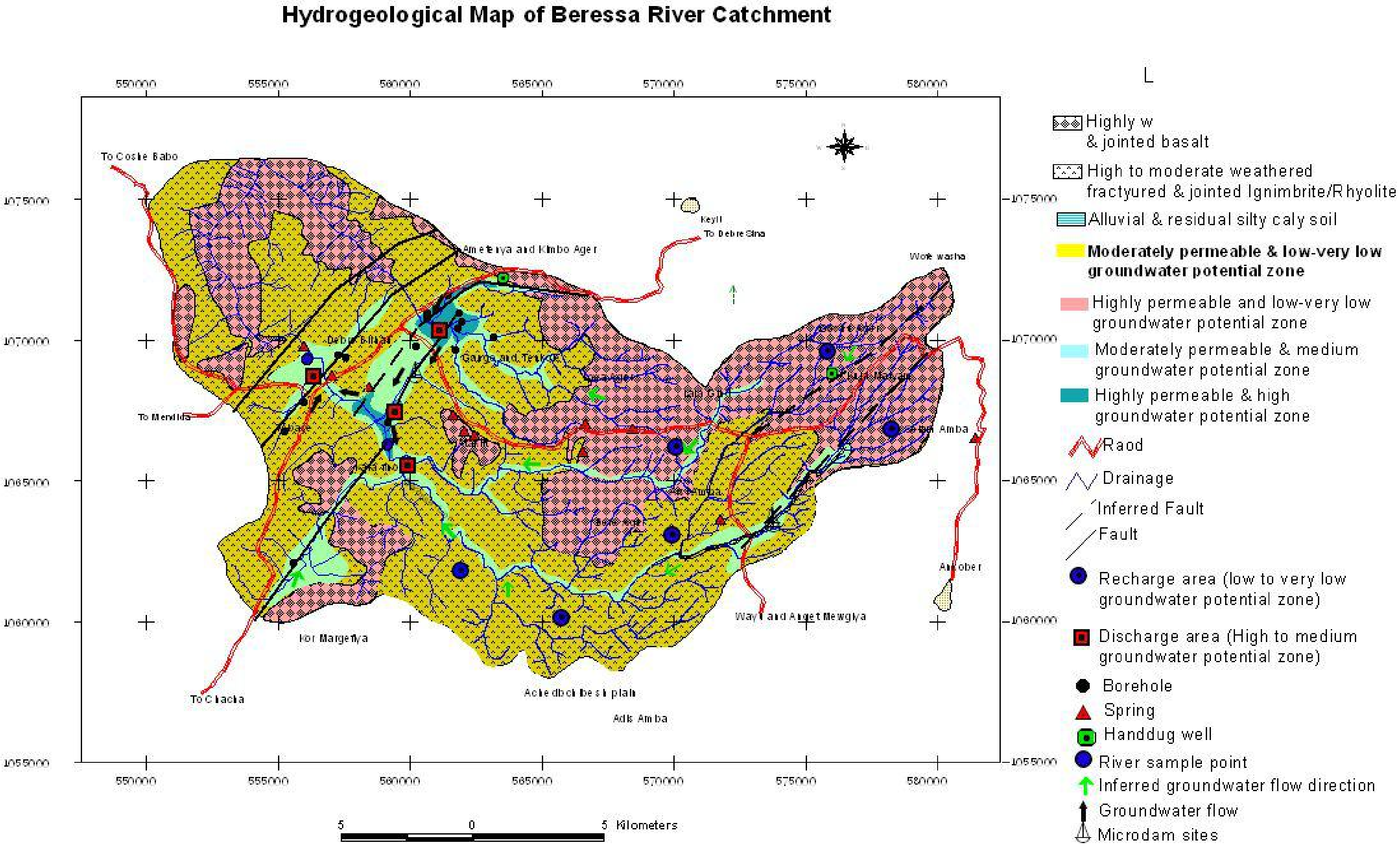


Figure 6.1 Hydrogeological map of Beressa river catchments.

6.1.1. High permeability and high groundwater potential zone

The hydrostratigraphic units of this zone are highly fractured and faulted ignimbrite / rhyolite. The permeability become higher due to fracturing effect of the normal fault running south west to north east about 2-3 km. distance south of Debre Birhan town. Because of high to medium permeability of recharge area, relatively low topography and flat to gentle slope of the area, the rain water percolate at higher elevation of the catchments flows to these highly fractured and faulted zone. In addition to the above reason, the horst like south west to north east elongated ridge formed probably by two parallel faults south and north of the Debre Birhan town may act as ground water damming. These conditions could increase the groundwater circulation and storage of the area. This area covers small land due to rugged ridges and valleys or undulated topography of the catchment.

The wells drilled on faulty area give 5-15 l/s yield, 10-283 m^2/d and 0.3-7m/d transmissivity and hydraulic conductivity respectively (Tab.6.1). The spring emanate from this faulty area have 2-10 l/s discharge rate. There for, the aquifer at this area is highly permeable and productive.

6.1.2. Moderate permeability and medium groundwater potential zone

The second hydrostratigraphic units are characterized by its moderately weathered, jointed and fractured ignimbrite/ rhyolite. Those ignimbrite / rhyolite formation far from faulty zone are less weathered, fractured and jointed where compared to basaltic formations.

The area found south of the town is faulted and fractured but groundwater potential is moderate due to the damming of south west to north east elongated ridge where the town situated. Even though some part of this area above the south west to north east elongated ridge is faulted and fractured, due to small recharge area and undulated nature of the topography the groundwater potential is moderate.

From 8 boreholes drilled in the area, only two boreholes (Dalecha NBH5 and Dalcha AFBBH) have complete pumping test data. The rest 6 boreholes do not have a complete pumping test data except well yield, static water table, and well depth etc. Some of these wells data obtained from "Debre Barman water resource verification report " conducted by GIBBS EASTERNRICA PLC. (1995). According to available pumping test and other data; the boreholes have 1-4 l/s yield, 1.54-2.22m^2/d transmissivity and 0.04-0.05 m/d hydraulic conductivity.

6.1.3. High permeability and low to very low groundwater potential zone

The third type of hydrostratigraphic units are characterized highly weathered, fractured upper basalt, and jointed and fractured lower basalt. The upper basalt outcrops at higher topography of the catchments where as the lower basalt exposed in Beressa river valley at the most lower topography of the study area.

Even if the permeability of this formation relatively high because of undulated topography, rugged valleys and ridges, most of the precipitation goes as surface runoff and the infiltrated water immediately drained and leave the area to relatively lower topography of the catchments (discharge area). Within this area, there are springs having very low discharge and hand dug wells used for local community.

6.1.4 Moderate permeability and low to very low groundwater potential zone

The fourth type of hydrostratigraphic units are moderately weathered jointed and fractured ignimbrite / rhyolite. As indicated in chapter 4 section 4.2.2.2, this formation outcrops below upper basalt and above the lower basalt.

Groundwater potential of this zone become very low due to undulated, rugged valleys and ridges and the precipitation goes as surface runoff and the infiltrated water immediately drained and leaves the area to relatively lower topography of the catchments (discharge area). The same to hydrostratigraphic units described in this chapter section 6.1.3, there are springs having very low discharge and hand dug wells used for local community.

6.2 Recharge and discharge area

A recharge area can be defined as that portion of the drainage basin in which the net saturated flow of groundwater is directed away from the surface and the water table is usually lies at some depth where as discharge area can be defined as the movement of the net saturated flow of groundwater is directed to word the surface and the water table usually lies at or very close to the surface (Freeze and Cherry, 1979).Recharge and discharge areas are mostly located at higher and lower topography in a given basin respectively. Recharge and discharge areas are low to very low groundwater potential zone and high to moderate groundwater potential zone respectively (Fig.6.1). Identifying the recharge and discharge area of basin is important for water resource management and utilization.

As indicated in hydrogeological map (Fig. 6.1), the main recharge area of the study area is the upper catchments of Beressa river that is undulated, rugged valleys and ridges on the way to Akober town and Mitak Amanuael and Wushawshign. Recharge area relatively covers a large part of study area when compared to discharge area. The lower elevated land of the study area gets recharge not only from precipitation but also groundwater flow from upstream side of the catchments.

Discharge areas are low lands of the study area that is around Debre-Birhan town, Dalecha well and Beressa well fields. The discharge area covers relatively small area than recharge area. It is possible to identify small patches possible discharge area within limits of recharge area along rivers valley (Fig.6.1).

6.3 Water resources

Springs, hand dug wells, boreholes and streams are considered as water resources in the study area. These water resources have been used for different social and economical purposes of the community within the study area. The availability of these water resources varies according to geomorphologic set up of the area.

6.3.1 Spring

Natural springs may be defined as points, lines or limited area of earth's surface through which groundwater rise up according to the hydrological characteristics of the various water bearing formations occurring at shallow or great depth. Springs occur in many forms and have been classified by means of their origin, rock structure, discharge, temperature and variability (Tenalem and Tamiru, 2001). Very small discharge said to be seepage where as relatively larger discharge could be defined as springs.

Within the study area springs are the most common available water resource. Their discharge varies according to the recharge area coverage, fracturing effect and seasonal variation. They display some seasonal discharge variation throughout the year, being typically at their lowest in May and June. The availability of springs and their discharge rate increase from higher to lower topography. The discharge rate varies from 0.2-10 l/sec and most of them are unprotected. Springs within the catchments are fractured springs (Annex 8.2)

6.3.2 Hand dug wells.

Hand dug wells are very shallow groundwater. Due to low transmissivity (T) and hydraulic-conductivity (K) of some upper layer soil and rock type, infiltrated rain water accumulated at shallow depth. Where the local or regional groundwater table is very shallow, it is possible to get hand dug wells.

In the study area, local people's use manually dug wells from alluvial and residual silt clay soil and from some very less fractured volcanic rocks (ignimbrite/ rhyolite). Some of these dug wells are seepage emanate at the contact between bed rock and the over laid soil, at foot of hills. There are very few properly constructed and hand pump installed hand dug wells within the study area.

6.3.3 Boreholes and their hydraulic characteristics

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

Almost all boreholes in the study area were drilled around Debre Birhan town except one well about 10 km south west from the town. The boreholes drilled on high permeability and groundwater potential zone have relatively good yield (5-15 l/sec), transmissivity (10-332 m^2/d) and hydraulic-conductivity (0.3-7.8 m/d) and where as those bore holes drilled on moderately permeable and groundwater potential zone have relatively small yield (1- 4 l/sec), transmissivity (1.5-2..22 m^2/d) and hydraulic-conductivity (0.04-0.045 m/d). Their transmissivity (T) and hydraulic-conductivity (K) varies according to hydrostratigraphic unit's characteristic such as degree of weathering, fracturing, faulting, topographic features, etc.

