ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SCIENCES

HYDROGEOLOGICAL INVESTIGATION OF CHACHA CATCHMENT A VOLCANIC AQUIFER SYSTEM, CENTRAL ETHIOPIA

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

BY: YONAS MULUGETA

JUNE, 2009

ADDIS ABABA

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SCIENCES

Hydrogeological investigation of Chacha Catchment a volcanic aquifer system, central Ethiopia

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

BY: **YONAS MULUGETA**

June, 2009

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.

Name: Yonas Mulugeta

Signature: ___________________

Date: ____________________

This thesis has been submitted for examination with my approval as University advisor

Name: Dr. Tenalem Ayenew (advisor)

Signature: ___________________________

Date: __________________________

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

HYDROGEOLOGICAL INVESTIGATION OF CHACHA CATCHMENT A VOLCANIC AQUIFER SYSTEM, CENTRAL ETHIOPIA

By
YONAS MULUGETA

Faculty of Natural Science
Department of Earth Sciences

Approval by board of examiners

Dr. Balemwal Atnafu ________________________
(Chairman)

Dr. Tenalem Ayenew ________________________
(Advisor)

____
(Examiner)

____
(Examiner)

ACKNOWLEDGMENT

First of all, I would like to praise God in the heaven who made it possible for me to begin and finish this work successfully.

It is my privilege to acknowledge the deep-hearted gratitude to my advisor Dr. Tenalem Ayenew, Assoc. Prof., Hydrogeology, Department of Earth Sciences, Addis Ababa University, for the professional and constructive comments and supervision throughout the pursuit of this research project. His guidance and constant encouragement made me strong enough to complete the present research work successfully.

I would like to thank Staffs of Addis Ababa University Earth Science Department; Dr. Belamewal Atnafu (Head), Dr. Seifu Kebede, secretary office members and all instructors deserve my appreciation for their help.

I am grateful to the Ministry of Water Resources, Geological Survey of Ethiopian (GSE), and National Meteorological Services Agency (NMSA) for providing the data needed for this thesis as well as for letting me use library service.

I acknowledge all my family for their ever-existing love and help. Specially, behind all this work mam is there, thank you mam.

TABLE OF CONTENT

LIST OF FIGERS

LIST OF TABLES

LIST OF PLATES

ABSTRACT

Hydrogeological investigation of Chacha catchment, a volcanic aquifer system is carried out on Chacha river shade which is situated about 105 km north east of Addis Ababa on the way to Debre Berhan and covers an area of about 1194 sq.Km with a considerable elevation difference from 700-3500 m.a.s.l and an average elevation of 2728m.River gorge, gentle slope and highland characterize the physiograph of the catchment The catchment gets 939 mm of annual mean rainfall and 13-15.6 °c average annual temperature. Potential evapotranspiration (PET) is estimated empirically 1141mm/yr. The area has two rainfall regimes (bimodal rainfall characteristics).

Recent Quaternery deposits, Tertiary Ignimbrites, Basalts, Tertiary Sediments and Mesozoic Sandstone constitute the stratigraphy of the area from the youngest to the oldest respectively.

The aquifer system has been defined based on hydrogeological characteristics of lithological units described by the geological maps and data from the field inventory. The hydrogeological characterization of the area revealed the following aquifer / aquitard system:

•.Porous aquifer developed in alluvial and colluvial sediments of the plateau, Tertiary sediments, Pyroclastics and Mesozoic sandstone in deep valleys.*(T=10-100 sq.m/d and Q=1-5 l/s)*

•Fissured aquifer developed in basalts on plateau and deep valleys.*(T=10-100 sq.m/d and Q=1-5l/s)*

•Mixed aquifer developed in fissured Ignimbrite and Basalt and porous Tertiary Sediments intercalating volcanic rocks on plateau. *(T=10-100 sq.m/d and Q=1-5l/s)*

•Aquitards developed in Ignimbrites forming water shed mountains along plateau – rift valley edge. *(T = 1 – 0.1sq.m/d and Q = 0.05 - 0.5 l/s)*

The water type in the Chacha catchment is predominantly calcium bicarbonate. Groundwater of the study area is generally suitable for Drinking water supply and irrigation.

Generally, the area has enormous surface water and ground water resources thus intensive sustainable water resources development is recommended by sinking dugwells and shallow wells not more than 60m depth on the plateau and small valleys. Springs can be developed on the flat plain and escarpments of the deep gorges. Drilled wells in the range of 100-150m are recommended for town water supply schemes. In addition to water supply, large scale irrigation and hydroelectric power development in Chacha catchment using available water resource specially ground water is possible.

1. INTRODUCTION

1.1 BACK GROUND

Ethiopia is an East African and tropical (3°N to 18°N) country affected by environmental degradation, including recurrent droughts which led to food insecurity. The drought stricken areas have been constantly degraded in the past several decades by improper utilization of natural resources. The central dissected highland of Ethiopia is no exception to the above mentioned fact. The rugged topography and high gradient coupled with intense deforestation aggravates the problem.

It is believed that an intensive sustainable water resources development can have a great role in the socio-economic growth of the country and in preventing the recurrent drought problems. A pre-requisite for an appropriate utilization and management of the water resources is the investigation and planning of the resources on small and large scale.

Access to the fresh water resources development is beyond the reach of the overwhelming majority of the population in the study area, Chacha catchment. Although the distribution is uneven, the area has enormous surface water and ground water resources. Very little has been done in the field of development of the water resources, particularly in areas of groundwater. Groundwater utilization has been limited to community water supply using shallow hand dug wells and unprotected springs. Limited deep boreholes were drilled in few rural areas. The use of deep ground water from boreholes for agriculture is almost non-existent. There is also an increasing demand for water supply, irrigation and hydroelectric power development in the area.

The Chacha catchment in the central high lands of Ethiopia is one of the richest water resources found within the Jemma sub basin, east of Abay basin. Abay basin drains a large area of the Ethiopian highlands. Jemma sub basin has a great significance in surface and base flow to Abay basin.

Since little is known about the detailed hydrogeology of the Chacha catchment, that is hydraulic connection between different aquifer units, water rock interaction controlling the natural ground water chemistry and its spatial evolution, more rigorous and site-specific analysis of the hydrogeology, ground water recharge, circulation and geochemical evolution patterns of the catchment are required. This will have paramount importance for locating appropriate new tube-well sites, for identification of surface and ground water interaction and for development and management of sustainable water resources.

1.2 OBJECTIVE AND SCOPE

1.2.1 GENERAL OBJECTIVE

The main objective of the hydrogeological investigation in the Chacha catchment is for ground water resource assessment and sustainable development which can be used by planners, decision makers of governmental and non governmental organizations which are prepared for urgent ground water resource development programs to solve the problem of an immediate water demand in the area for both short term drought relief and long term economic stability and development.

1.2.2 SPECIFIC OBJECTIVES

The specific purposes of the investigation efforts are:

- Collect, Organize and Obtain aquifer parameters for the hydrogeological units from field data and well drilling reports.
- Evaluate basic components of hydrologic cycles and identify recharge areas.
- Investigation of surface and ground water interaction within the catchment.
- Identify water bearing lithological units and their basic characteristics.
- Determine the regional and local groundwater flow systems in the catchment.
- Produce hydrogeological map of the catchment at the scale of 1:50,000.

- Categorize water quality within water bearing formations.
- Indicate the suitability of groundwater for community water supply, domestic purposes, livestock watering, irrigation, or industrial purposes.
- Suggest possible measures for sustainable integrated utilization of the surface and ground water resources.

The work covers satellite image interpretation, meteorological and hydrological data analysis, quantifying inventoried water points, collection of representative water samples and data for hydrogeochemical studies and evaluation of water resource management of the area. The findings are compiled at a scale of 1:50,000 which will provide basic information for the development of potential surface and ground water resource of the Chacha catchment.

1.3 LOCATION AND AERIAL EXTENT OF THE PROJECT AREA

Chacha catchment is located at the central highlands of Ethiopia, at the western margin of main Ethiopian rift that is east of Abay basin and south-east of Jemma sub basin. The Jemma sub basin is situated in south-east corner of Abay basin.

Geographically, the area is bounded by 39°00’E to 39°45’E longitudes and 9°15’N to 10°15’N latitude and with in 520000m - 565000m easting and 1025000m - 1110000m 37N UTM. It covers an area of about 1194sq.Km and 105 km from Addis Ababa on the way to Debre Berhan.

.

The area is mainly in the Debre Birhan sheet (NC 37-11) and covers parts of 8 sub sheets such as Chacha, Sheno, Debre Birhan, Sasit, Gina Ager, Inewari, Zemero and Metranya.

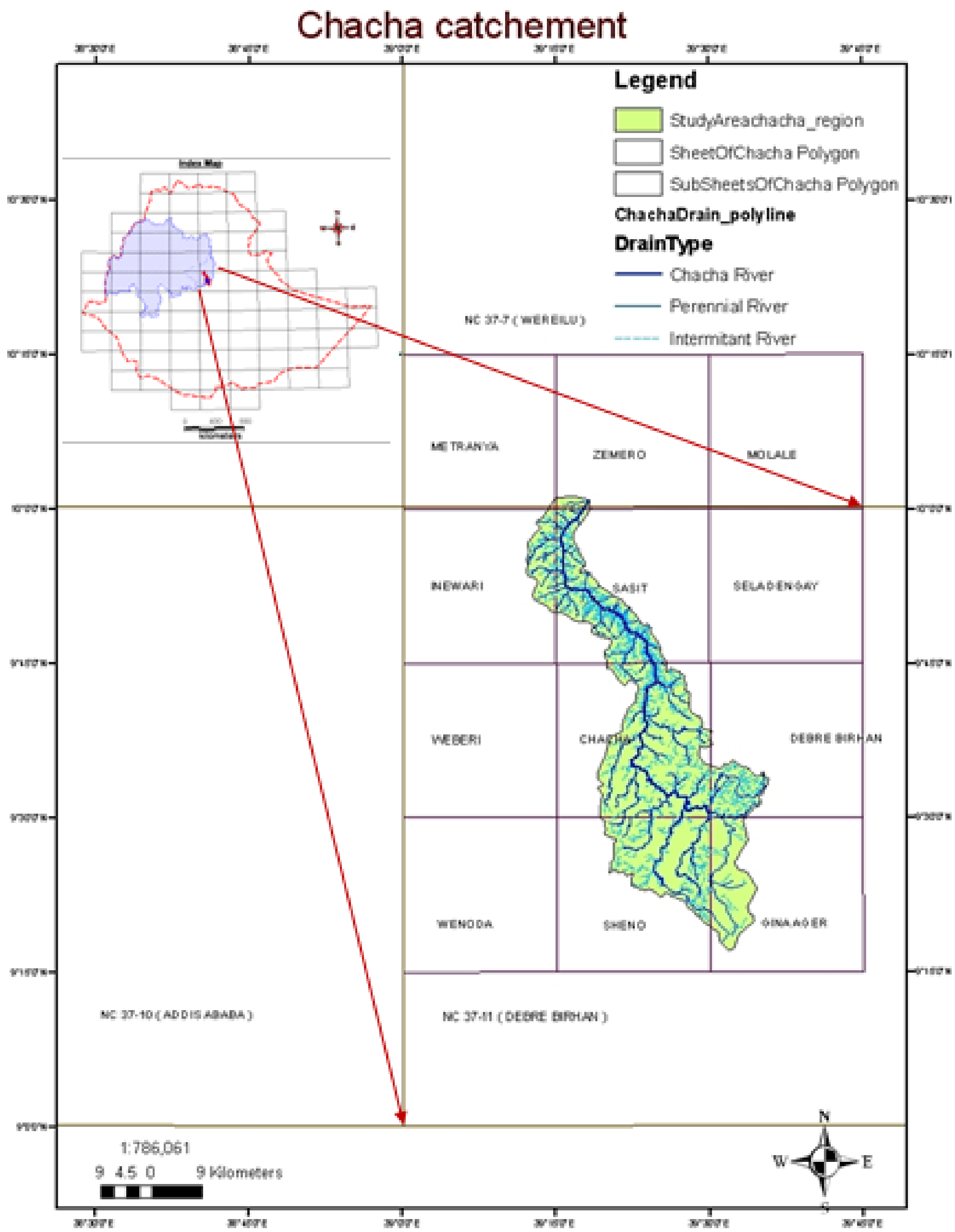


Figure 1.1 Location map of the Chacha catchment.

1.4 ACCESSIBILITY

The study area can be accessed by a number of all weather roads and foot trails. There is a good accessibility to the upper and middle part of the Chacha catchment because of relatively better road net works. The down stream part of the area is less accessible due to big gaurge formed by Chacha river.

Addis Ababa – Chacha is the only asphalt road under maintenance that runs diagonally with in the north – east of the study area. Mendida – Debre Birhan is another main all weather road that cross the study area in a east – west trend.

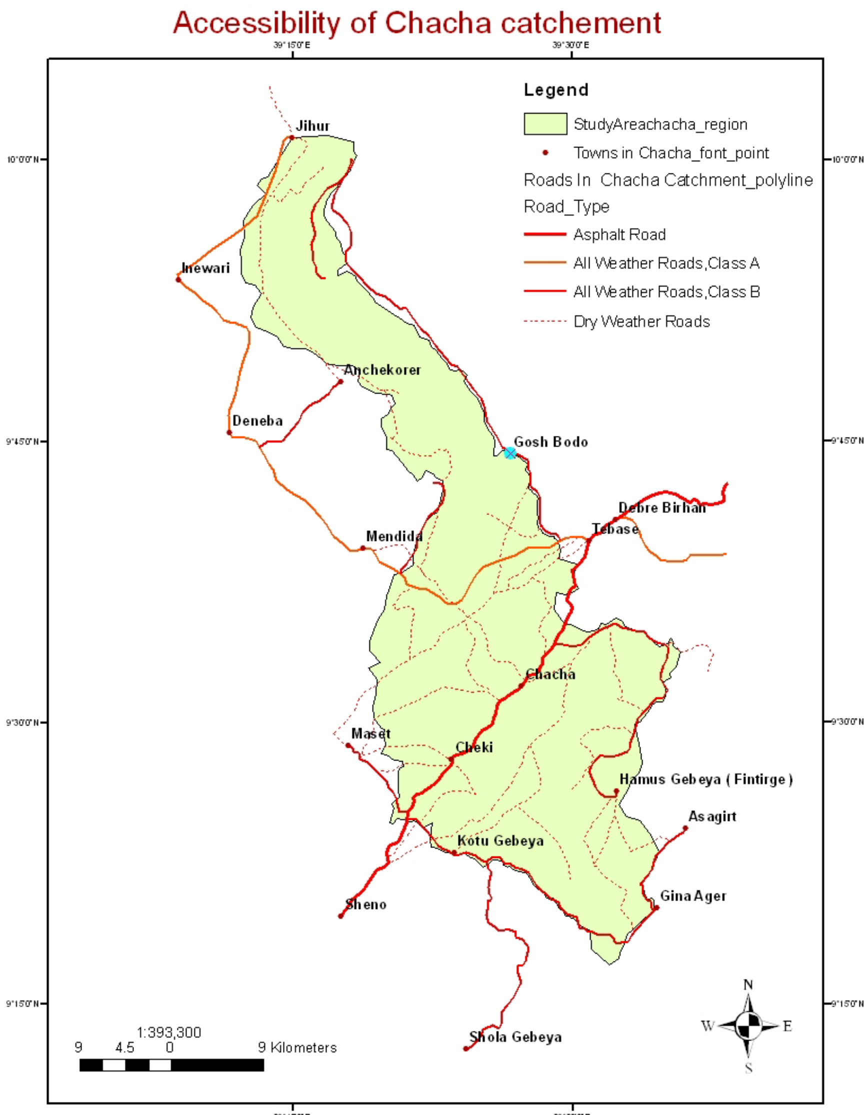


Figure 1.2 Accessibility map of the Chacha catchment.