Even though, there is uneven distribution of wells within the catchments; the pumping test data of 10 wells is being analyzed to understand the hydraulic characteristics of the aquifer. First, semi-log and log-log time-draw down curve is drawn and compared with the theoretical standard curves given by Kruseman and de Ridder (1990) to categorize in to unconfined, confined or leaky aquifer. These theoretical curves assumed to be homogeneous, isotropic and infinite lateral extent. But in practical world it is difficult to have this type of aquifer. There for, it is impossible to get the exact similar curve with theoretical curves.

As indicated borehole logging (Fig. 6.2) and geo-electrical section (Fig.5.6 and 5.7), water bearing formations of the boreholes are multiple volcanic aquifers that is ignimbrite/rhyolite and fragmented rock associated tuffs. In these types of aquifers there may be both unconfined and confined behaviour. But in drawn time-drawdown curves (Fig 6.3), confined aquifer behaviour dominates.

Dalecha BH2 and Dalech BH7 curves (Fig.6.3) behave densely fractured and double porosity confined aquifer. During pumping test, the boreholes try to stabilize slowly, this condition show that the wells get continuous recharge from wide fracture or relatively high permeable aquifer zone

Dalecha BH6 curve (Fig. 6.3) behaves pumped well in single plane vertical fracture or confined aquifer. During pumping test this well tries to stabilize after 40 minutes pumping times. The well gets contentious recharge from groundwater potential wide fractures or highly permeable aquifer zone.

Beressa BH4 curve (Fig.6.3) behaves, single plane vertical fracture well in densely fractured dike confined aquifer. The fracture might have a finite length and a high hydraulic conductivity.

To calculate hydraulic characteristics of the wells aquifer test software package is used. From available pumping test data, COOPER & JACOB confined aquifer methods is deployed. The result of calculated Hydraulic characteristics that is transmissivity (T) and hydraulic-conductivity (K) is displayed in table 6.1

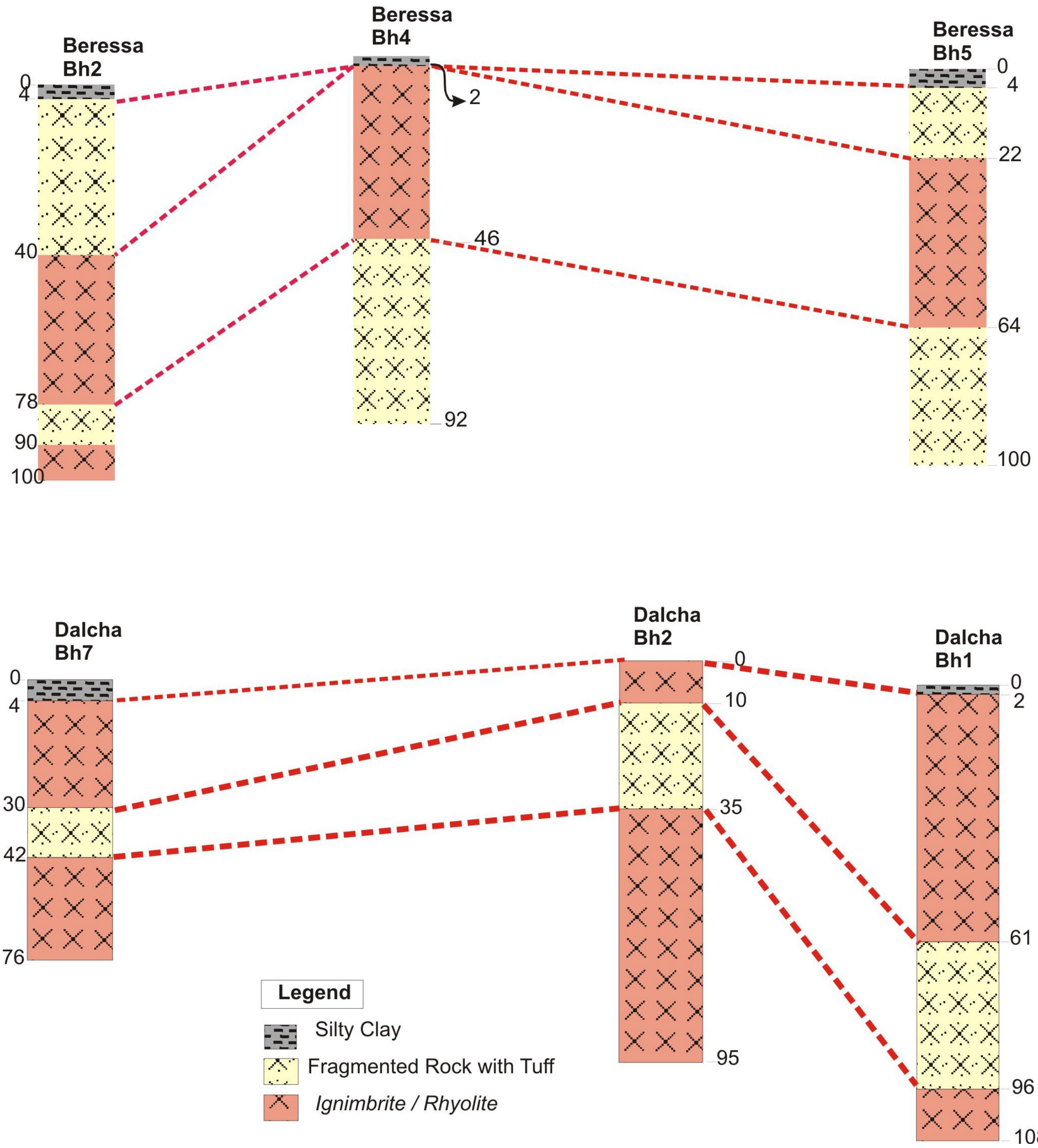


Figure 6.2 Borehole logging geological – section of Dalecha and Beressa well fields.

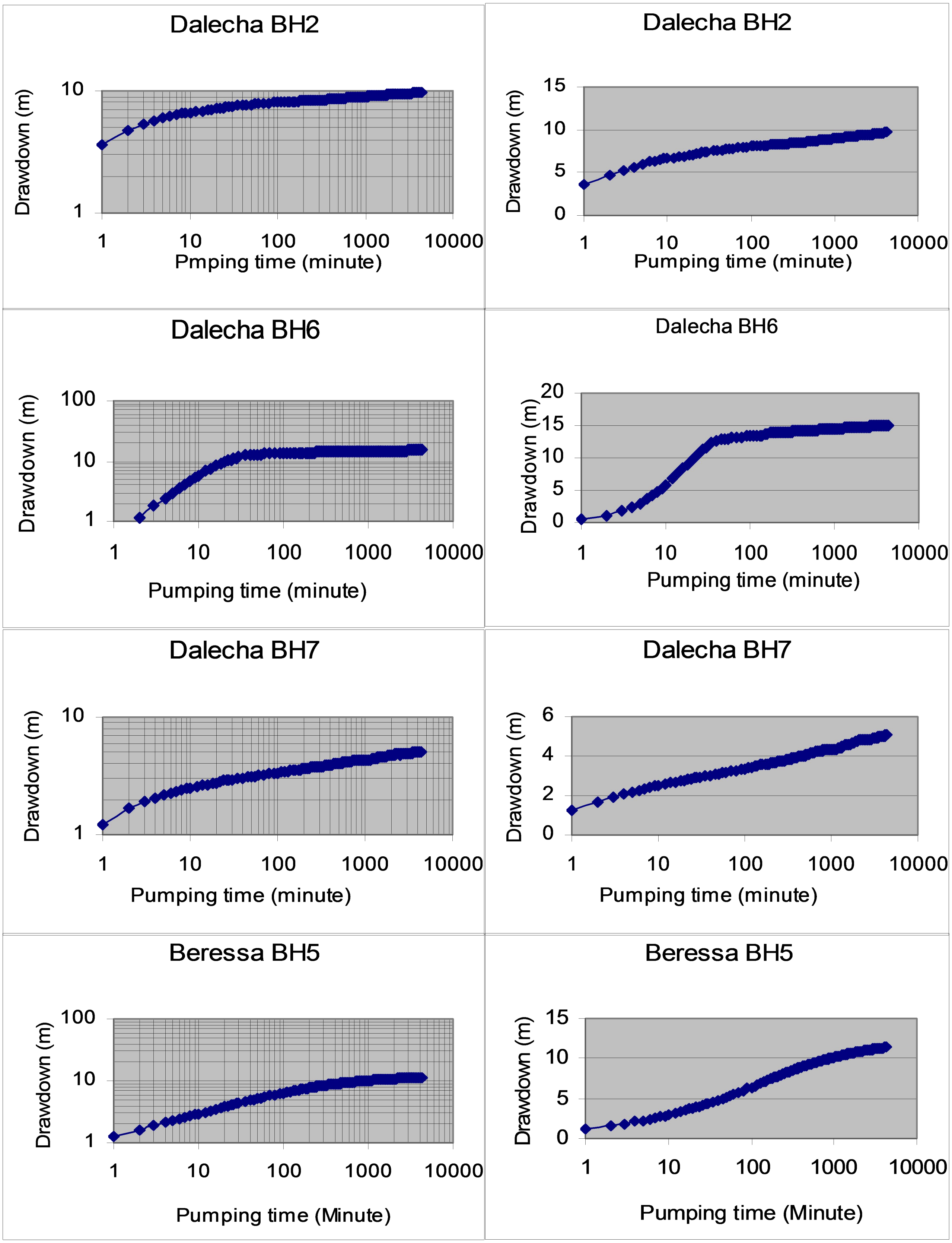


Figure 6.3 Log-log and semi-log plots of time-drawdown of pumping test data

Table 6.1 Hydraulic characteristics of some boreholes within Beressa river catchments.

No	Borehole	Location(UTM)		Alt. (m)	Aquifer type	Depth (m)	SWL (m)	Tested DWL (m)	Hours/ Tested Q (l/s)	Aquifer Thick. B (m)	T (m)	K (m)
		X	Y									
1	Dalecha NBH1	562106	1070685	2708	Ignimb/ rhyolite	108	12.79	39.68	72/7	35.74	12.70	0.35
2	Dalecha NBH2	562015	1071000	2806	Ignimb/ rhyolite	95.56	11.68	21.39	72/7	37.99	8.93	2.13
3	Dalecha NBH4	561880	1069590	2810	Ignimb/ rhyolite	125	9.2	35.65	72/5	42	11.96	0.28
4	Dalecha NBH5	563330	1070084	2812	Ignimb/ rhyolite	150	7.33	61.86	72/2.5	54	2.22	0.04
5	Dalecha NBH6	560803	1070784	2707	Ignimb/ rhyolite	108	7.4	40	72/12	48.9	181.44	3.71
6	Dalecha NBH7	561594	1071660	2804	Ignimb/ rhyolite	72	9.6	40	72/14.2	30.99	224.64	7.25
7	Beressa NBH2	559369	1067258	2780	Ignimb/ rhyolite	100.49	5.3	20.3	72/15.3	36.59	80.78	2.21
8	Beressa NBH4	559318	1066823	2787	Ignimb/ rhyolite	92	6.25	11	72/15	42.66	332.56	7.8
9	Beressa NBH5	559432	1066077	2789	Ignimb/ rhyolite	102	2.85	40	72/17	42.59	80.93	2.34
10	Aqua fine BH	560800	1071004	2818	Ignimb/ rhyolite	150	11.72	62.53	24/1.5	34.58	1.54	0.05

CHAPTER SEVEN

WATER RESOURCE EVALUATION

7.1 General

As explained by Freeze and Cheery (1979), the development of groundwater resource can be viewed as sequential processes with the following three phases.

1. Exploration stage: surface and subsurface geological and geophysical techniques are brought to bear on the search for suitable aquifer.
2. Evaluation stage that encompasses the measurement of hydrological parameters, the design and analysis of wells and analysis of aquifer yields.
3. Exploitation or management stage which must include consideration of optimal development stages and an assessment of the interactions between groundwater exploitation and regional ground water systems.

Nowadays, detail evaluation of known aquifer and careful management of known resources will take on great importance. The scope of ground water resource evaluation and management studies might best be indicated by the following series of question.

1. Where the best well fields should be found?
2. What are the long term-yield capabilities of the aquifer?
3. How much water will be stored in the basin and how much will leave the basin?
4. How surface water and ground water potentials distributed in the basin and how are they interact each other?

Therefore evaluation of water resource within a given basin or catchments is essential for efficient planning, exploration, utilization and management of available water resources. The practical work of water resources evaluation requires understanding and analysing hydrometeorological and hydrogeological parameters.

In the previous chapters; with available data, meteorological and hydrogeological parameters are analyzed to evaluate water resource of Beressa river catchments. One of the main objectives of this work is to evaluate water resource of the area in water balance approach. Water balance method is achieved through analysis of the various inflows, outflow and change of storage of water within the specified basin/catchment and period.

7.2 Water balance method of the catchments.

The water balance represents the hydrological gains and losses of a given system (reservoir, column of soil, aquifer, river basin, etc) over a specific period. It requires evaluation of in and out flowing amount of water within the area under consideration (Tenalem and Tamiru, 2001).

Generally water balance has the following form.

Inflow = Out flow ± Change in storage

Where inflow includes precipitation (P) and ground water inflow (Gi)

Outflow are actual evapotranspiration (AET) and ground water out flow (Go)

± Change in storage (±Δ S) are taken as change in water storage in this work.

Therefore the relation of these water balance components is as follow:

$$P + Gi = AET + SRO + I + Go \pm \Delta S \qquad (7.1)$$

Where I is infiltrated water to subsurface and it might recharge the groundwater of the study area.

The annual change of water storage assumed to be negligible or zero and ground water inflow (Gi) assumed to be equal to ground water out flow (Go). Finally water balance equation of the study area could be:

$$P = AET + SRO + I \qquad (7.2)$$

$I = P - AET - SRO$

P (annual precipitation) = 1119.37mm

AET (annual actual evapotranspiration) = 730.98mm

SRO (annual surface runoff) = 265.93mm

I (annual infiltrated water to subsurface) = $P - AET - SRO = 122.46mm$

The amount of water infiltrated to subsurface is 10.9% of precipitation. For 336 km^2 of the study area, that means 41.15 million cubic meter (mcm) of water might be infiltrated to subsurface.

7.1 General summery of analyzed hydrological data of Beressa river catchments.

Item	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
P (mm)	31.47	32.67	78.67	72.22	54.26	59.98	287.23	293.79	111.59	50.45	27.51	19.29	1119.37
PET(mm)	100.99	100.5	112.16	114.9	123.3	118.83	74.1	72.05	82	93.1	92.45	96.04	1181.4
AET (mm)	36.63	35.70	79.97	73.28	55.49	60.70	74.10	72.05	82.00	81.28	49.32	30.46	730.98
S (mm)	0	0	0	0	0	0	137.23	221.55	29.29	0	0	0	388.38
D (mm)	64.36	64.80	31.44	41.62	67.81	58.13	0.00	0.00	0.00	11.82	43.13	65.58	448.69
SRO (mcm)	0.16	0.12	0.22	0.34	0.49	0.8	13.4	29.82	8.19	1.85	0.54	0.15	56.11
BF (mcm)	0.19	0.16	0.01	0.27	0.39	0.46	5.98	18.9	3.93	0.66	0.26	0.18	31.4
Q (mcm)	0.35	0.28	0.23	0.61	0.88	1.26	19.4	48.72	12.1	2.5	0.81	0.33	87.51
SRO(mm)	0.78	0.56	1.04	1.61	2.33	3.77	63.7	141.3	38.8	8.75	2.57	0.71	265.93

7.3 Ground water resource evaluation of well fields.

As explained in chapter one section 1.1, Debrebirhan town water supply depends on groundwater resource exploited from boreholes. Evaluating ground water resource of the two well fields (Beressa and Dalecha well fields) is important for efficient planning, exploration, utilization and management of available water resource within each sub-catchment of the well fields.

7.3.1 Beressa well field

Beressa well field has 210 km^2 recharge area. It covers 62.5% of the study area. The water infiltrated to this sub-catchment is 25.78 mcm. If this water is considered to be recharged to groundwater storage and 50% of it is exploited for town and population water supply within sub-catchments; 12.89 mcm could be exploited annually without affecting the hydrogeological conditions of the sub-catchments.

7.3.2 Dalecha well field.

Dalecha well field has 50 km^2 recharge area. It covers 14.88% of the study area. The amount water infiltrated to subsurface of sub-catchment is 6.12 mcm. With same consideration of Beressa well field, if 50% of it is exploited for town and population supply within sub-catchments; 3.06 mcm could be exploited.

CHAPTER EIGHT
HYDROCHEMISTRY

8.1 General

The chemical composition of natural water is derived from many different sources of solutes, including gases and aerosols from the atmospheres, weathering and erosion of rocks and soils, solution and precipitation reactions occurring below the land surface, and cultural effects resulting from human activities. The ways in which solutes are taken up or precipitated and the amounts present in solution are influenced by many environmental factors, especially climate, structure and position of rock strata, and biochemical effects associated with life cycle of plants and animals, both microscopic and macroscopic (Hem,1992).

As a result of chemical and biochemical interaction between groundwater and the geological materials through which it flows, and to a lesser extent because of contribution from atmosphere and surface water bodies, ground water contains a wide variety of dissolved inorganic chemical constituents in various concentrations (Freeze and Cherry, 1979). The concentrations, relative proportions and rates of transport of dissolved materials in water sample reflect their sources path and interactions with different substances (Tenalem Ayenew, 1998). Therefore, hydrochemical data are important tools to study different water samples and safely limit of their utilization for various purposes.

8.2. Water sampling and analysis.

In any type of study in which if small samples of the whole substances under consideration are taken to be examined, there is inherent uncertainty because of possible sampling error. The extent to which small samples may be considered to be reliable representative of a large volume of material depends on several factors such as the homogeneity of the material being sampled and the number of samples, the manner of collection and the size of the individual sample (Hem, 1992).

To analyse geochemical properties of water within the Beressa river catchments, water samples were taken from upstream to lower stream of the catchments. A total of 19 water points were sampled depending on their geographic distribution and sound hydrogeological reasoning. Among these 19 water samples 3 were boreholes, 2 from hand dug wells, 2 from river and the rest 12 were from springs. But due to limitation of budget, 14 water samples chemical laboratory analysis were done in Ethiopia geological survey and Addis Ababa Water Supply and Sewerage Authority laboratory. Additionally 10 boreholes chemical laboratory data analysed by water work design and supervision enterprise laboratory in 2003-2004 were obtained from Tropics Business group PLC. To understand the hydrochemical property of the study area a total of 13 boreholes, 6 springs, 2 samples from Beressa river and 2 hand dug wells water samples chemically analysed data were used. These samples are plotted on hydrogeological map (Fig.6.1) and displayed on annex 5.3.

8.3 Water type classification

The presentation, classification and interpretation of chemically analysed water results depend on the specific objective of the analysis. For instance water intended to use for drinking is quite different water for industries or agriculture.

In order to identify groundwater interaction with subsurface geology and utilization of water for various purposes, it is essential to categorize and classify water on the basis of

- Total hardness
- Electrical conductivity (EC) and total dissolved solids (TDS)
- Major cations and anions

8.3.1 Classification based on total hardness

Hardness might be considered to be the soap consuming property of water and usually expressed in terms of calcium carbonate. Hardness of water may be divided into two types: carbonate and non-carbonate. Carbonate hardness includes that portion of calcium (Ca) and magnesium (Mg) ions that combines with bicarbonate and the small amounts of carbonate present. This is called temporary hardness because it can be removed by boiling. Non-carbonate hardness is the difference between total hardness and carbonate hardness. The amounts calcium and magnesium that combines normally with sulphate, chloride and nitrate ions (Tenalem Ayenew and Tamiru Alemayehu, 2001).

$$Hardness(H_T)=Ca*CaCO_3/Ca + Mg*CACO_3/Mg \quad (8.1)$$

Where H_T, Ca and Mg are expressed in mg/l.
Each concentration is multiplied by the ratio of the formula weight of $CaCO_3$ to the atomic weight of the ion (Freeze and Cherry, 1979).

The ratio in equivalent weight is given by:

$$Hardness\ (H_T) = 2.5(Ca^{2+}) + 4.1(Mg^{2+}) \quad (8.2)$$

Based on table 8.2, the water types in the study area grouped as soft and moderately hard except one spring and two boreholes. The laboratory results of three water samples become hard due to contamination of ground water from town effluent.

Table 8.1 Hardness classification of water (Durfer and Becker, 1964), as cited in Tanalem and Tamiru (2001)

Hardness in mg/l as $CaCO_3$	Water classes
0-60	Soft
61-120	Moderately hard
121-1800	Hard
>180	Very hard

Table 8.2 Water classification of Beressa river catchments based on hardness.