1.5 POPULATION AND SETTLEMENT

The study area is administrated mostly by north Shewa zone of the Amhara regional state and north Shewa zone of the Oromia regional state in the parts of north – west and south – west of the study area. Angolela Terana Asagrt, Debre Birhan Zuriana Keyit, Moretna Jiru, Saya Debir

Wayuna Ensaro, Hagere Mariam Kesem and Berehet are weredas found in Amhara regions while Kembibit and Abchuna Gnea weredas belong to Oromia national regional state.

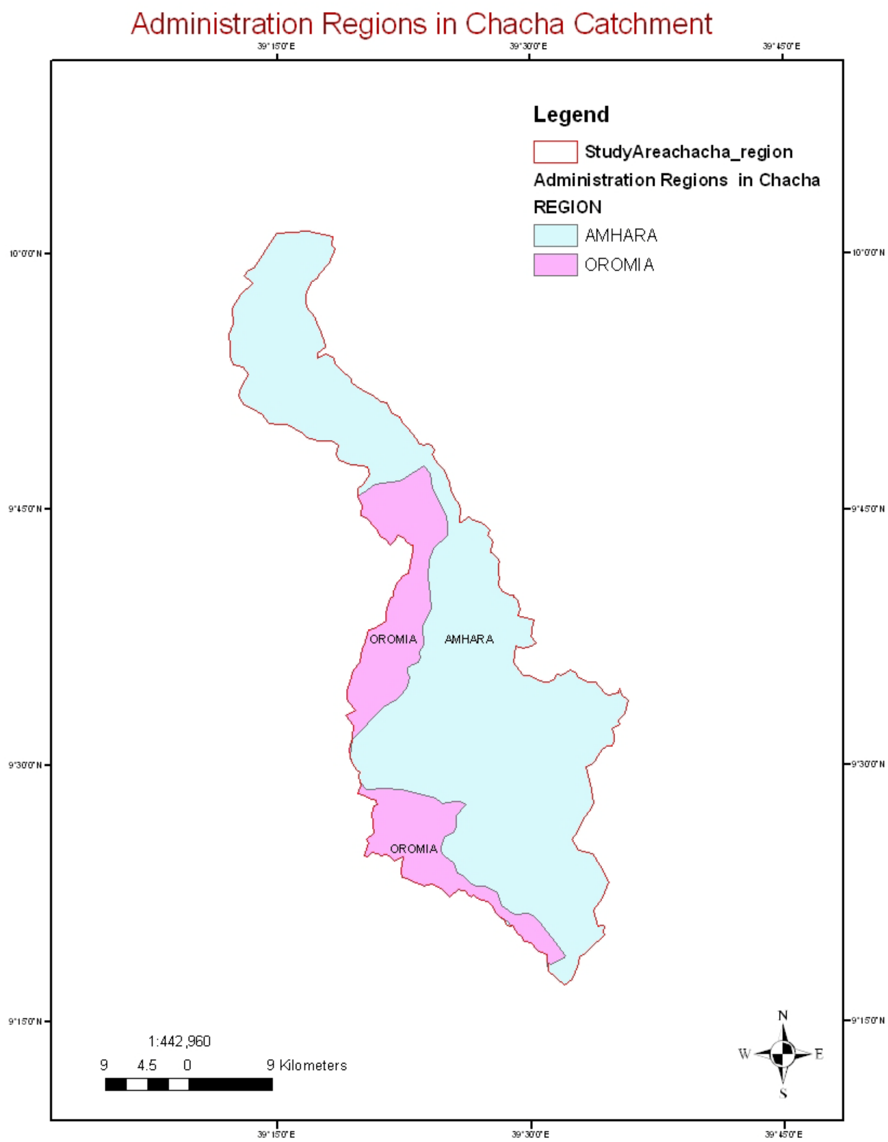


Figure 1.3 Administrative regions of the study area.

The population of the study area and the surrounding is unevenly distributed. This unevenness in the distribution of population of the zone is primarily the result of the differences in the suitability of environmental condition for settlement and secondly the result of Socio-Economic and historical factors.

Among the major environmental factors that influence population distribution in the area are mainly terrain characteristic (relief), presence or absence of perennial water bodies, the suitability of the land for farming and cattle breeding. The non environmental factors that contribute to the variation of population distribution are accessibility that is the development of communication networks and basic social infrastructures such as schools, health facilities, portable water, etc.

The great majority of people of the area live in rural areas depending on subsistence agriculture. A relatively large number of people live in the highlands and along or nearby water sources in the river valleys. Inhabitants of the area are engaged in different kinds of work, but most of them practice agriculture, cultivating different kinds of crops: teff, barley, maize, etc. In addition to agriculture most of the farmers raise domestic animals. The climatic conditions of the majority of the area are best suited for highland domestic animals like horses and sheep. Horses play important role for transportation of people and goods. The wool from the highland sheep's is used as a major input for Debre Birhan wool factory. The inhabitants of the study area are mainly from Amhara and Oromo ethnic groups. Some Guraghe and Tigray people also live in the towns like Chacha, Cheki and Hamus Gebeya. Amharic and Oromifa are widely spoken languages among the different ethnic groups.

Table 1.1 Population in the Chacha catchment.

Region	Wereda	Wereda coverage within the study area		Population density (pers/km2)	Population within the study area
		km2	%		
Amhara	Moretna Jiru	102.22	14.5	99	10,119.78
	Debre Birhan Zuria (Keyit)	193.19	16.1	96	18,546.24
	Saya Debir Wayuna Ensaro	95.39	8.8	108	10,302.12
	Angolela Terana Asagirt	556.13	56.4	85	47,271.05
	Berehet	0.15	0.015	30	4.50
	Hagere Mariamna Kesem	2.51	0.3	52	130.52
Oromia	Abechuna Gnea	114.91	29.5	146	16,776.86
	Kimbibit	129.83	15.9	87	11,295.21
	Total	**1194.33**			**114,446**

Source: Population by wereda, Central Statistics Authority Statistical Abstract 2006

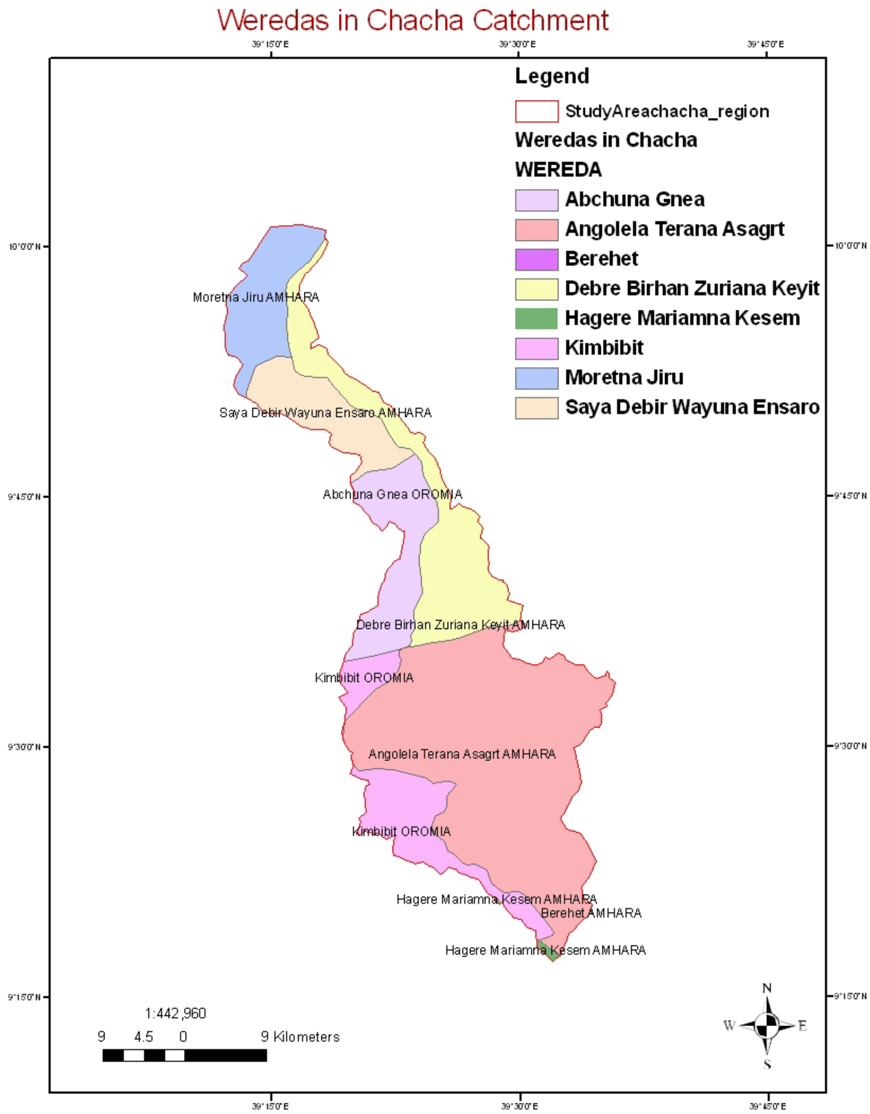


Figure 1.4 Position of weredas with in the study area.

1.6 DEMAND

Because of population increase and increasing demands for more water for agriculture, industry and community, a large number of areas fall into category of "water scarce" areas. Population (projected from CSA 2000 Figures) growth by region rate = 3.8% for urban and 2.23% for rural. This situation will be even worse in 2025 based on trends in population growth. Water scarcity less than 1000 m^3/a and water stress less than 500 m^3/a (Tesfay Tafesse, Nile question: Hydropolitics, Legal Wrangling, Modus Vivendi and Perspectives, LIT, 2001). There for people in the urban and rural need further development of sustainable water supply.

1.7 PREVIOUS WORKS

Few papers and reports concerning geology and hydrogeology of the area and vicinity have been written.

- The Hydrogeological map of Ethiopia in a scale 1:2,000,000 (Tesfaye Cherenet, 1988) classified the different rocks of the area in to aquifer groups of moderate yield, general recharge to ground water from rain fall is estimated as 50 to 150 mm/year (moderate) and general recharge to ground water from runoff localized along streams is estimated as moderate to high, Total Dissolved Solids (TDS) less than 500 ppm, and depth to ground water 0-100 m, exploitable in low relief areas.

- The Geological map of Ethiopia at scale 1:2,000,000 (compiled by Mengesha Tefera, Tadiwos Cherenet and Workineh Haro, Regional Geology Department, GSE,1990) classified the rock units of the catchment in to Tertiary, middle Miocene, Tarmaber Megezez formation (Transitional and alkaline basalt) in the up stream part of the catchment, Oigocene-Miocene Alage formation (Transitional and sub alkaline basalt with minor rhyolite and trachyte eruptives) in the middle of the catchment and Middle-Late Oligocene Aiba Basalt (Flood basalts with rare basic tuff) in the down stream of the Chacha catchment (North of the catchment) from young to old respectively.

- Molla Demlie et al (2007) have studied ground water recharge, flow and hydrogeochemical evolution in a complex volcanic aquifer system, central Ethiopia at the south western vicinity of the catchment.

- Hydrogeological map of the Jemma basin at 1:250,000 scale by the Geological Survey of Ethiopia (GSE).
- Few Localized water well sitting studies and unpublished regional hydrogeological investigations.

In general, published researches and scientific exercises could not be found in the catchment that cause a lack in detail and sub-detail information.

1.8 METHODOLOGIES AND PROCEDURES

To implement the prime objective of the investigation the necessary study approaches and methodologies is used. Such as:

Desk study: prior to the field work relevant materials like geological reports and maps is collected from Regional Geology and Geochemistry Department of GSE. Important data and reports in the study area are also collected from minister water. Topographic maps are purchased from Ethiopian map agency (EMA). Using the information collected and previous hydrogeological works preliminary interpretation of the data is made.

During field work: During the field work topographic and geologic maps of 1:50,000 scales are used as a base map. GPS is used for locating water points on the map. Based on lithological variation, topography and structure representative samples is collected and plotted on the base map regularly. Water points is collected for chemical analysis and/or inventoried at the spot. Insitu pH and EC measurements is conducted for all water samples using pH and EC meters respectively. Field photographs are captured for documentation and interpretation. Borehole data and inventoried water points is collected from regional water bureaus, NGO's and private drilling companies. Discharge of springs and is measured by floating, volumetric method and visual inspection.

After field work: Based on the detailed field observation, yield measurements of water points, chemical results of the water samples and data collected analysis and report writing is made. Data processing will be done with the help of software's such as Global Mapper-8, DEM, ErdasImagin 9.1, ArcGIS-9.2, MapInfo Professional 8.0 SCP, Surfer-8, Aquachem-4 and Excel.

Based on the detailed field observation, yield measurements of water points, chemical analysis of the water samples and data collected, aquifer classification and identification of productivity based on lithologic, structural, field hydraulic properties, transmissivity data, topographic setting and recharge condition will be made.

The investigation will have significant importance for locating appropriate new well sites and for development and management of sustainable water resources and also, as an additional in put for further study of the possible sources of potable water and irrigation in the area.

2. PHYSIOGRAPHY, VEGETATION, LAND USE/ LAND COVER AND SOILS

2.1 PHYSIOGRAPHY

The present topographic configuration and geomorphological development of the catchment is closely related to the geological, paleo-geographical development and a series of tectonic and erosional activities that took place over the study area and the surrounding. The south eastern part of the Chacha catchment is situated in the Ethiopian highland plateau adjoining the western escarpment of the rift valley closely related to the development of the Ethiopian Rift System and recent fluvial processes.

The eastern margin of the Blue Nile basin is typically characterized by deep cut gorges with sharp escarpments and flat top hills. Hence, the study area, which is the south eastern part of Blue Nile basin, is also characterized by highly dissected river valleys, gently sloping and undulating plains and highlands.

Digital Elevation Model (DEM)

The digital elevation model of the area shows that there is a sharp topographic variation close to the ridge in the south, southeast and east parts, while large part of the area is flat in center (fig.2.1).

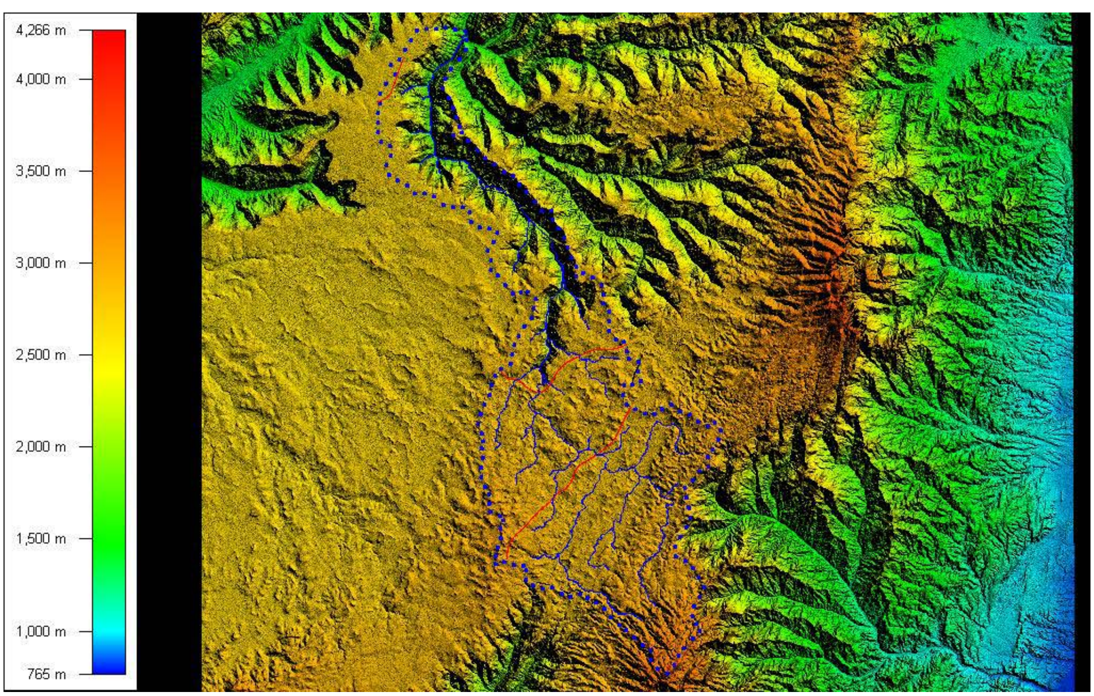


Figure 2.1 DEM of Chacha catchment and the surrounding.