Water source	No. of samples considered	Minimum value(mg/l)	maximum value(mg/l)	Average value	Water class
Bore holes	13	69.7	98		Moderately hard
	2	158.46	184	171.23	Hard
Hand dug wells	2	48.81	52.31	50.56	Soft
springs	2	42	48	45	Soft
	3	64	82		Moderately hard
	1			170.27	Hard
River	2	70	76	73	Moderately hard

8.3.2. Classification based on total dissolved solids (TDS)

Total dissolved solid include all solid materials in solution, whether ionized or not. As it is related to the sum of the concentration of all ions, it is directly related to the electrical conductivity. TDS of natural water range from less than 10ppm of dissolved solids for rain and snow, to more than 300,000ppm for some brine (Tenalem Ayenew and Tamiru Alemayehu, 2001). Water type classification based on their total concentrations of dissolved solids is the simplest classification (Devis and DeWiest, 1991).

More than 90% of the dissolved solids in ground water can be attributed to eight ions, Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, CO_3^{2-}, HCO_3^{-}, and SO_4^{2}. These ions are usually present at concentration greater than 1 mg/l (Fetter, 1994).

As displayed on table 7.4, the water type of Beressa river catchments is based on their TDS value is fresh water, this is because of short residence time within the catchments.

Table 8.3 Water classification based on TDS values (Source: Freeze and Cherry, 1979)

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

Table 8.4 Water classifications of Beressa river catchments based on TDS values.

Water source	No. of samples considered	Minimum	Maximum	Group
Bore hole	14	103	255	Fresh
Hand dug well	2	70	80	Fresh
spring	12	55.7	307	Fresh
River	2	70	106	Fresh

8.3.3. Classification based on major cations and anions

In order to categorize and classify water on the basis of their respective percentage composition of cations and anions, different graphical presentation is essential. Among these graphical presentation, Piper tri-linear diagram is the most useful methods. The major ionic species in most natural waters are Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, CO_3^{2-}, HCO_3^{-}, and SO_4^{2-}. A Piper tri-linear diagram can show the percentage composition of these ions. By grouping Na^{+} and K^{+} together, the major cations can be displayed on one tri-linear diagram. Likewise, CO_3^{2-} and HCO_3^{-} should be grouped in to one. Piper tri-linear diagram plotting points were done based on computer software package called Aquachem. In this work, classification and grouping was done for boreholes, springs, hand dug wells and rivers water resources (Fig. 8.1)

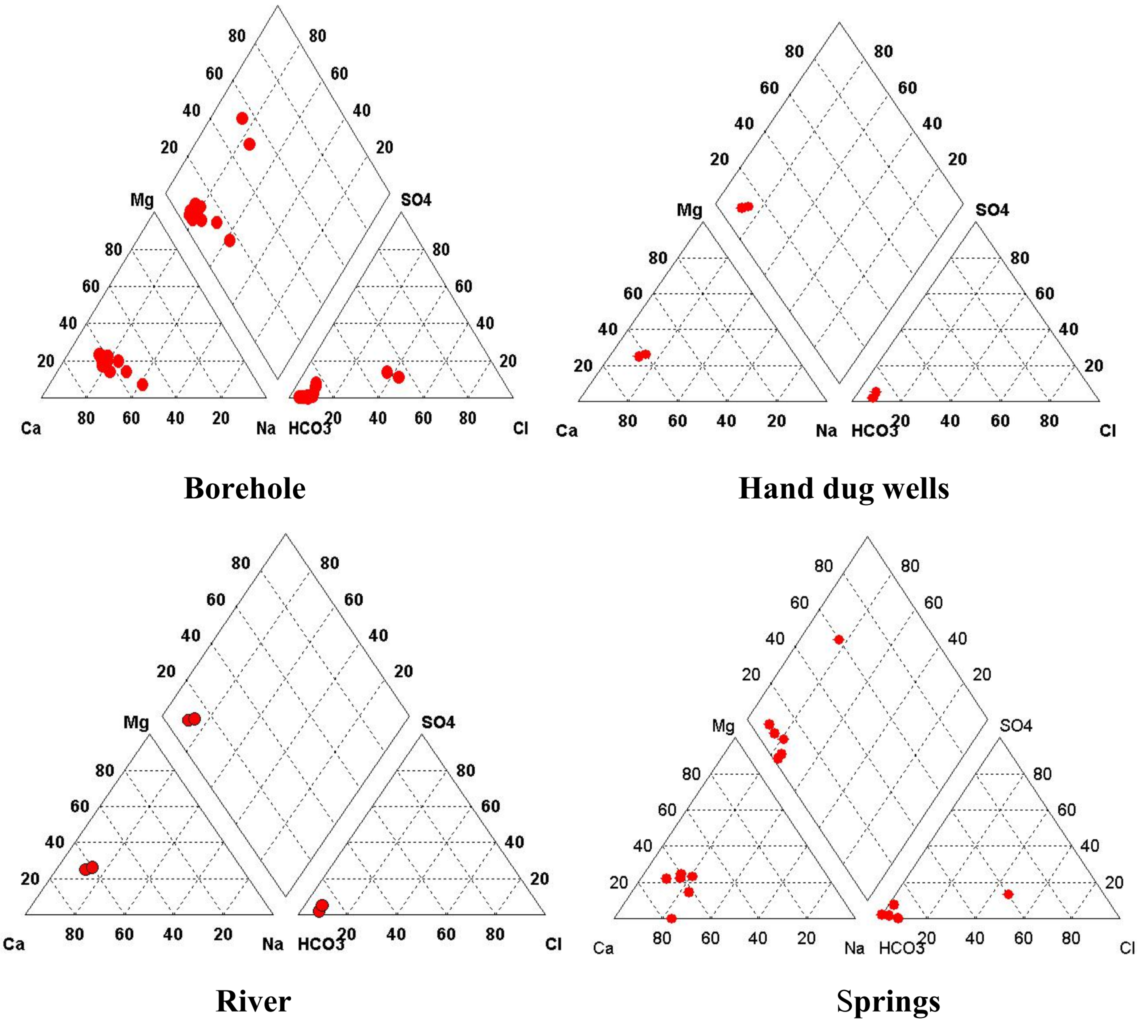


Figure 8.1 Piper tri- linear plots of water samples of Beressa river catchments.

8.3.3.1 Chemical behaviour of water samples

The chemical composition of groundwater is the combined results of the composition of water that enters the groundwater reservoirs and reactions with minerals present in the rock that may modify the water composition Apart from natural processes as controlling factors on the groundwater quality, in recent years, also the effect of pollution, such as nitrate from fertilizers and acid rains influence groundwater chemistry (Appelo and Postma, 1994).

The chemical behaviour of water in the catchments is fresh water and soft to moderately hard; except TTI borehole (DBTTIBH2), Divine providence sister's borehole (DPSBH) and Zerayakobe (DBZsp5) spring water showing unique behaviour due to contamination at the vicinity of Debre-birhan town (the cause will be discussed briefly in this chapter section 8.5).

As already discussed in chapter 1 and 2, the study area is highland physiography and Tertiary volcanic (basalt, ignimbrite, rhyolite and tuff) rocks. Weathering and dissolution of these volcanic rock release elements in to the water. Calcium is the dominant constituents of these rocks having silicate minerals of pyroxene, amphiboles and feldspar. Accordingly, the hydrochemical laboratory result of the study area show dominantly calcium followed by magnesium, sodium cations and bicarbonate anion. As displayed in figure 8.1 Piper tri-linear diagram, almost all water samples are Ca-HCO_3 and Ca-Na –HCO_3 type water; but there are some deviations by TTI borehole, Divine providence sister's and Zerayakobe spring water sample which shows Ca-HCO_3-Cl, Ca-Na-HCO_3-Cl and Ca-Cl-HCO_3 water type. The physical parameters and chemical constituents of each water sample displayed in annex 5.3.

There is no that mach recognized hydrochemical behaviour variation from upper to lower catchment because the infiltrated rain water leaves the recharge area with short residence time to discharge area due to undulated topography and relatively high permeability of the geological formation.

8.4. Water quality

The chemical and biological characteristics of water determine its usefulness for domestic, agriculture and industry (Davis and Dewiest, 1991). Water quality standards are regulations that are specific limitation on the chemical constituents present in the water. Accordingly, their utilization and consumption for various purposes are examined in view of rejecting and accepting it depending on intended uses (Fetter, 1994). A classification of water according to their possible uses is important.

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

Table 8.5 Comparison of water quality with WHO and Ethiopia water quality standards or guideline. (Source: WHO water quality standard, 1993 and Ethiopia quality guideline, 2002)

Water quality parameter	WHO(mg/l) standard	Ethiopia (mg/l) guideline	Water source (mg/l)			
			BH	HDW	Spring	River
PH	<8	6.5 - 8.5	6.47 - 7.78	6.0 - 6.87	6.4 -7.76	7.5 - 8.02
Color (TCU[b])	15	22				
Turbidity(NTU[c])	5	7	0 - 6			3.24 - 5.77
TDS	1000	1176	103 - 255	70 - 80	70 -250	106 - 118
Hardness		392	70 - 184	48 - 52	42 - 170	70 -76
Ammonia	1.5	0.4	0.001 - 0.46			0.038 - 0.074
Sodium	200	358	6.8 - 28	3.2 - 3.6	4 - 12	9 - 13.5
Aluminium	0.2	2				
Chloride	250	533	2.5 - 63	3	Nill - 57	2.5 - 8
copper	1	2				
Fluoride	1.5	3	0.19 - 0 .96	0.06 - 0.12	0.11 - 0.73	0.37 – 0.5
Sulphate	250	483	0.1 - 32	1 - 3	1 - 22	2.9 - 3.3
Nitrate (NO_3)	50	50	4.84 - 46	Up to 12	4.87 - 55	0.27 – 0.48
Nitrite (NO_2)	3	6				
Iron	0.3	0.4	Trace- 0.24			0.059 - 0.233
Manganese	0.1	0.13	Trace – 0.2			0.003 - 0.01

8.4.1. Water quality for domestic use

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

As displayed on table 8.5, except nitrate chemicals from TTI borehole, Divine providence sister's borehole and Zerayakobe spring, almost all chemical constituent are within the permissible limits of drinking water quality WHO standards and Ethiopia guideline.

8.5. Water pollution

Water pollution occurs when a body of water is adversely affected due to the addition of large amounts of materials to the water or any impairment of the suitability of water or any of intended uses, actual or potential, by man –caused changes in the quality of water. The effects of water pollution are varied. They include poisonous drinking water, poisonous food animals, unbalanced river and lake ecosystems that can no longer support full biological diversity, deforestation from acid rain.