Elevation difference between the peak of the highest ridge and the lowest point in Chacha river is significant. Figure 2.2 shows a satellite DEM image (30m) and a profile section indicating high and low areas along the line of interest.

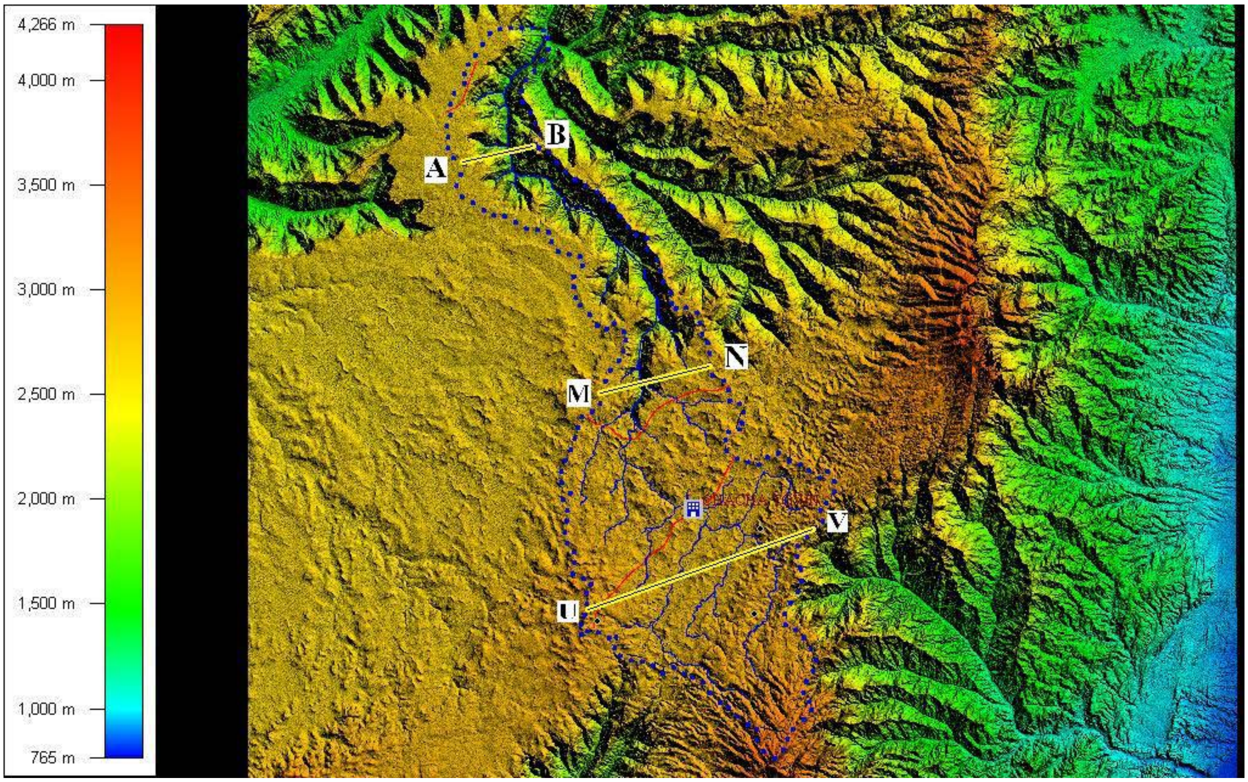


Figure 2.2 Top view of satellite DEM image of the study area showing relief of the area and profiles along the AB, MN and UV lines.

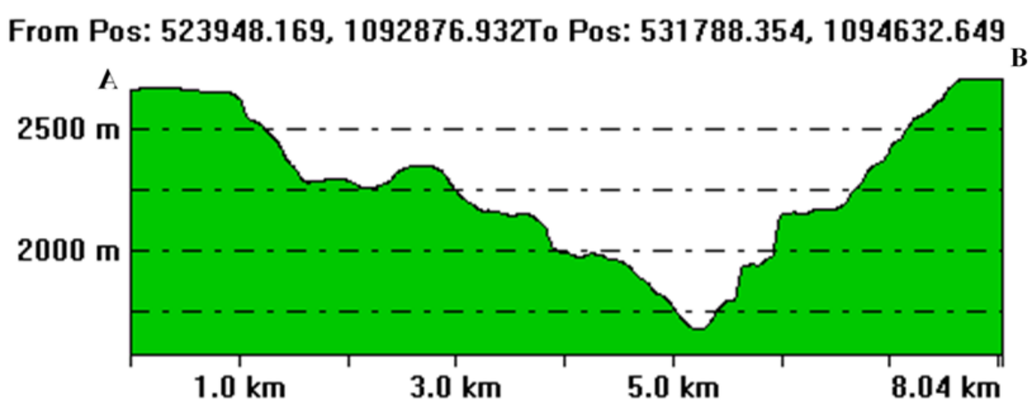


Figure 2.3 Down stream profile section of Chacha river along AB line.

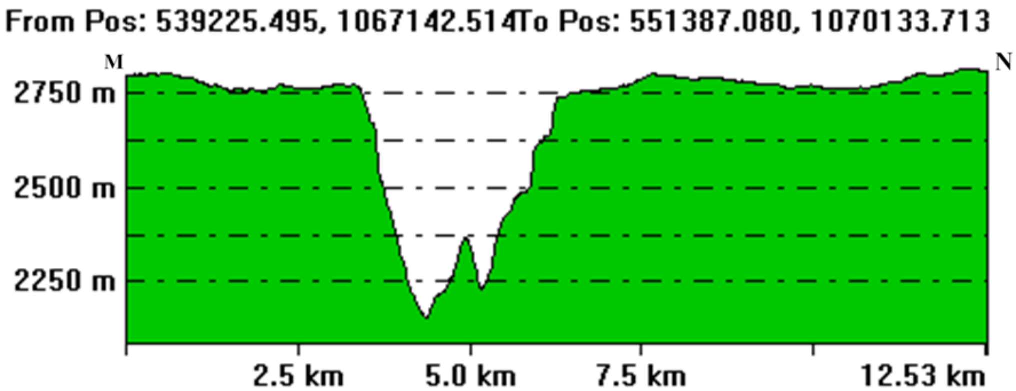


Figure 2.4 Middle stream profile section of Chacha river along MN line.

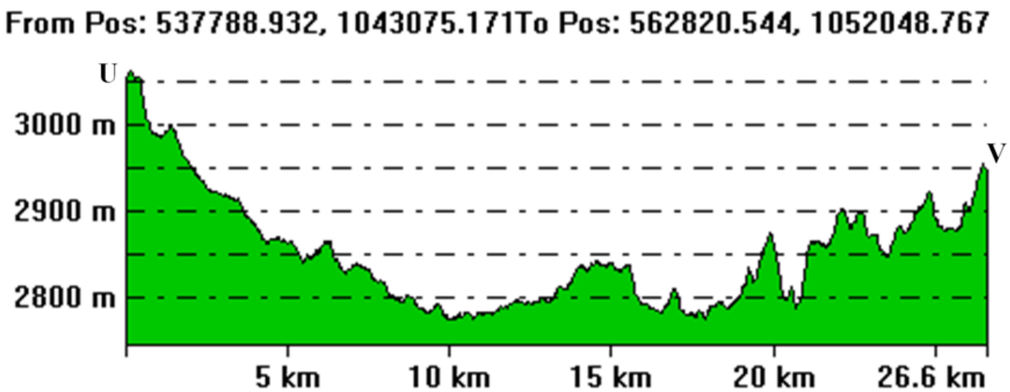


Figure 2.5 Up stream profile section of Chacha river along UV line.

Slop, Aspect, Hill Shade and TIN

Surface topographic slope gradient and direction control surface hydraulics directly and subsurface hydraulics indirectly. Large part of the Chacha catchment has a slope range of **0°-7.4°** (fig. 2.5) with a flat topographic setting (fig. 2.6). High slope gradient **54.6°-89.8°** is observed at the high lands with a slope direction of west, northwest, east and northeast mostly. The down stream gorge of Chacha river has a slope range of **27.1°-54.6°**. Gentle slope **7.4°-27.1°** is observed in the escarpment of down stream gorge. To configure the topographic setting, hill shade and TIN is made.

There is a considerable elevation difference in the Chacha catchment ranging from 700-3500 m.a.s.l with an average elevation of 2728m. Based on elevation difference, surface topography and morphology the study area can be generally divided into three Physiographic zones.

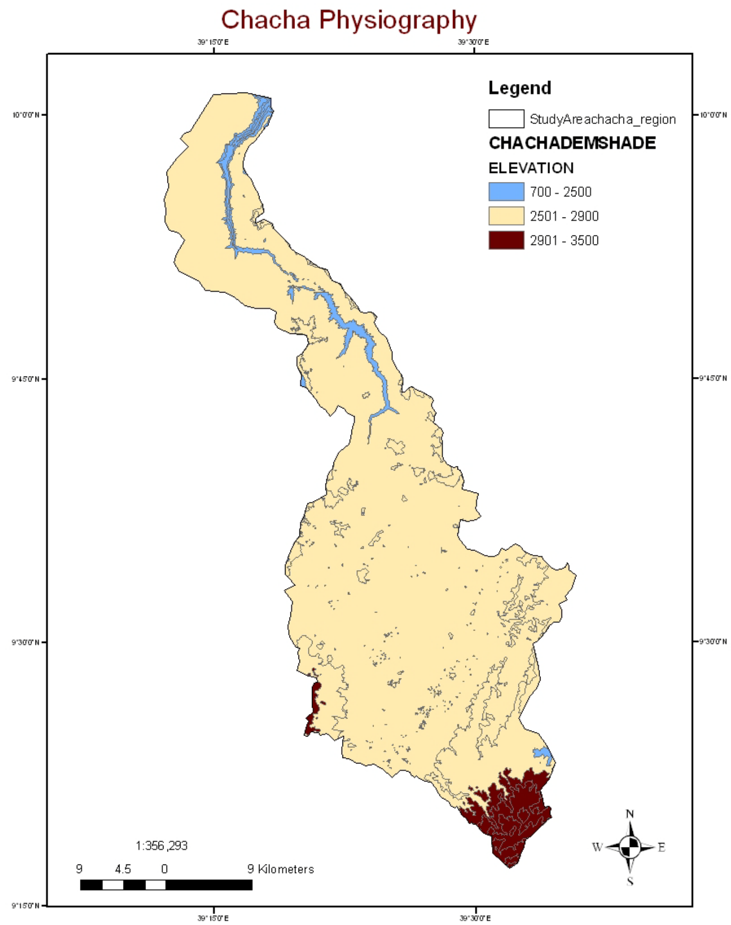


Figure 2.6 Physiographic zones of Chacha catchment.

I .***Chacha river Gorge***

This physiographic area occupies the north and northeastern corner of the study area (Fig. 2.9) elevation ranging from 700-2400 m.a.s.l and represents deep gorges of Chacha Rivers. The Mesozoic sediment is exposed here and the lowest elevation of the catchment is recorded in this physiographic zone with an altitude 700 m.a.s.l at Chacha river course (Fig.2.3). This part of the region makes up 0.03% of the area (35.41 km^2). In this topographic configuration Chacha River leave the catchment and drain to Jemma River.

II. ***Central flat plain and gentle slopes***

This physiographic region accounts about 99% (1104.17 Km^2) of the study area and the altitude ranges from 2500-2900 m.a.s.l, and mostly represented by flat plains covered by recent deposits while on gentle slopes Tertiary ignimbrite and basalts are partly exposed (Fig. 2.10). Most of the dwellers and towns are located in this physiographic region; due to the suitability of the topography for agriculture and dwelling, it is well inhabited and intensive farming is practiced on the area.

III. ***Highlands***

This physiographic region is found in extreme southeastern corner, southern corner and south-west of the study area (Fig. 2.11) covering about 0.5 %(56.51) of the study area. It is usually forms basaltic mountain picks and ridges. The altitude of this region ranges (2900-3500 m.a.s.l) and attains a maximum height of 3595 m.a.s.l at Mt. Megezez peak at extreme south of the catchment and Mt. Gara Dalota (3070 m.a.s.l), Mt. Gara Golba (3050 m.a.s.l) and Mt. Gara Kenisa (3030 m.a.s.l) cover south-west of the study area.

The area hosts few natural forests. The differences in altitude between high lands and low lands of the area have effects on the climatic conditions, vegetation and soil distribution, land use and land cover activities.

2.2 VEGETATION

Vegetation cover of an area helps to minimize water loss or degradation through surface run off or flooding by intercepting rainfall and increasing infiltration of water to soil and to ground water table. Vegetation distribution in the study area varies from place to place depending on variation in altitude, climatic conditions and population density.

The high land, which receives the highest rainfall, is partly covered with green forests, while areas to the north with little rainfall are covered with scattered eucalyptus, junipers and acacia trees.

Cultivation, burning and deforestation coupled with high gradient topographic setting have considerably changed the natural vegetation cover over much of the area, aggravating the rate of weathering and the rate of erosion. Runoff rate is increased while evapotranspiration and groundwater recharge decreases. Areas covered by Tertiary ignimbrite and basalts are mostly cultivated. Big trees and thick forests occur on the high land where the trap series are found.

Plate 2.1 Onion farm and eucalyptus trees Plate 2.2 Cactus trees

2.3 LAND USE AND LAND COVER

Land use and land cover distribution in the study area depends on variation in altitude, climatic conditions, population density, land use practice and agricultural activities. Human interference to the physical environment is great in the gentle to flat plain of the physiographic region. The high growth rate of population resulted in search of additional farmlands by clearing the existing small patches of vegetation covers; farming is also practiced on slopes which is aggravating the erosion rate. Different types of soil erosions like sheet and specially gully types are mainly observed.

The land use of the study area mainly classified in to a arable land, grass land, mosaic of shrubs and fields, pastures, wet land/pastures, river bed, barren land, sparse herbaceous, water bodies, forest-eucalyptus, forest-natural trees and shrubs(Fig. 2.7).

Intense cultivation is practiced in the upper and the middle part of the catchment and the lower part of the catchment is moderately cultivated. The major cereals cultivated seasonally in the area are wheat, barley, beans and peas and some vegetation like onion, cabbage and potato is cultivated by irrigation. Few natural trees in the area are found. The trees found in the area include mainly eucalyptus, junipers and few cactus. The high demand of wood for fire, charcoal and construction material has highly intensified the deforestation. There are also patches of barren lands which need special treatment.

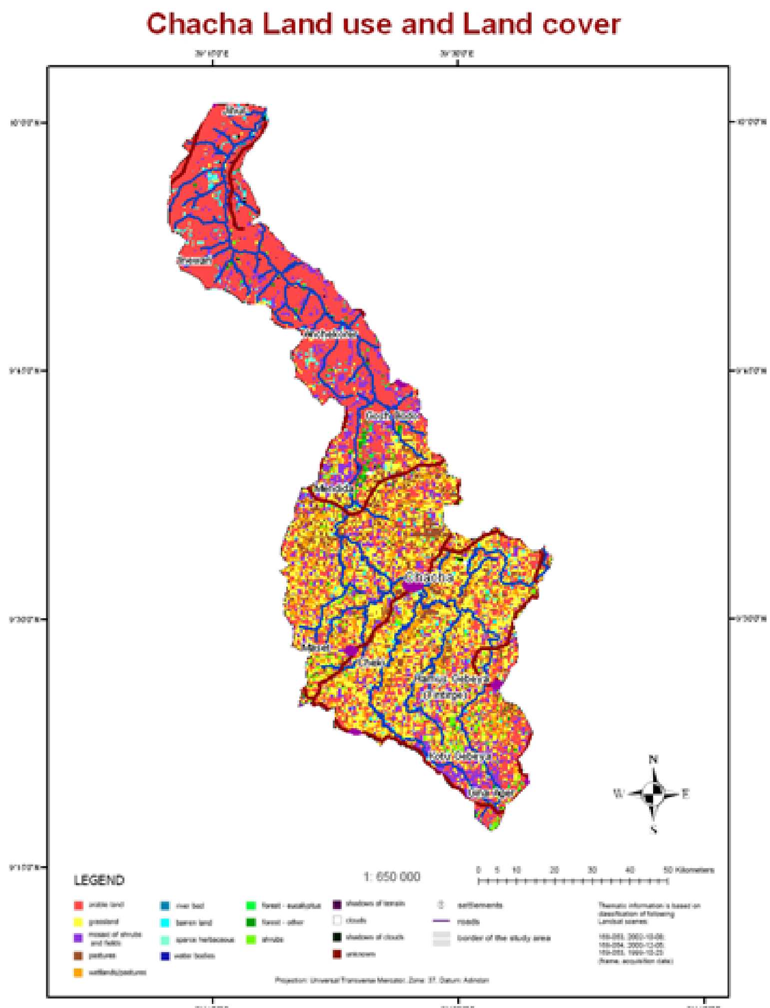


Figure 2.7 Land use and land cover map of Chacha catchment.

2.4 SOILS

Soil type distribution extent and characteristics in the study area depends on variation in geology, topographic setting and slope gradient, altitude, climatic conditions, population density, land use and land cover and agricultural practice. The western volcanic highlands have shallow to deep brown and black clay soils (Hydrogeology of Ethiopia). According to the geomorphologic map obtained from the Ministry of Agriculture, the study area is covered by eight types of soil covers (Fig. 2.15)

Vertic Cambisols/ Pellic is found in the middle and upper part of the catchment covering **531.51km^2**, which accounts for **54%** of the study area. Vertic Cambisols is the major unit in this type of soil. This soil type dominantly covers the area where farming activity is intensive. Cambisols are those soils, which are changed a lot in color and structure as a result of weathering.

Lithosols/ Eutric Cambisols is seen covering north eastern part of the catchment with an areal extent of **216.96km^2**, occupying about **22.1%** of the total area. Lithosols is the major unit in this type of soil. This soil type dominantly covers the area where farming activity is moderately intensive.

Pellic Vertisols bound the catchment from north to north west where the gradient is high and covering an area of **93.63km^2** that constitute about **9.5%** of the total area.

Eutric Cambisols/Vertic Cambisols is mainly found in the eastern part of the upper catchment south east of Chacha town. It covers **55.37km^2** with **5.6%** coverage of the total catchment. Eutric Cambisols is the major unit in this type of soil.

Pellic Vertisols/Lithosols is found at the escarpment of the southern high land that bound the catchment in the up stream. This unit has an areal extent of **41.71km^2**, which accounts **4.2%** of the total area. Pellic Vertisols is the major unit in this soil type.

Eutric Cambisols-Eutric Regosols covers the high land at extreme south of the study area where highest elevation is observed (3595m.a.s.l). It occupies an area of **16.82km^2** with **1.7%** coverage of the total study area.

Cambic Arenosols/Lithosols is the deposition in the gorges at extreme north of the study area where Chacha River leaves the catchment. It has the smallest areal coverage of **0.91km^2** that occupies about **0.1%** of the total catchment.

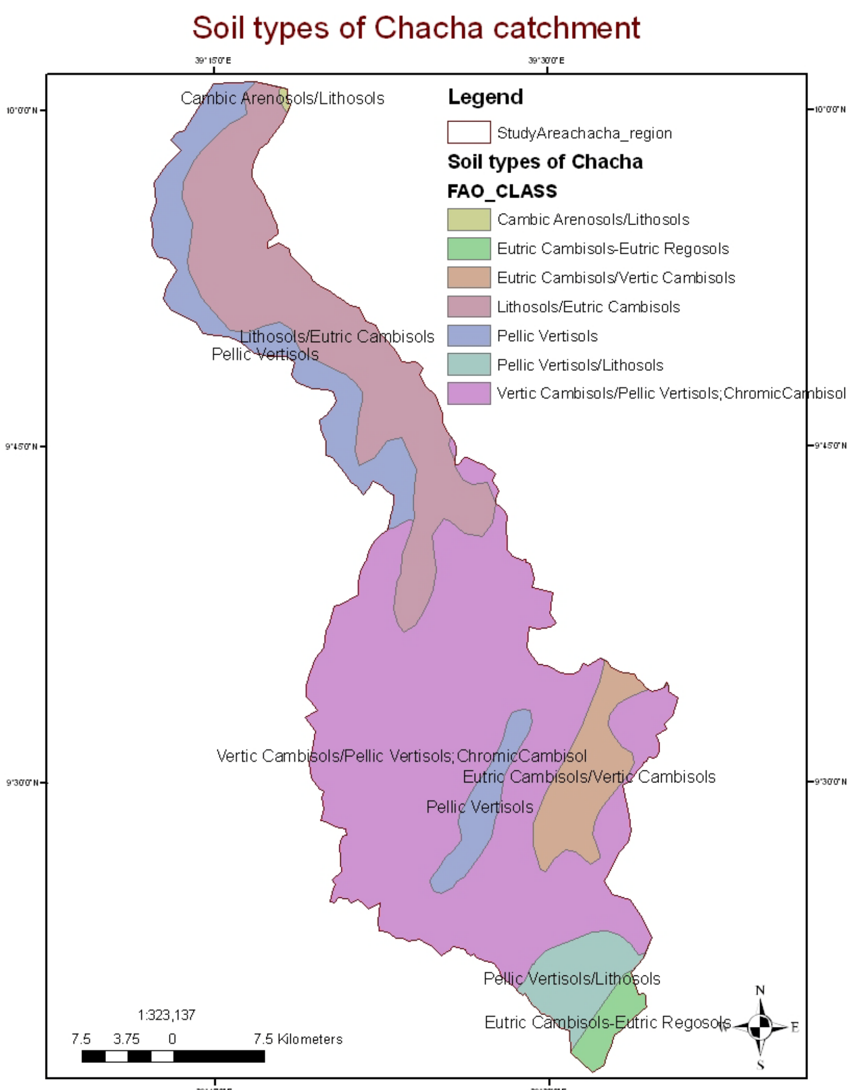


Figure 2.8 Soil types of the study area

3. HYDROMETEOROLOGY

3.1 GENERAL

Climate strongly affects soil, geomorphology, surface and subsurface hydrosphere of an area. The climate of an area is controlled by altitude, latitude, direction of wind and its distance from water bodies. Climatic conditions in Ethiopia and most equatorial regions are strongly influenced by their altitude. The National Meteorological Service Agency (NMSA) classified the climatic regions of Ethiopia in to the following zones.

Table 3.1 General climatic Division of Ethiopia (1981)

Annual mean Temperature	Temperature Region		Regional Altitude
Less than 10°C	'Kur'	Alpine	3300m.a.s.l and above
10-15°C	'Dega'	Temperate	2300-3300 m.a.s.l
10-20°C	'Winadega'	Subtropical	1500-2300 m.a.s.l
about 30°C	'Kola'	Tropical	500-1500 m.a.s.l
30-40°C	'Bereha'	Desert	Below 500 m.a.s.l

Climatic classification is also dependent on the distribution of annual mean temperature and precipitation. The climatic regions range from arid and tropical to wet areas and from hot low lands to cool tropical high lands. Each climatic region has a characteristic vegetation cover of its own.

Despite its proximity to the equator, Chacha water shade enjoys Afro-alpine temperate climate. According to NMSA (1981), the largest part of the water shade is represented by tropical highland climatic zone which is cool highland and warm temperate climate. Geomorphological setting of the shade which is situated in the central plateau also controls the climatic pattern. The climate of the Chacha water shade is characterized by three seasonal weather patterns. The main wet season (locally known as 'Kiremt') extends from July to September and contributes about

69.8% of the total annual rainfall. A minor rainy season from mid February to mid May mainly March and April contributes 11.4% of the moisture to the region (locally known as 'Belg'). The rest of the months of each year are more or less dry, at times with occasional erratic showers. In the area, the lowest and the highest annual mean precipitations are 905mm and 1395mm respectively and the minimum and the maximum annual mean temperatures are 12.7°C and 15.6°C respectively.

The climatic stations data within and around the study are obtained from NMSA, there are six meteorological stations recording different parameters.

Table 3.2 Meteorological stations within and around Chacha river catchment.

	Station name	**class**	**UTM /E/**	**UTM /N/**	**altitude**	**Observation. period**	**Acquired parameters**
1	Chacha	4	1054315	550301	2788	1954-05	RF
2	Debre Birhan	1	1068583	556006	2767	1954-05	RF, Temp, RH, Evap
3	Sheno	3	1030534	531194	2874	1959-05	RF, Temp
4	Deneba	4	1078202	521145	2673	1975-05	RF
5	Jihur	4	1107568	526543	2730	1974-05	RF
6	Aliyu Amba	4	1055252	588898	1692	1976-05	RF

Chacha meteorological station is found with in the Chacha water shade; Debre Birhan, Sheno, Deneba, Jihur and Aliyu Amba stations are situated surrounding the shade.

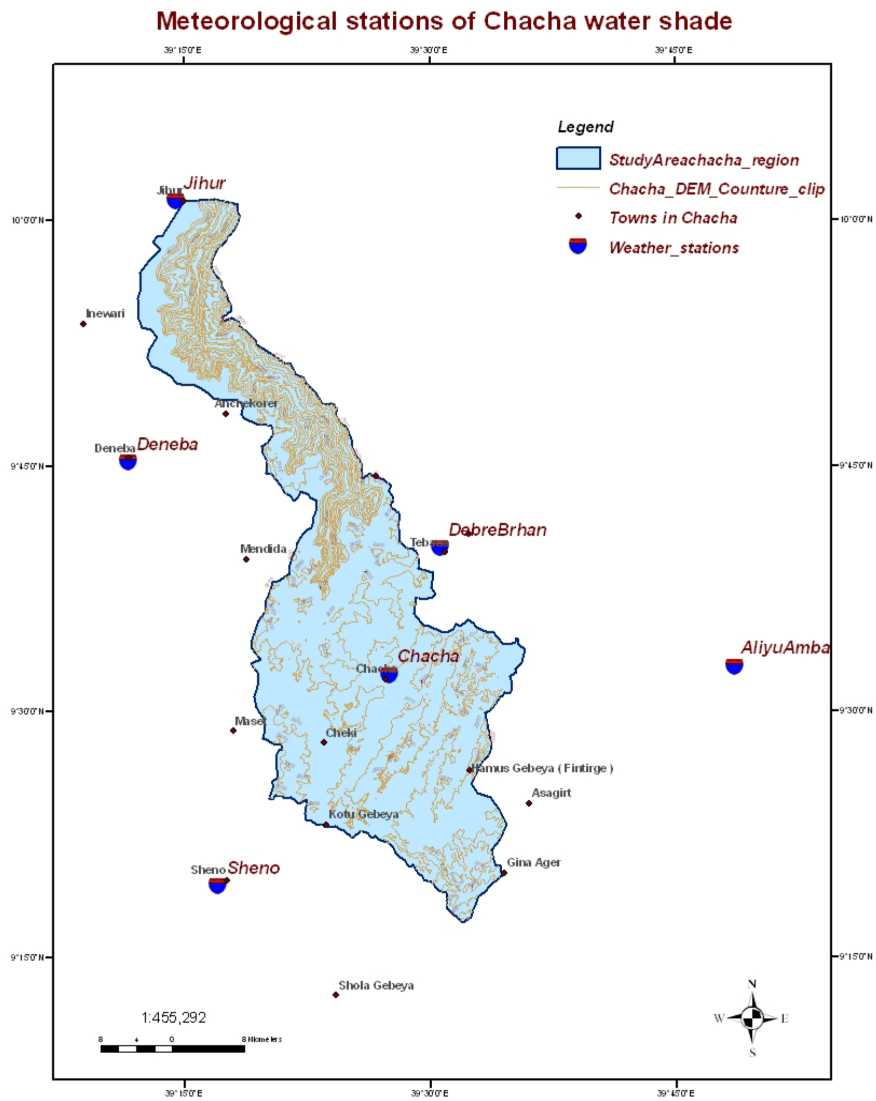


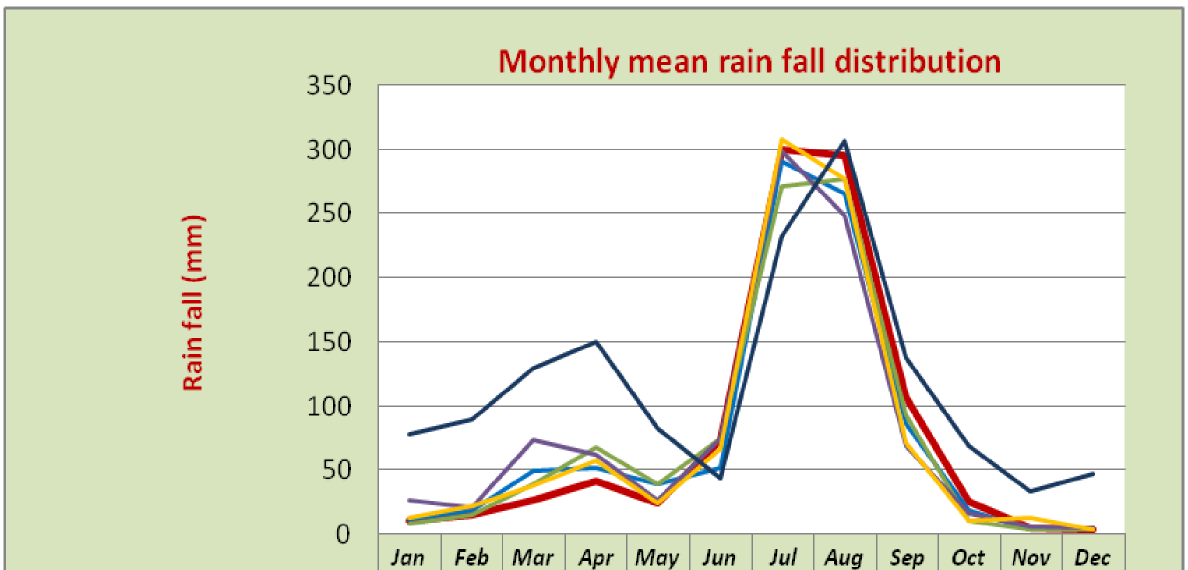
Figure 3.1 Meteorological stations within and around Chacha water shade.

3.2 PRICIPITATION

The physiography and geomorphology of the Chacha shade, together with the vegetation, influence the relation ship between precipitation over the water shade and water drained from it.

Rainfall in the study area is mainly caused by orographic and direction of moisture bearing seasonal air currents. The duration, amount and spatial distribution of the rain fall in the area is controlled by south-westerly winds, south-easterly winds, north easterly winds and high pressure cell developed over north-east Africa and the Arabian peninsula. These are the main factors accounting for seasonal distribution of rain fall.