Polluted water contains organisms and substance that make it unsuitable or unfit for use. Water may be polluted as result of a leakage from septic tank, sewerage effluent spreading on the ground, garbage waste (Appelo and Postman, 1994). All solutes introduced in to the hydrologic environment as a result of man's activities are referred to as contaminants, regardless of whether or not the contaminations reach levels that cause significant degradation of water quality. The term pollution is reserved for situations where contaminant concentrations attain levels that are considered to be objectionable (Freeze and Cherry, 1979).

In the study area, the possible sources of pollution are municipal and industrial at the vicinity of Debre-Birhan town. The town municipal and industrial solid and liquid wastes released to open land surface and to Beressa river. Due to fractured and jointed nature of local geology, these wastes might leach and infiltrate to subsurface and contaminate ground water.

Accordingly, there is an indication of groundwater contamination as observed on water samples taken from TTI borehole, Divine providence sister's borehole and Zerayakobe spring designated by DBTTIBH2, DBDPSBH and DBZsp5 (Annex 5.3).

8.5.1 Nitrate pollution

The main source of nitrate can be microbial breakdown of soil organic matter, organic manure, plant residues and agricultural input (fertilizer). From 23 water sample chemical analysis, most of them have very low nitrate ion concentration in the form of NO_3 except TTI borehole, Divine providence sister's and Zerayakobe spring (Tab.8.6 and Annex 5.3) water samples. The most likely cause of nitrate pollution in these water samples might be disposal of the town municipal solid and liquid wastes released to open land surface. Due to fractured and jointed nature of local geology of the town situated, these wastes might leach and infiltrate to subsurface and contaminate groundwater. As indicated in table 8.5, the maximum permissible limit of WHO standard and Ethiopian water quality guideline is 50 mg/l. Therefore, using TTI borehole, Divine providence sister's borehole and Zerayakobe spring for drinking purpose is resulting blue baby disease to infants, gastric tumour and cancer.

Table 8.6 Nitrate ions concentration in Beressa river catchment water samples.

Water source	No. of samples considered	Minimum	Maximum	Average value
Bore hole	12	4.8	19.8	8.75
	2	46.52	55	50.76
Hand dug well	1	12.85	12.85	12.85
ring	5	4.87	8.19	6.61
	1	53.16	53.16	53.16
River	2	0.27	0.48	0.38

8.5.2 Chloride

Drinking water quality WHO and Ethiopian guideline value for chloride value is 250 mg/l and 533 mg/l respectively (Tab.8.5). Chloride ions problems are more common in plant species rather than human being. Except TTI borehole, Divine providence sister's Borehole and Zerayakobe spring (Tab.8.7 and Annex 5.3) most of the water samples chemical analysis have low chloride ion concentration. The relatively higher chloride ion concentration in TTI borehole, Divine providence sister's Borehole and Zerayakobe spring may occurred due to detergents and potassium hypo chloride chemicals used for disinfecting the Debre-Birhan water supply.

Table 8.7 Chloride ions concentration in Beressa river catchment water samples.

Water source	No. of samples considered	Minimum	Maximum	Average value
Bore hole	12	2.5	8.84	5.69
	2	46	63.8	54.9
Hand dug well	2	3	3	3
spring	4	1.5	4	2.5
	1	57	57	57
River	2	2.5	8	5.25

8.5.3 Fluoride

This ion has low solubility and occurs in igneous and sedimentary rock. Apatite, Amphiboles such as hornblende and some of the micas contains fluoride. Rocks in alkali metals, and also obsidian, are as a class higher in fluoride content than most other igneous rocks. Fluoride is commonly associated with volcanic or fumarolic gases (Hem, 1992). The source of fluoride ion in this area might be the presence of tuff formation.

Fluoride in drinking water can have toxic effects in both excess and deficiency. WHO guide line value set 1.5 mg/l for excess fluoride as susceptibility in deficiency is highly dependent on nutritional status. Excess fluoride may lead to dental or skeletal fluorosis. A lack of fluoride may cause dental caries, a weakening of the teeth.

As observed from table 8.8, all water samples in Beressa river catchment have 0.11-0.96 mg/l fluoride ions concentration range. These values are under WHO guideline values and there is no health risk due to fluoride ion.

Table 8.8 Fluoride ions concentration in Beressa river catchment water samples

Water source	No. of samples considered	Minimum	Maximum	Average value
Bore hole	14	0.19	0.96	0.53
Hand dug well	2	0.06	0.12	0.09
spring	6	0.11	0.73	0.38
River	2	0.37	0.50	0.21

8.5.4 Microbiological water pollution.

The microbiological quality of drinking water has been implicated in the spread of infectious diseases such as cholera, typhoid, hepatitis, guinea worm, schistosomiasis, etc. Many of these diseases are associated with water.

The most likely polluted water by microorganisms are surface water, very shallow groundwater that is hand dug wells, springs emanate from shallow water bearing formation and swampy area, machine drilled wells in shallow aquifer because the sources of these water have a great chance to be contaminated by diseases causing microorganisms. Most of the time, springs emerged from deep aquifer zone and deep water wells have low chance to be contaminated by diseases causing microorganisms or the organisms do not survive at deep aquifer zone.

In this work, some water samples were tested whether or not contaminated by coliform bacteria using membrane filtration methods. The coliform bacteria groups are organisms originating in the intestinal tract of warm blooded animals (Faecal-coli or E-coli) and organisms from soil or vegetation (Aero bacteria). As indicated in table 8.9, some of water samples were contaminated with coliform bacteria. WHO standards concerning bacteriological analysis allow no total coliform per 100 ml of water sample. The causes of contamination in these water samples are poor sanitary protection of springs, dug wells and municipal waste disposal.

Table 8.9 Bacteriological laboratory result for different water sources (analyzed by Laboratory)

No	Date of sampling	Sample code	Name of water source	Total coliform bacteria of the test(cfu/100ml)	Possible cause of contamination	Possible remedies
1	28/12/96	DBAsp1	Atikilt spring	3	Poor sanitary protection	1* & 2*
2	28/12/96	DBGsp2	Gorto spring	free		
3	28/12/96	DBKsp3	Kosso spring	free		
4	28/12/96	DBZsp4	Zarayakob spring	10	Waste disposal	2*
5	28/12/96	DBTTI2	TTI borehole	free		
6	28/12/96	DBDBH1	Dalecha borehole	free		
7	29/12/96	DBBHW1	Beyo dug well	5	Poor sanitary protection	1* & 2*
8	29/12/96	BDAHDW2	Arguagerdug well	10	Poor sanitary protection	1* & 2*
9	29/12/96	DBDsp5	Dawet mesno spring	4	Poor sanitary protection	1* & 2*
10	30/12/96	DBMsp	Mesno sprig	5	Poor sanitary protection	1* & 2*

1* = Sanitary protection 2* = Chlorination cfu = coliform forming units.

CHAPTER NINE

Conclusion and Recommendation

9.1 Conclusion

The study area is the upper catchments of Beressa river which covers 336 km^2 bounded within 39°,27',20" E to 39°,44',14" E longitude and 9°,33',50" N to 9°,44',38" N latitude and having average elevation ranges from 2100m to 3675 m above mean sea level. The area has 13-16 ^{0}c average annual temperature and temperate (weyna daga) to cool (kur) climate.

Five meteorological stations within and around study area had recored 865-1677mm annual rainfall. Chacha and Ankober stations record minimum (865mm) and maximum (1677mm) annual values respectively. Rainfall values vary with altitude and wind ward side of the orography or mountain barriers. The area has two rainfall regime (bimodal rainfall characteristics) that is small rain (bulg season) in the month of March and April and big rain (kiremt season) in the month of July, August and September. Aerial depth of annual rainfall computed by theissen polygon and isohyetal methods have almost equal value and it is taken to be 1120mm.

From the available meteorological data, open water evaporation and potential evapotranspiration is calculated using penman combined method and the results are 1336mm and 1180mm respectively. Lower monthly open water evaporation and potential evapotranspiration is occurred in the months of July and Augest because of high humidity in the atmosphere, lower wind speed and lower daily sunshine hours due to cloudiness while higher open water evaporation and potential evapotranspiration in the month of may due to lower humidity in the atmosphere, higher wind speed and higher daily sunshine hours. Based on soil, land use /land cove categories and meteorological data, the actual evapotranspiration of the basin is calculated using Thornthwait and Mather soil water balance model and the annual AET is 731mm. 65% of the rainfall leaves the catchments by evapotranspiration.

From annual average of Beressa river discharge gauged near Debre-Birhan town, 87.51million cubic meter (mcm) or 415mm of water leaves annually from catchments of 211 km^2 area. From soft ware base flow separation methods, the annual base flow and surface runoff of Beressa river catchment is 149mm and 265.93mm respectively.

From the computed water balance of the study area, the amount of water infiltrated to subsurface is 122.46 mm and 10.9% of precipitation. This water is 41.15 million cubic meter (mcm) for the total 336 km^2 of the study area. This infiltrated water could recharge the groundwater.

The local geology of the area is mainly weathered, fractured basalt, ignimbrite / rhyolite and some localized alluvial and residual silt clay soil patches. The upper catchment is relatively undulated, rugged ridges and valleys. Most of the precipitation goes as surface runoff and the infiltrated water immediately drained and leaves the area to relatively lower topography of the catchments (discharge area). The groundwater is mainly controlled by its topography in the recharge area.

Around Debre-birhan town (discharge), because of high to medium permeability of recharge area, relatively low topography and flat to gentle slope of the area, the rain water percolate at higher elevation (recharge area) of the catchments flows to these highly fractured and faulted zone. In additions to the above reason, the horst like south west to north east elongated ridge may dam the groundwater above this ridge and increase the groundwater circulation and storage of the area. The wells drilled on this faulty area give 5-15 l/s yield, 10-283 m^2/d transmissibility (T) and 0.3-7m/d hydraulic conductivity (K).

The hydrostratigraphic units of this relatively groundwater potential zone are highly fractured and faulted ignimbrite / rhyolite and fragmented rock tuff. The aquifer is multiple and mainly behaves confined aquifer. From geophysical survey data, the aquifer depth reaches up to 200m.

From 30 water samples field physical parameters measurement and 24 water samples chemical laboratory analysis, all water samples are fresh water (TDS =55-307 mg/l), soft to moderately hard water while three contaminated water samples are hard water.

Based on chemical laboratory analysis except three contaminated water samples, all water samples are Ca-HCO_3 and Ca-Na- HCO_3 water types. These water types show high land water behaviour. The water sampled from Debre-Birhan town is Ca-HCO_3-Cl, Ca-Na-HCO_3-Cl and Ca-Cl-HCO_3 water types respectively.

The infiltrated rain water has short residence time at recharge area due to undulated topographic nature of the area and high permeability of geological formation and so there is no significant hydrochemical special variation within the catchment.