The main rainfall season of the study area is during the wet season from June to September. The rainfall distribution patterns of the area for the stations are of bimodal type that is relatively higher rainfall records in the month of March and April apart from the wet season is observed. Aliyu Amba station facing to the rift in the Awash basin has highest records in March and April (Fig.3.2). The maximum monthly mean rainfall amount for the four stations like Chacha, Debre Berhan, Deneba, and Jihur are 299.6 mm, 290.7 mm, 298.3 mm, and 308.4 respectively, which are recorded in the month of July, the maximum monthly mean rainfall of Sheno and Aliyu Amba stations are recorded 277.2 mm and 306.3 respectively in August. Annual mean rainfall amount of 928.5mm/yr, 908.7mm/yr, 888.5mm/yr, 922.2mm/yr, and 905mm/yr have been recorded for Chacha, Sheno, Debre Berhan, Deneba, and Jihur stations respectively. Aliyu Amba has recorded the maximum annual mean rain fall amount of 1395.4mm/yr in the area.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chacha(1988-2005)	10.4	15.8	26.8	41.7	24.5	73.7	299.6	294.8	106.3	25.6	5.4	3.9
Debre Berehan(1984-2005)	11.1	18.2	49.5	52	39.3	51.7	290.7	265.4	85.5	17.9	3.7	3.5
Sheno(1984-2005)	8.5	16.3	39.6	68.2	39.8	74.6	271	277.2	92.9	11.8	4.4	4.4
Deneba(1997-2005)	26	20.3	73.5	62.1	25.9	74.7	298.3	247.9	68.2	15.5	5.2	4.6
Jihur(1992-2005)	13.1	22.2	37.3	57.7	24.4	66.7	308.4	278	71.6	10.2	12	3.4
Aliyu Amba(1976_2005)	77.4	88.8	129.8	149.4	81.9	43.1	232.2	306.3	137.4	69.1	33.3	46.6

Figure 3.2 Monthly mean rainfall distributions for six stations with in and around the area.

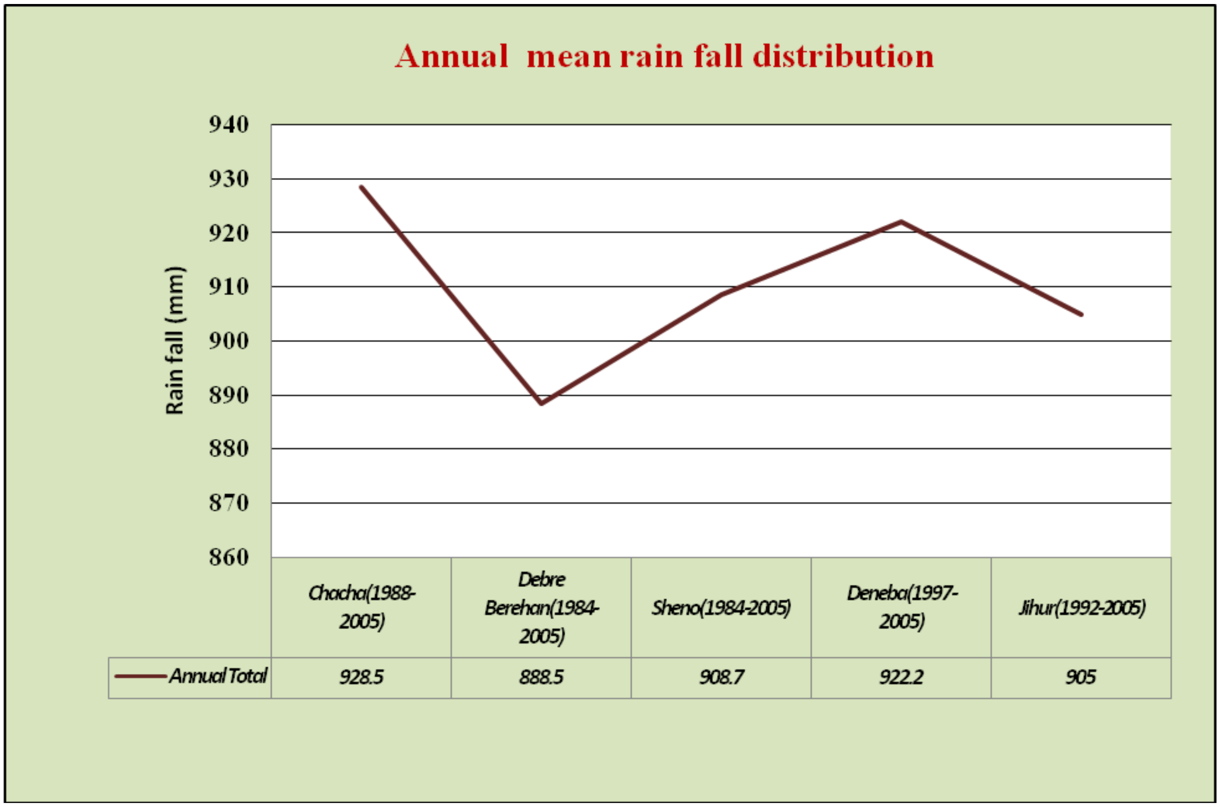


Figure 3.3 Annual mean rainfall distributions for five stations in and around the area.

3.2.1 DETERMINATION OF AERIAL DEPTH OF PRECIPITATION

A rainfall measurement is a point observation and may not be used as a representative value for the whole area under consideration. To obtain more reliable and representative result, the effective uniform depth of precipitation for the catchment has to be worked out. There for, the point measurement has 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, such as: Arithmetic mean, Theissen polygon and Isohyetal methods.

3.2.1.1 An arithmetic mean method: This method is reliable when the topography is flat; the rain gauge stations are closely and evenly spaced. However, to quantify and then compare the variations of precipitation depths in the whole water shade, the method is applied hear.

Table 3.3 Annual mean areal depth of precipitation obtained from arithmetic mean.

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual Precipitation
Chacha(1988-2005)	10.4	15.8	26.8	41.7	24.5	73.7	299.6	294.8	106.3	25.6	5.4	3.9	928.5
Debre Berhan(1984-2005)	11.1	18.2	49.5	52	39.3	51.7	290.7	265.4	85.5	17.9	3.7	3.5	888.5
Sheno(1984-2005)	8.5	16.3	39.6	68.2	39.8	74.6	271	277.2	92.9	11.8	4.4	4.4	908.7
Deneba(1997-2005)	26	20.3	73.5	62.1	25.9	74.7	298.3	247.9	68.2	15.5	5.2	4.6	922.2
Jihur(1992-2005)	13.1	22.2	37.3	57.7	24.4	66.7	308.4	278	71.6	10.2	12	3.4	905
Aliyu Amba(1976_2005)	77.4	88.8	129.8	149.4	81.9	43.1	232.2	306.3	137.4	69.1	33.3	46.6	1395.4
Mean	**24.4**	**30.3**	**59.4**	**71.8**	**39.3**	**64.1**	**283.4**	**278.3**	**93.6**	**25**	**10.7**	**11.1**	**991.4**

There for, the arithmetic annual mean precipitation of the Chacha water shade is **991.4mm**

3.2.1.2 Theissen polygon method: This method calculates the weighted average of each rain gauge stations which are unevenly distributed. Aliyu Amba station has no influence over the Chacha water shade.

Table 3.4 Annual mean areal depth of precipitation obtained from theissen polygon.

Stations	Area of influence (km2)	Weighted Area (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Chacha (1988-2005)	**694.4**	**58.2**	6.1	9.2	16	24	14.3	42.9	174	172	61.9	15	3.1	2.3	**540.4**
DebreBerehan (1984-2005)	**198.4**	**16.6**	1.8	3	8.2	8.6	6.5	8.6	48.3	44.1	14.2	3	0.6	0.6	**147.5**
Deneba (1997-2005)	**131.8**	**11**	2.9	2.2	8.1	6.8	2.9	8.2	32.8	27.3	7.5	1.7	0.6	0.5	**101.4**
Jihur (1992-2005)	**136**	**11.4**	1.5	2.5	4.3	6.6	2.8	7.6	35.2	31.7	8.2	1.2	1.4	0.4	**103.2**
Sheno (1984-2005)	**33.7**	**2.8**	0.2	0.5	1.1	1.9	1.1	2.1	7.6	7.8	2.6	0.3	0.1	0.1	**25.4**
AliyuAmba (1976_2005)	**0**	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**1194.3**	**100**	**12.5**	**17**	**37**	**48**	**27.6**	**69.4**	**298**	**282**	**94.4**	**21**	**5.8**	**3.9**	**917.9**

There for, annual mean areal depth of precipitation in Chacha water shade obtained from theissen polygon is **917.9mm**.

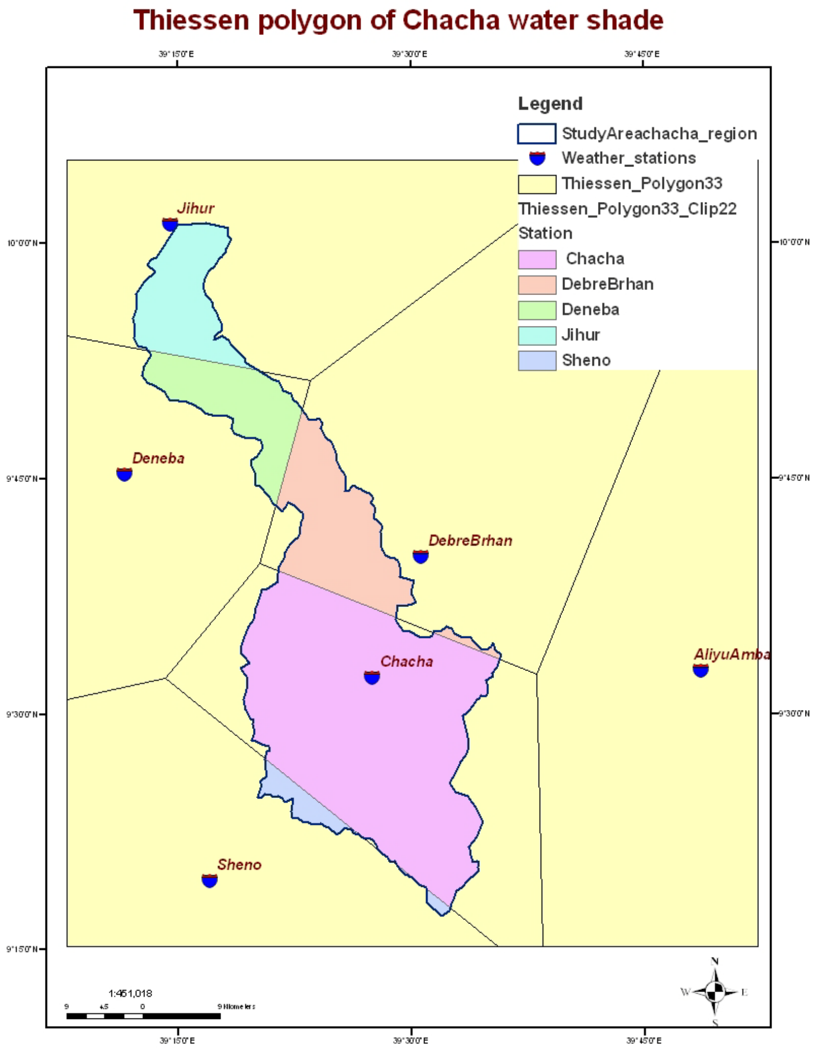


Figure 3.4 Theissen polygon map of Chacha water shade.

3.2.1.3 Isohyetal method: This method is applied by preparing an isohyetal map that join points of equal rain fall value and then measure their inter-isohyetal area. One advantage of the method for determining catchment average is that it allows the influence of physiographic parameters to be taken in to account. These factors include elevation, slope, and distance from the coast and exposure to rain- bearing winds (Shaw, 1988). The method yields an annual mean precipitation of 938.97mm.

Table 3.5 Isohyetal method of calculating annual rainfall in Chacha catchment

No	Isohyetal range(mm)	Average isohyetal(mm)	Net enclosed area(km^2)	Weighted area (%)	Weighted rainfall(mm)
1	880-900	890	273.12	22.87	203.54
2	900-920	910	422.22	35.35	321.68
3	920-940	930	89.57	7.5	69.75
4	940-960	950	75.03	6.28	59.66
5	960-980	970	67.79	5.68	55.1
6	980-1000	990	59.55	4.99	49.4
7	1000-1020	1010	59.09	4.95	50
8	1020-1040	1030	59.39	4.97	51.19
9	1040-1060	1050	47.67	3.99	41.9
10	1060-1080	1070	31.56	2.64	28.25
11	1080-1100	1090	9.34	0.78	8.5
	Total		1194.33	100	**938.97**

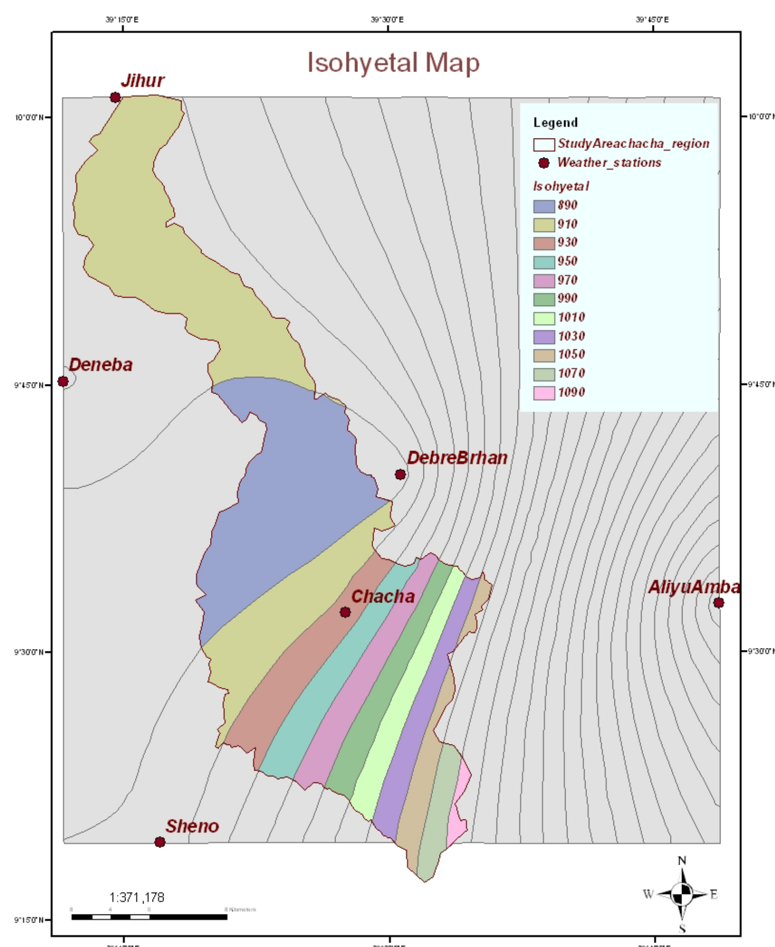


Figure 3.5 Isohyets and spatial variations of depth of precipitation.

The mean annual rainfall calculated from arithmetic mean method (991.4mm/yr) in the catchment over estimate the amount; this is due to uneven distribution of stations and undulating nature of the topography. For example, Aliyu Amba station far from the catchment with a different scenario and annual mean value is evenly averaged out for the study area. Sheno, Deneba and Debere Berhan stations with different topographic setting are also considered as uniform spatial distribution over the area. Where as, the result of mean annual rainfall computed by theissen polygon and isohyetal methods 917.9mm/yr and 938.97mm/yr respectively are respectively equivalent. The value from theissen method is less than the value from isohyetal method. The cause may be due to the influence moisture from Aliyu Amba station (southeast direction) is totally discarded. But the isohyetal method allows the influence of Aliyu Amba that is topographic/spatial variations and direction of moisture bearing wind and there impacts over the study area are considered. There for, annual mean rainfall **938.97mm/yr** calculated by isohyetal method is best fit for the Chacha catchment. It is the median of over and under estimation of annual mean rainfall distribution in the study area.

3.2.2 DEPTH OF PRECIPITATION AND SURFACE ELEVATION

As one goes from the southern highlands of the catchment to the north, the amount of rain fall shows a general trend of decrease. The highlands receive annual mean rainfall of 928.5mm (Chacha station, 2788 m.a.s.l). On the other hand, the northern sub areas receive annual mean rainfall of 905mm (Jihur station, 2730 m.a.s.l). But the surrounding stations in the adjacent catchments act differently from the general trend that is Sheno (908.7mm, 2874m.a.s.l) and Deneba (922.2mm, 2673m.a.s.l) stations situated at the west of the catchment show inverse relation of altitude and annual mean rain fall and Aliyu Amba station (1395.4mm, 1692m.a.s.l) south east of the catchment in Awash basin has high rain fall and low altitude that is also different from the general trend. Debre Birhan station (888.5mm, 2767m.a.s.l) east of the catchment has low rain fall and low elevation that agree with the general trend but greater correlation coefficient/gradient. The general trend of direct linear relation of rainfall and elevation over the catchment has a correlation coefficient of R^2=0.202. There for, Aliyu Amba station is found in the wind ward side of north easterly winds and Sheno and Deneba stations mainly get there moisture from south easterly winds.

Generally, the above fact indicates that geomorphological variation in the Chacha water shade and the surrounding plays a great role in moisture distribution.

Table 3.6 Depth of precipitations and altitudes

Stations	UTM /E/	UTM /N/	altitude(m)	Mean annual P(mm)
Chacha(1988-2005)	1054315	550301	2788	928.5
Sheno(1984-2005)	1030534	531194	2874	908.7
Debre Berhan(1984-2005)	1068583	556006	2767	888.5
Deneba(1997-2005)	1078202	521145	2673	922.2
Jihur(1992-2005)	1107568	526543	2730	905
Aliyu Amba(1976-2005)	1055252	588898	1692	1395.4

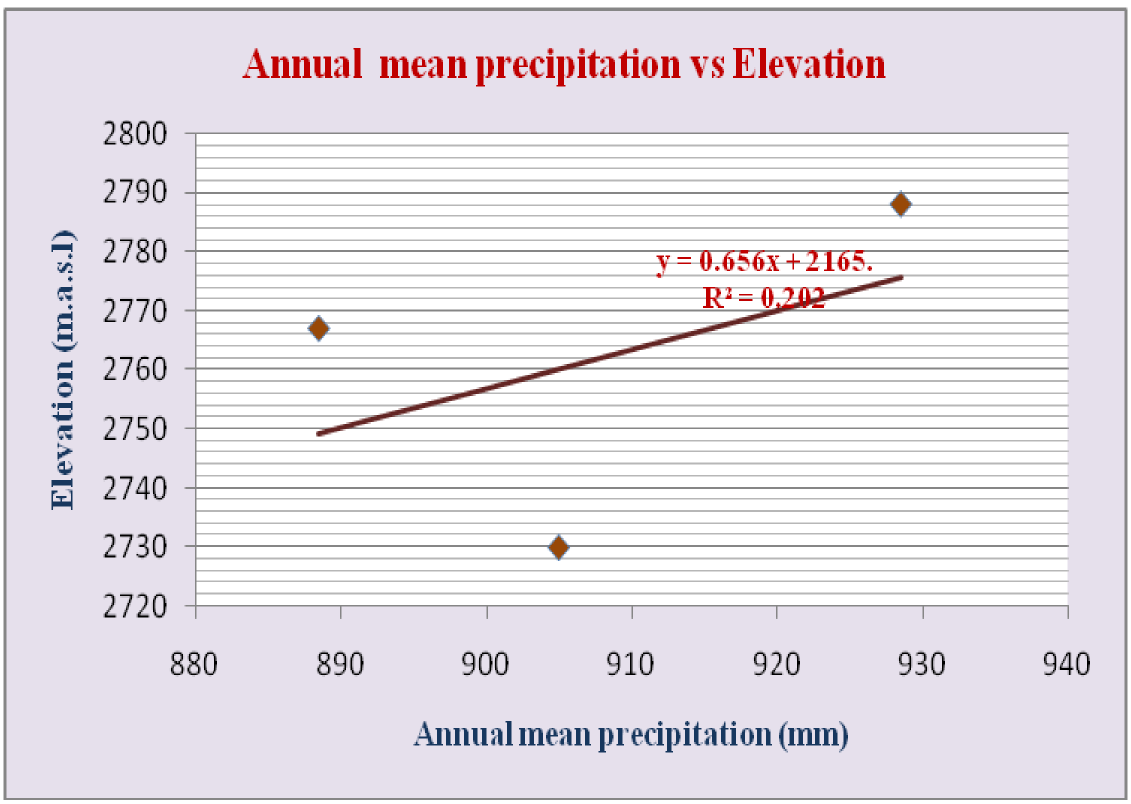


Figure 3.6 Relation ships between depth of precipitations and surface elevations.

3.2.3 RAIN FALL COEFFICENT

Months are partitioned in to rainy and dry in the given hydrologic year based on the values of rainfall coefficients. The rain fall coefficient is calculated by dividing monthly mean rain fall to one twelve of the annual mean rain fall. It is given by the formula:

$\mathbf{R_C = P_m / (P_Y/12)}$ Where: R_C = Rain fall coefficient,

P_m = Monthly mean rainfall depth

P_Y = Yearly mean rainfall depth

Table 3.7 Monthly mean and rainfall coefficient of the Chacha catchment.

Methods	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mean total
Monthly arithmetic Mean	24.4	30.3	59.4	71.8	39.3	64.1	283.4	278.3	93.6	25	10.7	11.1	991.4
Monthly theissen polygon Mean	12.5	17	37	48	27.6	69.4	298	282	94.4	21	5.8	3.9	917.9
Monthly Mean/**Pm**	18.5	23.7	48.2	59.9	33.5	66.8	290.7	280.2	94	23	8.3	7.5	954.7
Monthly amount of the year (%)	1.9	2.5	5.1	6.3	3.5	7	30.5	29.4	9.9	2.4	0.9	0.8	
Coefficient	**0.24**	**0.3**	**0.62**	**0.77**	**0.43**	**0.85**	**3.72**	**3.58**	**1.2**	**0.29**	**0.11**	**0.1**	
Py=938.97mm/yr **Py/12**= 78.25mm													

On the basis of the rainfall coefficient values and Classification schemes, months in the water year are classified as

i) Dry months: October, November, December, January, February and May.

ii) Small rainy months: March, April and June.

iii) Big rainy months: July, August and September.

The following table gives a broad classification of months of a water year (after Daniel Gemechu, 1977).

Table 3.8 Classification schemes of monthly rainfall values

	Dry months	Rainy months			
		Small rains	Big rains		
			Moderate Concentration	High Concentration	Very high Concentration
	$R_c < 0.6$	$0.6<R_c<0.9$	$1<R_c<1.9$	$2<R_c<2.9$	$R_c \geq 3$
Months	October	March	September		July
	November	April			August
	December	June			
	January				
	February				
	May				

According to Daneil Gemechu (1977) classification displayed on Table 3.8, the study area has two rainfall regimes (bimodal rainfall characteristics). During the month of March and April the area got small rain (Bulg season) which is about 11.4% of the total annual mean while July, August and September months got about 69.8% of annul mean rainfall or big rain (Kiremt season) and the remaining 18.8% of the total mean annual rainfall is contributed by the dry months.

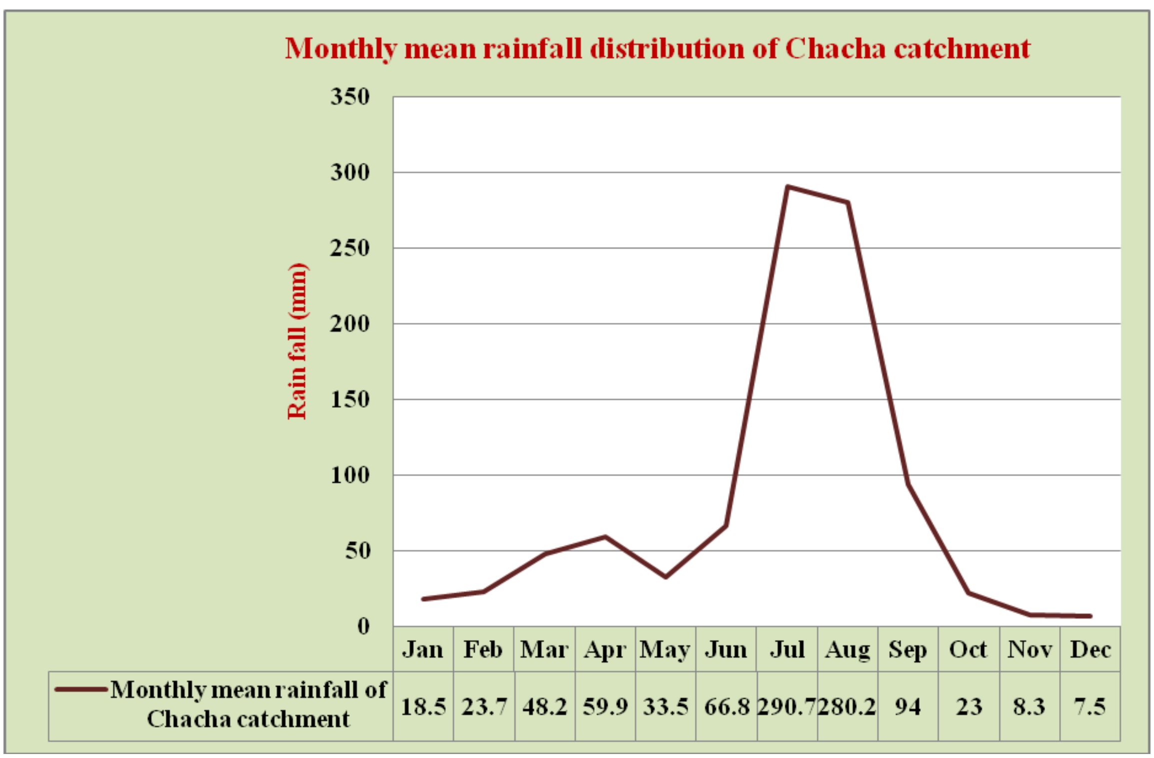


Figure 3.7 Monthly mean rainfall distribution of Chacha catchment.

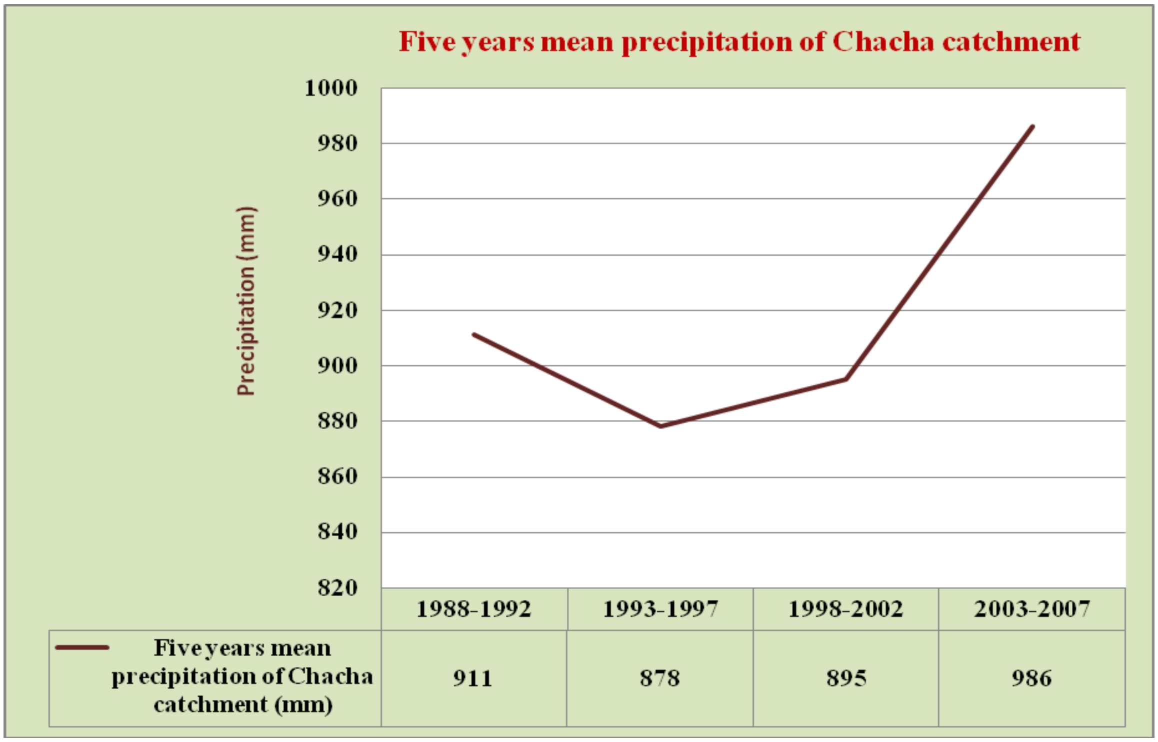


Figure 3.8 Five years aggregate mean precipitation trend of Chacha catchment (1988-2007).

3.3 TEMPERATURE

Temperature of the water surface is dependent on solar radiation and has direct influence on the rate at which water molecules leave the surface and enter the overlying air. Change in water surface temperature and overlying air mass temperature have a profound short-term effect up on the rate of evaporation.

Similarly like precipitation the other parameter temperature is calculated as annual average of daily minimal and maximal values from the surrounding stations that is used to represent the catchment. All values show significant differences from place to place, which is done by position and altitude of the stations. To obtain dependency on altitude, the average temperatures were plotted according the altitude of the station Fig 3.10. The data show significant dependency with linear relationship.

Table 3.9 Monthly mean temperature distributions for four stations in the area.

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Debre Berhan Mon Mean Min Temp	4.4	5.5	7.5	7.7	7.3	7.3	8.8	8.7	7.2	3.5	2.3	3.4
Debre Berhan Mon Mean Max Temp	19.8	20.4	20.7	20.6	21.5	22	19	18.3	18.7	19	19	19
Debre Berhan Mon Mean Temp	**12.1**	**13**	**14.1**	**14.2**	**14.4**	**15**	**14**	**13.5**	**13**	**11**	**11**	**11.2**
Sheno Mon Mean Min Temp	5.3	6.8	7.6	8.1	9	8.2	7.4	7.4	7.8	6.4	6.3	5.5
Sheno Mon Mean Max Temp	18.7	18.9	18.9	18.9	19.8	19	18	17.7	17.8	17	18	18.6
Sheno Mon Mean Temp	**12**	**12.9**	**13.3**	**13.5**	**14.4**	**14**	**13**	**12.6**	**12.8**	**12**	**12**	**12.1**
Mendida Mon Mean Min Temp	7.8	7.8	8.6	9.5	9.7	9.6	9.3	9.4	8.9	7.8	6.3	6.4
Mendida Mon Mean Max Temp	21.8	22.4	22.1	22.1	22.5	23	19	18.8	19.5	20	21	20.8
Mendida Mon Mean Temp	**14.8**	**15.1**	**15.4**	**15.8**	**16.1**	**16**	**14**	**14.1**	**14.2**	**14**	**14**	**13.6**
Lemi Mon Mean Min Temp	10.4	10.9	10.8	11.3	11.4	11	10	10.4	10.6	9.5	8.8	9.1
Lemi Mon Mean Max Temp	22.3	23.4	24.1	23.3	23.6	24	19	18.8	20.8	21	22	21.9
Lemi Mon Mean Temp	**16.4**	**17.2**	**17.5**	**17.3**	**17.5**	**17**	**15**	**14.6**	**15.7**	**15**	**15**	**15.5**

The monthly mean temperature of four stations such as Sheno, Debre Berhan, Lemi and Mendida stations show variation in depth but similar trend through out the year. The general trend shows slight increasing in temperature till mid of June and then a sharp drop is observed between mid of June and July (Fig 3.9). Maximum temperature is recorded in May and June attaining its highest pick mostly in mid of June. The temperature starts to drop from mid of August and September till mid of October and November. The minimum mean monthly temperature is registered in mid of October and November. Station Lemi attains minimum mean monthly temperature in mid of August.