Nitrate ions concentration is above the permissible level of WHO and Ethiopia drinking water standards. These water samples source might be contaminated from disposal of the town municipal solid and liquid wastes released to open land surface.

From 10 water sample microbiological test, 6 samples water source polluted by coliform bacteria due to waste disposal and poor sanitary protection.

9.1 Recommendation

Based on available data, analysis and the out come of this study, the following recommendations are given.

- In order to minimize land degradation, recover the degraded land and increase infiltration rate or maximize groundwater potential, land and water conservation activities should be practiced in highly degraded land of the catchment that is terracing, forestation, etc.
- The present water resource development activities like water harvesting, spring development, hand dug well constructions or shallow wells machine drilling particularly in rural areas are very low. In order to solve drinking water supply and food deficiencies problems, water resource development activities should be practiced in most of the rural areas within the catchment.
- In order to understand well and evaluate the aquifer behavior and groundwater potential zone precisely, additional test wells could be drilled which can be used as productive well for required purposes keeping fair distribution within the catchment with appropriate drilling and pumping test is recommended.
- Water wells drilled for Debr-Beirhan town water supply are concentrated and have small inter well spacing in small sub- catchment or Dalecha well field (9 boreholes). With the same distance and relatively big sub-catchment and high groundwater potential area (Beressa well field), only three water wells were drilled. It is recommended to minimize the number of pumping wells in Dalecha well fields and drilling additional wells with full aquifer penetration in Beressa well field

- TTI borehole, Divine providence sister's borehole and Zerayakobe spring have nitrate pollution and Zerayakobe spring has microbiological pollution. Using these water sources has health risk and it is recommended not to use these water sources for any domestic purposes.
- Due to poor sanitary protection many springs and hand dug wells are microbiologically polluted. There for, these water sources needs continuous follow up, sanitary protection and disinfection to keep healthy and productive the rural community.
- The geology where the town and the well fields located is highly fractured, faulted and permeable. Unless proper municipal and industrial waste management is practiced, it is preferable not to expand the town to these well fields to protect groundwater from the contamination or pollution.

Reference

1 Appelo, C.A.J. and Postma, D. (1994). Geochemistry, groundwater and pollution. A.A, Balkema, Rotterdam, the Netherlands, 536pp.

2 BCEOM French Engineering Consultants (1999). Abbay River Basin Integrated Development Master Plan Project: Natural resource. Ministry of Water Resource, Addis Ababa, part 1, volume 1, 89pp

3 BCEOM French Engineering Consultants (1999). Abbay River Basin Integrated Development Master Plan Project: Land resource development. Ministry of Water Resource, Addis Ababa, phase2, part 2, volume 9, 331pp and part 3, Volume 10,78pp

4 Bouwer, H. (1978). Ground water hydrology. McGraw-Hill, New York, 480pp

5 Daniel Gemechu (1977). Aspect of climate and water balance in Ethiopia. Addis Ababa University press, Addis Ababa, 79pp.

6 Davis, N.S. and DeWiest, J.M.R. (1991). Hydrogeology. John Wiley Sons, New York, 463pp.

7 Dingman,S.L. (1994). Physical hydrology. Prentice-Hall, NewJersy, 557pp.

8 Dunne, T.and Leopold B.L. (1978). Water in environmental planning. Freeman, San Fransisco, 815pp.

9 Fetter, C.W. (1994). Applied hydrogeology. Third edition, Prentice-Hall, New Jersy, 695PP.

10 Freeze, R. A. and Cherry J. A. (1979). Ground water. Prentice-Hall, New Jersy, 616pp.

11 Hem D. J. (1992). Study and interpretation of chemical characteristics of natural water. Third edition, United States Geological survey water supply paper 2254, United States government printing office, Washington, 264pp.

12 Jayarami, p. (1996). A text book of hydrology. Laximi publications (P) LTD. New Delhi, 530pp.

13 Justin-Visentin, E., Nicoletti, M., Tolomeo, L. and Zanettin, B. (1974). Miocene and Pliocene volcanic rocks of Addis Abba-Debrebirhan area (Ethiopia): geo-petrographic and radiometric study. Francesco Giannina and Pegli Napoli, Italy, 17pp.

14 Kazmin, V. (1975). Explanation of the geological map of Ethiopia. Bulletin number one. Geological survey of Ethiopia, Addis, Addis Ababa, 14 pp.

15 Kazmin,V. (1979). Stratigraphy and correlation of volcanic rocks in Ethiopia. Ethiopian institute of geological survey, Addis Ababa, 26pp.

16 Kieffer, B., Arndt, N., Lapierre, H., Bastien, F., Bosch, D., Pecher, A., Gezahegn Yirgu, Dereje Ayalew, Weis, D., Jeram, D.A., and Keller, F., Meugniot, C. (2004). Flood and shield basalt from Ethiopia: Magmas from the African supperswell. Journal of petrology, volume-45, page 793-834..

17 Kruseman, G.P. and de Ridder, N.A. (1990). Analysis and evaluation of pumping test data.International Institute for land Reclamation and Improvement. ILRI publication, No 47, Waguigen, the Netherlands, 377pp.

18 Maidment, D.R (1993). Hand book of hydrology. McGraw Hall, New York, 660pp.

19 Marla, et. Al. (1979). A geological map of Ethiopia and Somalia and Comments with a map of major landforms. Department of geology and palaeontology, university of Florence, Italy, 173pp.

20 Mesfin Sahele (2001). Hydrogeological investigation of the upper and middle Borkena river catchments, Northern Ethiopia, Wollo. Unpublished M.Sc. Thesis, Addis Ababa University, Addis Ababa, 144pp.

21 Mohr, P.A. (1962). The geology of Ethiopia. University college of Addis Ababa press, Addis Ababa, 268pp.

22 Mohr, P.A. (1983). Ethiopian flood basalt province. Review article, nature vol.303 (577-585), Department of geology, university college Galway, Ireland, 577-584pp.

23 Molla Fetene (2004). Water resource evaluation of Ribb river basin north western Ethiopia, South Gonder. Unpublished M.Sc. Thesis, Addis Ababa University, Addis Ababa, 150pp.

24 Raghunath, HM. (1987). Ground water. Second edition, New age international publisher, 563pp.

25 Reynold, J.M.(1997). An introduction to applied and environmental geophysics. John Wiley & Sons LTD,Baines Lane.CHichester, West Sussex PO19 IU,.England,796pp.

26 Sen, Z. (1995). Applied hydrogeology for scientists and engineers. Lewis publishers, Boca Paton, New York, London ,and Tokyo, 563pp.

27 Shaw, E.M. (1988). Hydrology in practice. Second edition, Chapman and Hall, New York, 539pp.

28 Tamiru Alemayehu (2000). Water pollution by natural inorganic chemicals in the central part of the main Ethiopian Rift. SINET: Ethiopian Journal of Science.23(2):197-214

29 Tenalem Ayenew and Tamiru Alemayehu (2001). Principle of hydrogeology. Department of geology and geophysics, Addis Ababa University, 125pp.

30 Tenalem Ayenew (1998). The hydrological system of the Lake District basin, central main Ethiopian rift, Ph.D. Thesis, ITC Publication, 259pp.

31 Tesfaye Chernet (1993). Hydrogeology of Ethiopia and water resources development. Ethiopian Institute of Geological Surveys, Ministry of Mines and Energy, Addis Ababa, 222pp.

32 Todd, D.K. (1988). Ground water hydrology. John Wiley & Sons, New York, 535pp.

33 US army Corps of Enginners Manual (1995). Geophysical exploration for Engineering and environmental investigations. Dep. of the US army corps of engineers Wasgington, DC, 4.8-4.30pp

34 Wilson, E.M. (1983). Engineering hydrology. Third edition, Macmillan publisher's ltd. Hong Kong, 309pp.

35 Zanettin, B., Gregnnanin , A., Justin –Visentin, E., Mezzagasa, G. and Peccirillo, E. M. (1974). Petrochemistry of the volcanic series of the central eastern Ethiopian plateau and relationships between tectonics and magmatology. Societa Cooperative Tipografica, Padova, 34pp.

36 Zanettin, B., Gregnnanin, A., Justin-Visentin, E., Morbidelli, L. and Peccirillo, E. M., (1974). Geologigical and petrological researches on the volcanics of central Ethiopia. Societa Cooperative Tipografica, Padova, 6pp.

37 Zanettin, B. and Justin –Visetin, E. (1975). Tectonical and Volcanological Evolution of the western afar Margin (Ethiopia). Schweizerbart, 300-309pp.

38 Zanettin, B., Justin-Visetin, E. and Piccirillo, E.M. (1978). Volcanic succession, tectonics and magmatology in central Ethiopia. Societa Cooperative Tipografica, Padova, 15pp.

Annex 1. Monthly total rain fall at DEBRE-BERHAN Station

Alt 2750m Long 39^0 30^0E Lat 9^o 38^o N

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
1984	0.0	0.0	26.6	0.0	80.0	90.2	181.2	122.7	106	0.0	0.0	0.0	607.1
1985	17.4	0.0	27.3	58.6	83.2	15.8	314.6	376.6	88.4	6.5	5.7	0.0	994.1
1986	0.0	74.7	99.2	52.5	27.0	142	271.3	274.7	116	11.3	0.0	0.0	1068.3
1987	5.0	19.2	108	51.7	100.2	0.0	32.3	309.5	47.5	18.7	0.0	6.3	698.5
1988	10.6	34.6	16.9	83.1	16.2	16.0	286.2	290.0	153	12.1	0.0	0.0	918.2
1989	2.3	40.5	97.6	42.7	1.4	41.1	211.3	177.4	67.7	18.6	0.0	30.7	731.3
1990	0.0			59.5	0.9	1.6	321.0	217.2	169	0.6	0.0	0.0	769.5
1991	4.8	8.3	64.6	21.0	12.0	63.7	215.6	387.5	86.6	6.4	0.0	6.4	876.9
1992	30.3	26.7	19.4	80.2	19.3	13.3	307.6	267.6	90.2	41.9	0.5	1.8	898.8
1993	4.3	63.2	0.0	116.9	60.5	9.1	405.5	168.4	108	43.2	0.0	1.1	979.9
1994	0.0	0.0	95.6	0.0	23.2	92.7	281.7	222.9	102		36.5	0.0	854.3
1995	0.0	28.5	19.1	68.4	26.5	23.3		233.8	60.4	5.1	0.0	1.7	466.8
1996	20.7	2.8	75.4	9.7	129.2	138.0	336.4	252.5	24.3	0.0	3.0	0.0	992.0
1997	29.5	4.0	41.2	82.4	25.9	95.1	272.1	200.6	34.8	89.1			874.7
1998	26.7	13.2	14.9	49.3	43.0	13.5	337.3	289.0	70.6	5.2	0.0	0.0	862.7
1999	0.0	0.0	26.5	2.8	11.8	48.9	362.4	365.1	52.4	59.6	1.4	0.0	930.9
2000	0.0	0.0	25.9	47.3	37.1	46.6	352.4	317.5	105	28.5	18.8	6.8	986.1
2001	0.0	33.8	70.5	18.8	64.6	34.9	406.3	260.4	32.2	4.1	0.0	3.4	929.0
2002	18.1	28.0	60.6	46.1	18.4	28.4	214.4	295.8	109	3.1	0.0	8.4	830.4
2003	15.6	36.3	60.2	85.7	3.8	93.5	334.1	288.7	74.2	0.0	0.0	7.4	999.5
Mean	**9.3**	**21.8**	**50.0**	**48.8**	**39.2**	**50.4**	**286.5**	**265.9**	**84.8**	**18.6**	**3.5**	**3.9**	**882.7**