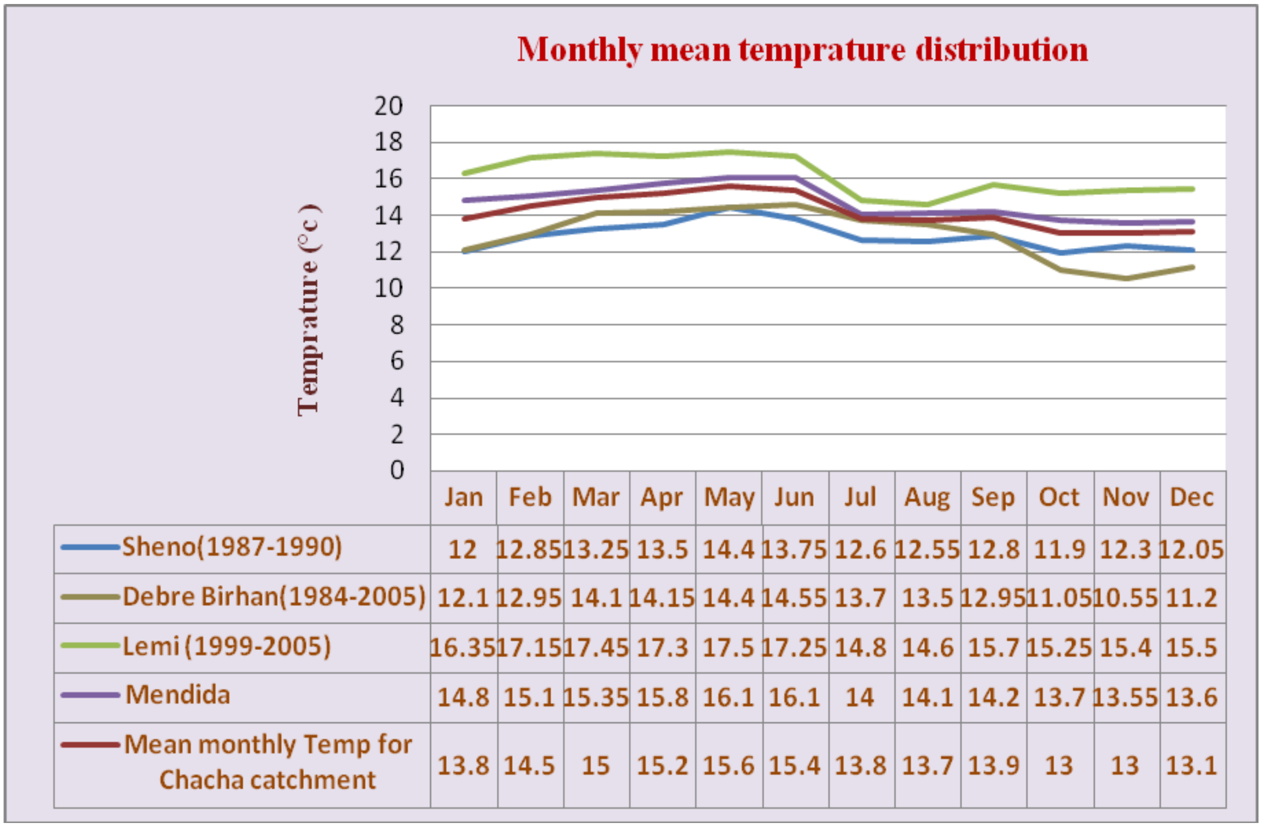


Figure 3.9 Monthly mean temperature distributions for four stations around the area.

Altitude is one of the determinant factors of climatic elements (temperature and rainfall). As altitude increases temperature decreases and the amount of rain fall increases. This is true in the study area that altitude has an inverse linear relation with monthly average temperature. On the other hand, there is also an inverse relation ship between altitude and evapotranspiration that is as altitude increases evapotranspiration decreases and vice versa.

Table 3.10 Annual Mean Temperature and altitude

Stations	UTM /E/	UTM /N/	altitude(m)	Minimum Mon Mean Temp(°c)	Maximum Mon Mean Temp(°c)	Annual Mean Temp(°c)
Sheno(1987-1990)	1030534	531194	2874	11.9	14.4	**13.15**
Debre Berhan(1984-2005)	1068583	556006	2767	10.55	14.55	**12.55**
Lemi (1999-2005)	1083336	489190	2703	14.6	17.5	**16.05**
Mendida	1067319	534287	2803	13.55	16.1	**14.82**

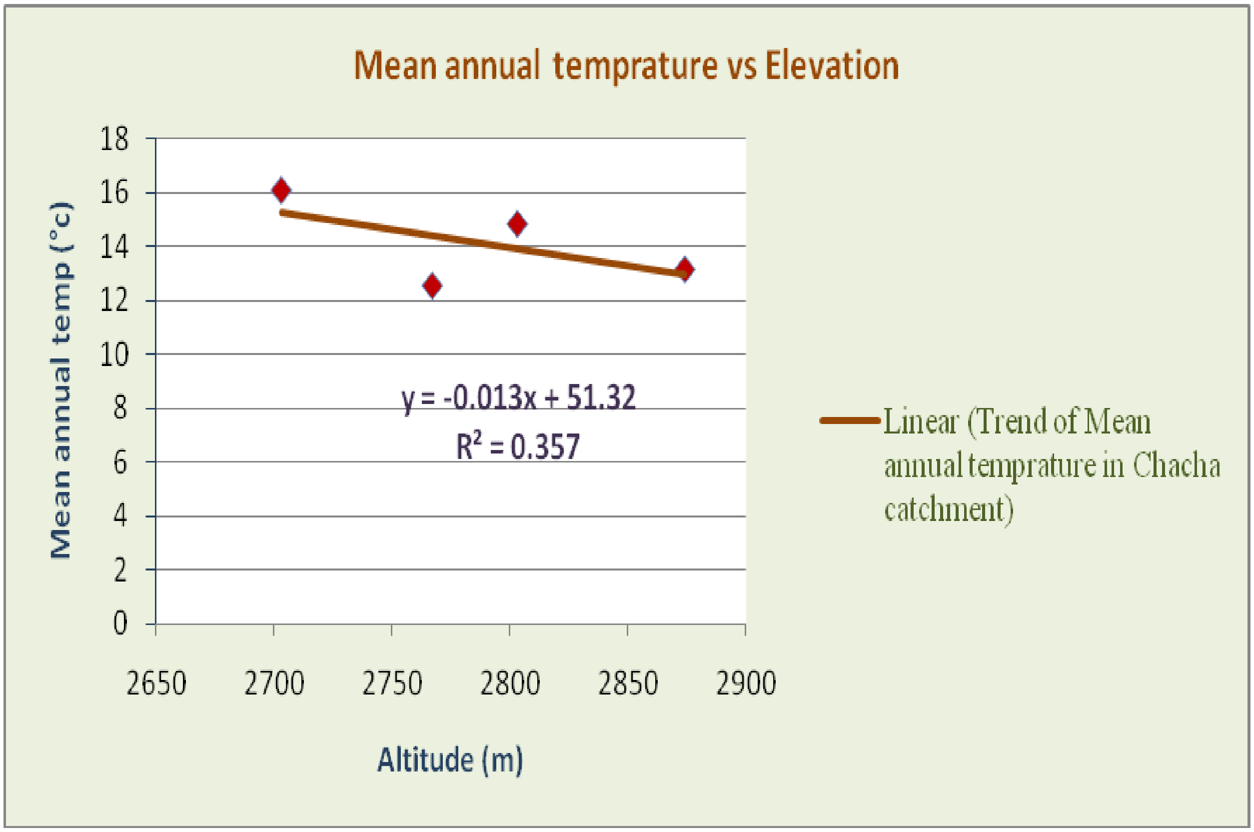


Figure 3.10 Relation ships between mean annual temperature and surface elevation.

3.4 RELATIVE HUMIDITY (RH)

Relative humidity is the relative measure of partial pressure of water vapor to the saturated vapor pressure of water in the gaseous mixture of air and water at a given temperature. Relative humidity is expressed as a percentage and is calculated in the following manner:

$$RH = \frac{p_{(H_2O)}}{p^*_{(H_2O)}} \times 100\%$$

Where: RH is the relative humidity of the gas mixture

P (H_2O) is the partial pressure of water vapor in the gas Mixture; and

P*(H2O) is the saturation vapor pressure of water at the temperature of the gas mixture.

The relative humidity of a system is dependent not only on the temperature but also on the absolute pressure of the system of interest. 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.

The RH of the study area determines the rate of evaporation. The mean relative humidity of the area recorded at Debre Berhan station during 24 years (1982-2005) reaches its pick in the month of July and August, while the minimum of the relative humidity is registered in May and June. Thus annual mean RH of the maximum and minimum monthly mean values of the area is 72.95%. The annual range of relative humidity is 21.7%.

Table 3.11 Monthly Mean Relative Humidity at Debre Berhan station.

Debre Berhan station (1982-05)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean RH at 0600 in %	84.1	81.5	84.2	85.7	84.6	86.8	93.2	93.9	92.2	90.4	84.5	80.8
Monthly mean RH at 1200 in %	54.1	52.6	55.8	57	48.8	49.3	75.8	78.9	68.2	57.9	54.7	54.5
Monthly mean RH at 1800 in %	64.2	57.6	60	60.2	53	51.7	74.9	78.6	70	63.4	59.6	61.3
Monthly mean RH in %	**67.4**	**63.9**	**66.7**	**67.6**	**62.1**	**62.6**	**81.3**	**83.8**	**76.8**	**70.6**	**66.3**	**65.6**

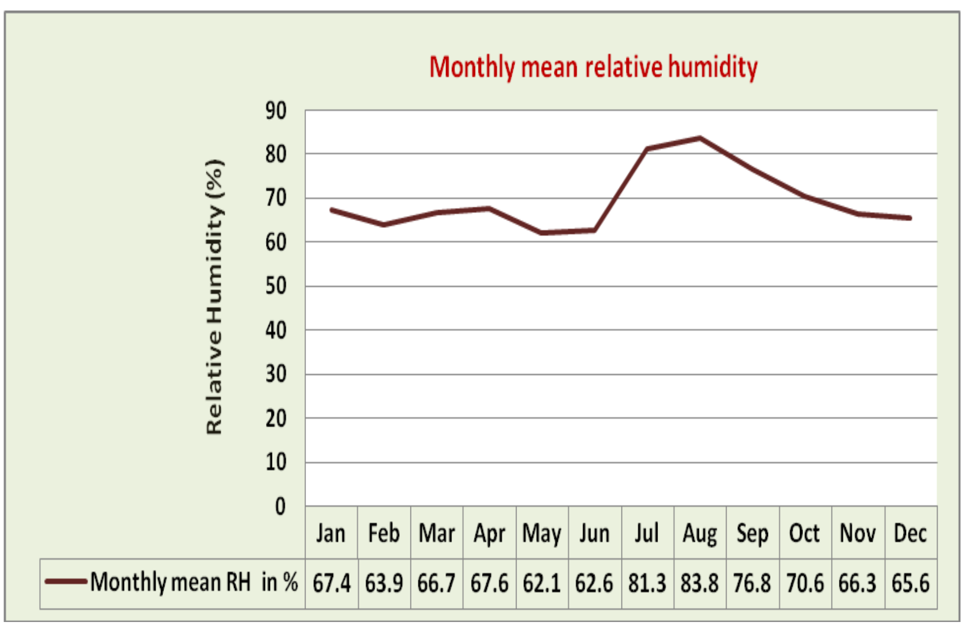


Figure 3.11 Monthly Mean Relative Humidity in the Debre Berhan station (1982-2005)

3.5 SUNSHINE HOURS

Total daily amount of evapotranspiration rate is dependent on the total daily sunshine hour. From Table 3.10, it can be noted that the mean maximum sunshine hour is recorded in January (9.2) and November (9.1) while the mean minimum is registered in July (5.5) and August (5.9). There for, annual mean sunshine hour of the area from maximum and minimum monthly mean is 7.35 hours.

Table 3.12 Mean monthly sunshine hours of Debre Berhan station

Debre Berhan station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean sunshine hours	**9.2**	**8**	**7.3**	**7.1**	**7.8**	**7.2**	**5.5**	**5.9**	**6.6**	**8.9**	**9.1**	**8.3**

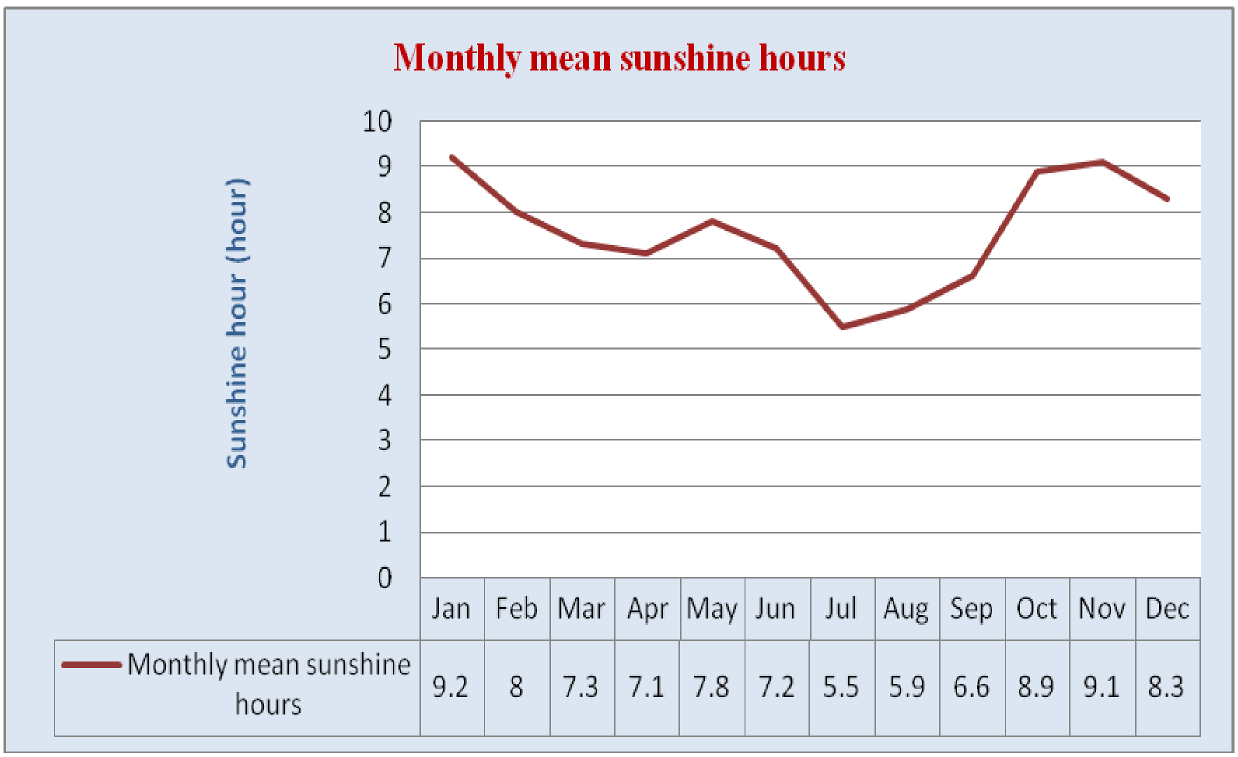


Figure 3.12 Monthly mean sunshine hours at Debre Berhan station.

3.6 WIND SPEED

One of the factors of evaporation is wind speed, the decrease of wind speed resulting in non-removal of saturated vapor that affects evaporation rate. The wind speed of the Debre Berhan station reaches its pick in February and the wind is relatively calm in the month of July and August. The annual mean wind speed of the area from maximum and minimum monthly mean is 2.05 m/s.