Annex 2. Monthly maximum temperature at DEBRE-BERHAN Station

Alt 2750 m Long 39˚,30' E Lat 9˚, 38' N

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1984	20.0	21.3	22.0	23.5	21.0	20.3	19.3	20.2	18.4	19.8	19.4	18.0
1985	19.5	19.8	20.4	18.9	19.7	21.7	18.7	18.4	18.2	18.2	18.6	
1986	20.4	19.9	19.1	19.0	20.9	19.4	18.6	18.1	18.3	18.5	19.0	19.5
1987	19.5	20.9	19.5	19.7	19.5	22.0	22.4	19.5	19.8	19.5	19.8	20.1
1988	18.9	18.7	21.5	20.6	22.1	22.1	17	17.6	18	17.4	17.9	18.3
1989	19.0	18.5	19.7	18.1	20.5	21.4	18.8	18.3	18.2	18.0		
1990	19.0			20.1	22.6	23.0	18.6	18.9	18.4	18.2	18.5	18.8
1991	19.9	20.0	20.6	20.8	22	22.5	18.0	17.8	19	18.2	18.6	18.3
1992	18.1	18.9	21.7	21.5	21.6	22.6	18.3	16.6	17.5	17.3	17.3	18.7
1993	18.9	18.7	20.6	19.4	19.9	21.9	18.5	18.9	17.7	18.0	18.2	18.9

1994	19.7	20.9	20.4	21.4	22	21.4	19.4	17.6	18.1		19.3	19.8
1995	20.9	20.8	21.3	20.8	22.1	23.6		18.7	19.4	19.2	19.8	19.7
1996	19.1	21.0	20.7	####	20.1	19.2	18.5	18.6	19.6	18.9	18.7	18.4
1997	18.6	20.1	21.2	19.8	21.3	21.1	18.0	18.3	19.3	18.3		
1998	19.8	20.9	20.9	21.4	22.4	23.3	17.8	17.7	18.7	18.6	18.4	18.4
1999	19.4	21.5	20.5	21.8	22.6	22.4	17.1	18.1	18.5	17.9	17.7	18.5
2000	19.6	20.5	21.5	20.7	21.8	22.7	18.3	17.7	18.5	18.4	18.5	19.4
2001	20	21	19.2	21.2	22.2	21.5	17.9	17.5	19.5	19.8	19.5	19.3
2002	19.5	21.2	20.6	21.4	23	22.8	21.5	18.1	18.4	19.6	19.7	19.3
2003	20.3	21.4	21.2	20.8	22.5	22.5	18	18.3	19	19.4	19.1	19.4
Mean	**19.5**	**20.3**	**20.7**	**20.6**	**21.5**	**21.9**	**18.7**	**18.2**	**18.6**	**18.6**	**18.8**	**19.0**

Annex 3. Monthly minimum temperatur in ˚c at <u>DEBRE-BERHAN</u> Station

Alt ___2750 m_ Long__39˚,30'__ Lat ________9˚,38'__

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
1984	0.9	0.9	6.8	5.6	8.0	7.9	8.4	7.8	6.5	1.1	3.5	3.5	
1985	5.3	4.8	7	7.9	8.1	7.4	8.4	8.4	7	4.5	4.3	4.9	
1986	3.8	7.4	7.6	8.6	7.7	8.7	8.3	8	6.1	4.5	4.3	5.1	
1987	3.4	6.6	8.8	8.0	10.7	7.7	8.2	8.9	7.6	5.5	4.2	5.0	
1988	6.6	6.7	8.4	8.2	7	6.6	12.8	9.0	7.4	4.0	1.8	1.1	
1989	0.5	6.2	7.4	8.1	5.5	6.3	8.8	9.2	9.4		1.2	6.7	
1990	3.1			6.8	5.5	5.9	8.6	8.9	7.3	2.0	2.0	0.2	
1991	5.3	6.1	8.4	7.7	8.1	7.4	9.0	8.9	7.1	1.6	1.8	0.8	
1992	6.8	7.9	8.5	7.3	6.5	6.9	8.2	9.0	7	3.6	3.9	4.2	
1993	5.8	6.9	5.8	8.2	6.8	6.5	8.8	8.6	8.1	4.4	1.5	2.5	
1994	3.6	5.1	8.7	8.1	7.1	7.1	8.4	7.8	6.7		0.8	2.5	
1995	2.8	7.5	6.7	8.7	6.5	6.7		9.2	7	2.8	1.2	5.9	
1996	6.3	4.6	7.4	7.1	6.9	7.7	8.2	8.5	6.3	1.4	2.1	3.2	
1997	6.1	2.2	8.2	7.0	6.7	8.5	8.6	8.1	7.1	6.1			
1998	7.7	8.5	9.3	9.6	7.6	7.2	9.3	9.4	7.3	3.7	1.0	2.1	
1999	2.2	3.1	5.9	5.5	5.8	6.3	8.6	8.6	6.2	4.6	-1.2	1.8	
000	2.1	3.4	5	7	7.0	5.7	8.6	8.1	6.8	3.3	1.7	1.0	
2001	3.1	5.2	8.3	6	8.1	7.9	9.2	9.1	6.4	3.3	3.1	4.7	
2002	4.9	6.2	8.4	7.5	7.6	7.6	6.2	9.1	7.5	3.2	3.1	7.2	
2003	5.3	5.3	7.9	9.5	7	8	9.7	9.5	8.1	3	2.7	1.6	
Mean	**4.3**	**5.5**	**7.6**	**7.6**	**7.2**	**7.2**	**8.8**	**8.7**	**7.1**	**3.5**	**2.3**	**3.4**	

Annex 4. Summary of mean monthly of BERESSA RIVER (near Debre Berhan town) flow in m^3/s

Longitude _______________ Latitude ______________ Altitude ________________

YEAR	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG	SEP	OCT	NOV.	DEC	AN.MEAN
1973	0.10	0.09	0.07	0.10	0.16	0.16	6.17	19.73	14.32	0.18	0.14	0.11	3.44
1974	0.12	0.08	0.12	0.19	0.12	0.15	12.61	20.41	4.18	4.91	4.18	0.16	3.93
1975	0.10	0.08	0.10	0.18	0.18	0.39	4.55	15.78	12.49	0.28	0.20	0.08	2.87
1976	0.04	0.04	0.12	0.13	0.23	0.11	5.50	24.22	4.65	0.16	0.33	0.14	2.97
1977	0.14	0.10	0.08	0.10	0.12	0.14	7.46	8.90	0.43	1.73	0.25	0.12	1.63
1978	0.13	0.10	0.16	0.13	0.16	0.14	4.85	14.82	5.56	1.24	0.15	0.22	2.31
1979	0.17	0.10	0.10	0.16	0.31	0.33	7.25	10.42	0.79	0.24	0.03	0.04	1.66
1980	0.05	0.08	0.10	0.10	0.10	0.08	1.43	13.40	11.01	1.71	0.16	0.06	2.36
1981	0.16	0.13	0.14	0.25	0.18	0.16	0.22	26.15	6.69	1.75	0.12	0.12	3.01
1982	0.14	0.18	0.16	0.35	0.27	0.26	1.38	44.12	2.36	1.79	0.15	0.11	4.27
1983	0.09	0.07	0.11	0.21	0.58	0.36	2.80	20.22	1.43	0.15	0.11	0.11	2.19
1984	0.07	0.06	0.06	0.06	0.26	0.36	7.44	3.44	1.69	0.16	0.10	0.07	1.15
1985	0.08	0.07	0.07	0.12	0.18	0.14	3.55	14.56	2.59	0.12	0.08	0.08	1.80
1986	0.08	0.09	0.33	0.28	0.16	0.17	9.09	27.61	6.52	0.22	0.15	0.14	3.74
1987	0.12	0.14	0.18	0.40	0.50	0.21	0.18	5.14	0.35	0.53	0.17	0.16	0.67
1988	0.17	0.16	0.19	0.23	0.27	0.29	4.99	30.87	8.50	0.50	0.16	0.14	3.87
1989	0.14	0.13	0.14	0.25	0.15	0.19	2.50	11.57	3.31	0.25	0.18	0.19	1.58
1990	0.16	0.20	0.22	0.53	0.24	0.20	6.51	10.89	13.60	0.35	0.12	0.12	2.76
1991	0.12	0.11	0.12	0.16	0.24	0.31	5.26	37.09	4.00	0.26	0.11	0.10	3.99
1992	0.11	0.11	0.10	0.12	0.11	0.13	3.15	15.53	8.30	0.37	0.14	0.11	2.36
1993	0.09	0.13	0.10	0.23	1.43	0.25	24.88	5.24	1.51	2.86	0.16	0.12	3.08
1994	0.11	0.11	0.14	0.15	0.23	0.29	15.58	39.97	12.47	0.15	0.14	0.10	5.79
1995	0.09	0.08	0.10	0.20	0.22	0.24	5.16	15.34	5.36	0.20	0.18	0.20	2.28
1996	0.19	0.16	0.40	0.77	1.64	1.38	12.67	16.68	2.50	2.64	0.37	0.31	3.31
1997	0.30	0.28	0.35	0.63	0.48	0.88	13.20	11.67	0.53	2.34	0.61	0.18	2.62
1998	0.35	0.24	0.25	0.44	0.70	0.48	8.00	20.56	5.75	0.71	0.20	0.20	3.16
1999	0.12	0.10	0.12	0.10	0.14	0.23	12.73	20.00	3.63	1.27	0.08	0.04	3.21
2000	0.03	0.04	0.03	0.05	0.13	0.10	4.65	22.03	4.17	1.45	0.26	0.04	2.75
2001	0.06	0.35	0.56	0.25	0.33	0.19	9.66	13.61	0.93	0.30	0.25	0.17	2.22
2002	0.15	0.15	0.17	0.13	0.17	0.24	1.25	21.11	4.78	0.10	0.07	0.09	2.37
2003	0.08	0.09	0.07	0.35	0.15	0.23	6.54	8.21	1.83	0.11	0.00	0.01	1.47
MEAN	*0.12*	*0.12*	*0.16*	*0.24*	*0.33*	*0.28*	*6.81*	*18.36*	*5.04*	*0.94*	*0.30*	*0.12*	*2.74*

Annex 5.1 Water points physical parameters and laboratory chemical analysis result

No	Source	code	Location (UTM) X	Location (UTM) Y	Alt.(m)	Aquifer	Depth(m)	SWL(m)	Tested DWL(m)	Hr/Tested Q (l/s)	Aq. Th. (b)(m)	T (m^2/d)	K. (m/d)
1	Borehole	Dalecha NBH1	562106	1070685	2807	Ign / rhyolite	108	12.79	39.68	72/7	35.74	12.7	0.35
2	Borehole	Dalecha NBH2	562015	1071000	2806	Ign / rhyolite	95.56	11.68	21.39	72/7	37.99	80.93	2.13
3	Borehole	Dalecha NBH4	561880	1069590	2810	Ign / rhyolite	125	9.2	35.65	72/5	42	11.96	0.28
4	Borehole	Dalecha NBH5	563330	1070084	2812	Ign / rhyolite	150	7.33	61.86	72/2.5	54	2.22	0.04
5	Borehole	Dalecha NBH6	560803	1070784	2807	Ign / rhyolite	108	7.4	40	72/12	48.9	181.44	6.04
6	Borehole	Dalecha NBH7	561594	1071660	2804	Ign / rhyolite	72	9.6	40	72/14.2	30.99	224.64	7.25
7	Borehole	Dalecha OBH1	561269	1070401	2806	Ign / rhyolite	70	6.66	44.97	5l/s			
8	Borehole	Dalecha OBH2	562001	1070430	2805	Ign / rhyolite	70	6.66	44.97	5l/s			
9	Borehole	Beressa NBH2	559369	1067258	2780	Ign / rhyolite	100.49	5.3	20.3	72/15.3	36.59	80.78	2.21
10	Borehole	BressaNBH4	559318	1066823	2787	Ign / rhyolite	92	6.25	11	72/15	42.66	332.56	7.8
11	Borehole	B ressaNBH5	559432	1066077	2789	Ign / rhyolite	102	8	40	72/17	42.59	80.93	2.37
12	Borehole	Sheep breed. BH	560400	1069750	2790	Ign / rhyolite	96			0.7l/s			
13	Borehole	Divine pro.s.BH	557750	1069300	2785	Ign / rhyolite	111	29.6		1.6l/s			
14	Borehole	T.T.I. BH	557442	1069410	2800	Ign / rhyolite	67	33.5		3.5l/s			
15	Borehole	Military camp. BH	556150	1067600	2825	Ign / rhyolite							
16	Borehole	Marine com. BH	555400	1066500	2785	Ign / rhyolite	90	11.9		4 l/sec			
17	Borehole	I.L.C.A. BH	555750	1061500	2750	Ign / rhyolite	97			1l/s			
18	Borehole	Dalcha AFBBH	560800	1071004	2830	Ign / rhyolite	150	11.72	62.53	24/1.5	34.58	1.54	0.05

Annex 5.2 Location of springs and type in Beressa river catchment

No	Source	Name	Code	Location (UTM) X	Y	Alt.(m)	Q (l/s)	Obs.date	Formation	Type	T(^{0}c)	Ph	EC(us/cm)	TDS
1	spring	Kosso	DBKsp3	562549	1066364	2943	0.5	28/12/96	basalt	Fractute	17	6.73	122.7	70
2	spring	Zerayakob	DBZsp4	558582	1068197	2766	2	28/12/96	rhyolite/ Ign.	Fractute	17.2	6.4	485	250
3	spring	Diwit	DBDsp5	571880	1063194	3065	0.4	29/12/96	rhyilite/Ign	Fractute	16.5	7.2	163	90
4	spring	Cheffe	DBCHsp6	568550	1066600	3050	1	30/06/97	basalt	Fractute	16	7.33	148	81
5	spring	Akober	DBAKsp7	581565	1066250	3100	2	7/7/1967	basalt	Fractute	19.9	7.73	92.6	55.7
6	spring	Power station	DBBPSsp8	556084	1069716	2724	1	8/7/1997	basalt	Fractute	19.4	6.84	190.6	113.4
7	spring	Atakilt	DBAsp1	561770	1067129	2850	1	28/12/96	basalt	Fractute	16.7	6.6	154	73
8	spring	Gorto	DBGsp2	562170	1066504	2915	0.2	28/12/96	basalt	Fractute	18	6.8	144.5	68
9	spring	Mesno		566770	1066800	2930	0.2	30/6/97	basalt	Fractute	16.3	7.25	171.5	105
10	Spring	Wonna		566700	1065750	2980	2	Jan-97	basalt	Fractute	17.1	7.45	175.5	108
11	Spring	Malefia		557163	1068633	2769	0.5	8/7/1996	Rhyolite/Ign	Fracture	17.1	6.69	616	307
12	Spring	Gashemeda		558372	1068195	2760	10	7/8/1997	Rhyolite/ign	Fracture	18	6.68	150	80

Annex 5.3 Water points' physical parameters and laboratory chemical in Beressa river catchment

NO	Saample ID	Site	Date	Lithology	Location			PH	T(°c)	EC	TDS	Na	K	Mg	Ca	Mn	Fe	NH4	F	Cl	SO4	NO3	NO2	HCO3	CO2
					Y	X	Z																		
1	019/96	Dalecha BH4	29/06/03	Ign/rhyolite	1069590	561880	2810	7.69		210	132	10	2.2	5.35	28				0.96	3	0.78	4.8		113	
2	11935	Dalecha OBH1	29/12/96	Ign/rhyolite	1070520	561780	2805	6.95	19.3	188	122	7.6	2.7	4.2	21				0.41	6	2	6.2		93	17
3	11938	TTIBH1	28/12/96	Ign/rhyolite	1069410	557442	2800	6.47	19	425	255	12	2.8	10.5	46.5				0.19	46	16	46.52		83	
4	11942	Dalecha OBH2	29/12/96		1070730	561330	2800	7.2	19	198	125	6.8	2	4.6	23				0.42	6	1	7.92		98	11
5	168/96	Dalecha NBH1	28/11/03	Ign /Rhyolite	1070685	562106	2807	7.27		204	146	9.2	3.2	5.1	25.2	0.2	0.017	0.28	0.58	5.96	0			108	
6	184/96	Dalecha NBH2	18/12/03	Ign / rhyolite	1071000	562015	2806	7.12		205	124	8.2	3	4.1	25.2	0.1	0.04		0.42	5.78	0.6	19.8		87.9	
7	185/96	Dalecha AFBBH	22/12/96	Ign / rhyolite	1071004	560800	2830	7.78		288	164	28.5	5	2.6	31.1	0.1	0.022		0.58	8.86	11.4	4.84		155	
8	203/96	Beressa NBH4	20/01/04	Ign/rhyolite	1066823	559318	2787	7.93		229	150	13	4.1	4.1	30.2	0.1	0.024			5.8	1.1	13.6		114	
9	215/96	Beressa NBH2	28/01/04	Ign/rhyolite	1067258	559369	2780	7.16		203	132	8.2	3.8	4.6	25.2		0.007		0.84	5.8	0.1	7.04		117	
10	228/96	Dalecha NBH6	4/2/2004	Ign/rhyolite	1070784	560803	2807	7.28		188	116	7.7	2.6	5.1	25.2		8E-04		0.35	2.9	0.3	7.5	0	103	
11	229/96	Beressa NBH5	10/2/200	Ign/rhyolite	1066077	559432	2789	7.24		190	123	8.7	3	5.6	24.4		0.012		0.42	3.9	0.4	7.04		108	
12	230/96	Dalecha NBH7	16/02/04	Ign/rhyolite	1071660	561594	2804	7.15		194	128	7.4	2.7	5.6	25.2		0.011		0.46	3.9	0.4	11.9		99.6	
13	384/03	Dalecha NBH5	9/3/2003	Ign/rhyolite	1070084	563330	2812	7.73		205	162	20	4.5	4.86	31.2				0.96	7.94	7.65	7	0	132	
14	DBAHW-1	Hand dug well	29/12/96	Basalt	1072335	563678	2845	6.87		132	80	3.2	1.6	3.6	15				0.12	3	1	12.85		61	15
15	DBAHW-2	Hand dug well	29/12/96	Basalt	1068740	576165	3170	6		122	63	3.6	0.2	3.6	13.6				0.06	3	3			63	6.16
16	DBAKsp7	Spring	7/7/1996	Basalt	1066250	581565	3100	7.73	19.9	92.6	55.7	6	1.3	1.94	13.6				0.73	0	1	6.42		58.6	
17	DBBPSsp8	Spring	8/7/1997	Basalt	1069716	556084	2724	6.84	19.4	191	113	9.8	3	5.83	23.2				0.35	1.5	7.2	5.97		107	
18	DBBR-1	Beressa river	7/7/1997	Ign /rhyolit	1066000	559269	2750	7.5		176	106	7	3.5	3.89	21.6				0.5	6	2.9	2.12		112	3
19	DBBR-2	Beressa river	7/7/1997		1069250	556250	2740	8.02		196	119	6	3.4	4.86	22.4	0.003	0.059		0.5	8	2.9	1.2		88	3
20	DBCHsp6	Spring	30/06/97	Basalt	106600	568550	3050	7.33	16	148	81	8	0.9	0	22.4				0.59	1.5	1.1	8.19		78.1	
21	DBDsp5	Spring	29/12/96	Ign/rhyolite	1063194	571880	3065	7.2	16.5	163	90	3.6	0.8	4	20				0.36	4	0.36	4.87		85	14
22	DBKsp3	spring	28/12/96	Basalt	1066364	558582	2766	6.73		123	70	4	0.8	3.4	13.6				0.11	3	0	7.92		61	36
23	DBZsp4	Sprigs	28/12/96	Ign / rgyolite	1068197	558582	2766	6.4	17.2	485	232	15	3.4	11	50				0.16	57	22	53.16		83	
24	DPSBH	D. pro.sisters	17/09/91	Ign / rhyolite	1069300	557750	2785	6.6				27.2	4.6	11.7	54.5				0.4	63.8	32.5			146	

Remark Unless Stated in bracket, all concentrayions are in mg/l