Table 3.13 Mean monthly wind speed of Debre Berhan station 2m above the ground surface

Debre Berhan station (m/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean wind speed	**2.3**	**2.6**	**2.3**	**2**	**2.2**	**2.1**	**1.6**	**1.5**	**1.7**	**1.7**	**2**	**2.3**

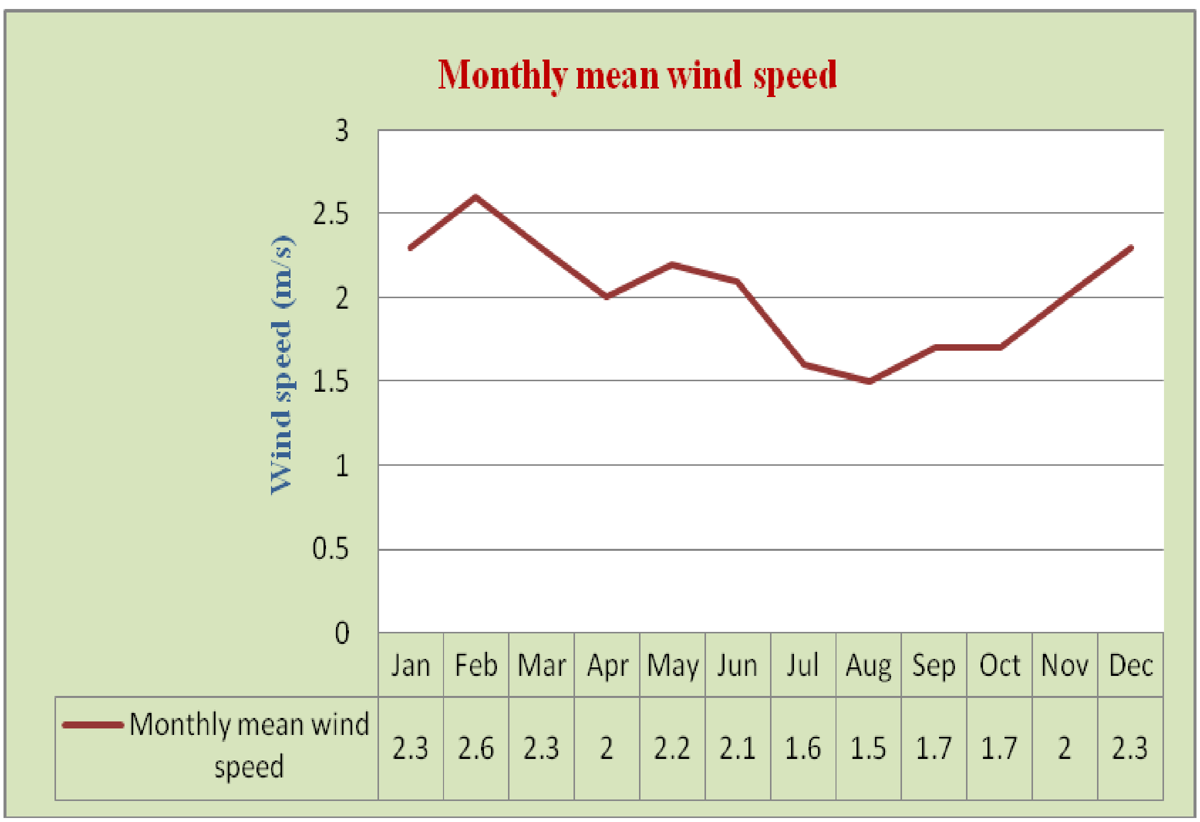


Figure 3.13 Monthly mean wind speeds at Debre Berhan station.

3.7 EVAPOTRANSPIRATION

Evaporation is the movement of water molecules to the atmosphere from free water surface, bare soil, etc. Free water evaporation is only the mechanism for mass transfer of water to the atmosphere. Growing plants are continuously pumping water from the ground into the atmosphere through a process called transpiration (Hendricks & Hansen, 1962). Evapotranspiration is the conversion of water molecules to vapor by evaporation (open water body) and transpiration (plants) away from the watershed surface to the atmosphere (Axon, 1982).

A quantitative understanding of evapotranspiration is of vital practical importance in several respects: over the long term, the difference between evapotranspiration and precipitation is the water available for direct human use and management. Thus quantitative assessments of water resources and the effects of climate and land-use change on those resources require a quantitative understanding of evapotranspiration. Direct measurement of evapotranspiration is much more difficult and expensive and is usually impractical. Thus an array of methods has been developed that provide estimates of evapotranspiration based on measurement of more readily measured quantities.

3.7.1 POTENTIAL EVAPOTRANSPIRATION (PET)

Potential evapotranspiration is the rate at which evapotranspiration would occur from an area completely and uniformly covered with growing vegetation which has access to an unlimited supply of soil water and with out advection or heat storage effects that 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, 1948 and Fetter, 1994). And according to Jensen et.al.,1990, operational definition, practically PET is defined by the method used to calculate it, and many methods have been proffered. These methods can be classified on the basis of their data requirements (Jensen et. al., 1990) as temperature based, that uses only air temperature and some times day length; radiation based, that uses net radiation and air temperature; combination, based on the Penman combination equation which uses net radiation, air temperature, wind speed and relative humidity; and pan, that uses pan evaporation, some times with modifications depending on wind speed, temperature, and humidity.

3.7.1.1 Thornthwaite method

Thornthwaite method is based upon the assumption that potential evapotranspiration is dependent only up on meteorological conditions and ignores the effect of vegetative density and maturity. Thornthwaite produced a formula for calculating PET based on temperature as index of energy available for evapotranspiration with an adjustment being made for the latitude, location and number of daylight hours (Dunne and Leopold, 1978)

First, Thornthwaite defined the heat index i_m for any month m as

$$i_m = (t_m/5)^{1.514} \qquad (4.2)$$

m = 1, 2, 3…12

Where t_m is mean monthly temperature in °C. The twelve monthly heat indexes are then added to obtain the annual heat index I.

$$I = \Sigma(t_m/5)^{1.514} \qquad (4.3)$$

The monthly potential evapotranspiration is then calculated from the equation:

$$PET = 16N_m\,(10t_m/I)^a \qquad (4.4)$$

$$a = 6.75 \times 10^{-7}I^3 - 7.71 \times 10^{-5}I^2 + 1.792 \times 10^{-2}I + 0.49239\ldots \qquad (4.5)$$

(to 2 significant figures)

N_m is the day light factors used to correct unequal day length between months obtained from a table by dividing the possible sunshine hours for the appropriate latitude by 12 (in our case 10°N) and expressed by:

$$N_m = \frac{\text{possible sunshine hours for the particular month}}{12} \qquad (4.6)$$

Table 3.14 Mean annual PET obtained from Thornthwaite method.

Elements	Months												Total (mm/yr)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
t_m	13.8	14.5	15	15.2	15.6	15.4	13.8	13.7	13.9	13	13	13.1	
i_m	4.65	5.01	5.28	5.38	5.6	5.49	4.65	4.6	4.7	4.25	4.25	4.3	
N_m	0.39	0.42	0.44	0.45	0.47	0.46	0.39	0.38	0.39	0.35	0.35	0.36	
PET	52.12	56.83	60.6	63.3	67.26	66.57	56.61	55.14	54.92	48.74	47.92	48.02	**678.05**
I = 58.16 ; a = 1.406													

Accordingly, the weighted mean annual PET of the Chacha catchment based on Thornthwaite method is **678.05 mm/yr** (Table).

3.7.1.2 Penman aerodynamic and energy budget combined method

Penman combined the energy balance with the mass transfer methods of evaporation estimates; and derived an equation to compute the evaporation from an open water surface using standard climatological records of sunshine, temperature, humidity and wind speed. Later on the equation was modified (MAFF, 1967 in Shaw, 1994) to allow for the condition under which evaporation plus transpiration takes place from a vegetated surface.

The basic equation of penman to calculate potential evapotranspiration, PET, is

$$PET = \frac{\frac{\Delta}{\gamma} Ht + Eat}{\frac{\Delta}{\gamma} + 1} \qquad (4.5)$$

Where Ht is the available heat and is calculated as

$$Ht = 0.75RI - Ro \qquad (4.6)$$

Where *RI* is the incoming radiation, and

Ro is the outgoing radiation.

RI is a function of Ra, the solar radiation (fixed by latitude and season) modulated by a function of the ratio, n/N, of measured to maximum possible sunshine duration. And “n” is bright sunshine over the same period, h/day

$$Eat = 0.35(1+u_2/100)(e_a-e_d) \qquad (4.7)$$

Where u_2 – mean wind speed at 2m above the surface, miles per day

e_a – saturated vapor pressure at air temperature Ta

e_d - mean vapor pressure of the air.

The saturated vapor pressure at air temperature e_a (Ta) is given to good approximation by:

$$e_a(Ta) = 6.11\exp(17.3Ta/Ta+237.3) \qquad (4.8)$$

With vapor pressure in mb and temperature in °C

The vapor pressure of the air (e_d) depends on the relative humidity, RH, as well as the air temperature Ta:

$$e_d = RH\ e_a\ (Ta) \qquad (4.9)$$

Where RH is expressed as a ratio

The empirical equation for the incoming radiation, RI, takes the form

$$RI\ (1-r) = 0.75\ Ra.fa\ (n/N) \qquad (4.10)$$

r-is the albedo (reflection coefficient for incident radiation; r = 0.25 for the catchment covered with mature forest, bushes and shrubs, grasses and cultivated crops).

fa (n/N) takes several forms. The study area, located south of 54 1/2° N (10°N), thus fa (n/N) takes the form:

$$fa\ (n/N) = (0.16 + 0.62\ n/N) \qquad (4.11)$$

The empirical equation for the outgoing radiation takes the form:

$$Ro = \sigma\ T_a^4\ (0.47 - 0.075\sqrt{ed})\ (0.17 + 0.83\ n/N) \qquad (4.12)$$

Where T_a^4 is the theoretical black body radiation at Ta which is then modified by functions of the humidity of the air (ed) and the cloudiness (n/N).

In calculating PET, the following equation for H is used:

$$H = 0.75\ Ra\ (0.18 + 0.55\ n/N) - 0.95\ \sigma T_a^4\ (0.10 + 0.90\ n/N)\ (0.56 - 0.092\ \sqrt{ed}) \qquad (4.13)$$

Potential evapotranspiration was calculated using this empirical formula and according to this formula, a potential evapotranspiration of 1921mm was found over the area.

Table 3.15 Mean annual PET obtained from Penman combination method

Elements	Months												Annum (mm/y)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
T (^{0}C)	13.8	14.5	15	15.2	15.6	15.4	13.8	13.7	13.9	13	13	13.1	
n(Hrs/d)	9.2	8	7.3	7.1	7.8	7.2	5.5	5.9	6.6	8.9	9.1	8.3	
N (Hrs/d)	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5	
n/N	0.79	0.68	0.61	0.58	0.62	0.57	0.44	0.48	0.55	0.75	0.78	0.72	
RH (%/100)	0.67	0.64	0.67	0.68	0.62	0.63	0.81	0.84	0.77	0.71	0.66	0.66	
U2 (miles/d)	122.4	139.2	122.4	108	117.6	112.8	86.4	81.6	91.2	91.2	108	122.4	
Ea (mmHg/d)	11.84	12.38	12.79	12.93	13.23	13.06	11.8	11.76	11.91	11.23	11.23	11.31	
Ed (mmHg/d)	7.93	7.92	8.57	8.79	8.2	8.23	9.59	9.88	9.17	7.97	7.41	7.47	
D/g	1.58	1.65	1.69	1.71	1.75	1.73	1.58	1.58	1.59	1.51	1.51	1.52	
R_a (mm/d)	12.8	13.9	14.8	15.2	15	14.8	14.9	15	14.8	14.2	13.1	12.5	
E_{at}	3.04	3.73	3.29	3.01	3.83	3.6	1.47	1.2	1.83	2.18	2.78	2.99	
f_a (n/N)	0.65	0.58	0.54	0.52	0.54	0.51	0.43	0.46	0.5	0.63	0.64	0.61	
R_I (1-r) (mm/d)	6.24	6.05	5.99	5.93	6.08	5.66	4.81	5.18	5.55	6.71	6.29	5.72	
σT_a^4 (mm/d)	13.66	13.8	13.9	13.92	13.96	13.94	13.7	13.64	13.68	13.5	13.5	13.52	
Ro (mm/d)	2.92	2.62	2.35	2.25	2.44	2.28	1.74	1.82	2.08	2.76	2.93	2.75	
H_T	3.32	3.43	3.64	3.68	3.64	3.38	3.07	3.36	3.47	3.95	3.36	2.97	
PET (mm/day)	3.21	3.54	3.51	3.43	3.71	3.46	2.45	2.52	2.84	3.24	3.13	2.98	
PET (mm/mon)	96.3	106.2	105.3	102.9	111.3	103.8	73.5	75.6	85.2	97.2	93.9	89.4	**1140.6**

Here, based on penman empirical formula, potential evapotranspiration of the Chacha catchment is estimated as **1140.6 mm/yr** (Table).

From Thornthwaite and Penman combination methods of potential evapotranspiration (PET) estimation over the catchment, the PET obtained from Penman combination method seems to be representative. Thornthwaite method underestimates the value. Therefore, for further analyses the catchment's PET is assumed to be **1140.6 mm/yr**.

3.7.2 ACTUAL EVAPOTRANSPIRATION (AET)

Actual evapotranspiration is the amount of evaporation and transpiration that occurs under a given climatic and soil moisture conditions. Therefore, it is always less than or equal to potential evapotranspiration (PET).

TURC METHOD

Determines actual evapotranspiration, AET, directly from mean annual precipitation; based on the empirical formula which is expressed as:

$$AET = \frac{P}{\sqrt{0.9+(P/L)^2}} \qquad (4.14)$$

Where P=annual Precipitation

L=330+25T+0.05T

T=Mean annual air temperature (^{0}C)

In this method, the dominant factors in evapotranspiration are precipitation and temperature. Using this method, an actual evapotranspiration value of **563 mm/yr** was obtained for the study area.

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 Chacha river catchment is 150 mm and 266 mm respectively.

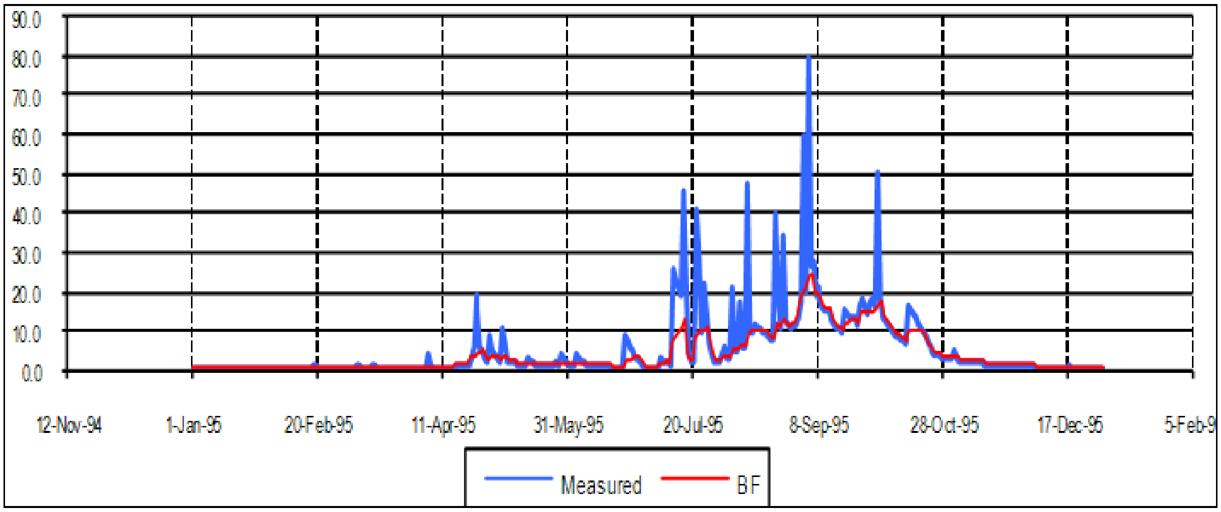


Figure 3.14 Base flow (mcm) and runoff separation from the river discharge.

3.8 CHLORIDE MASS BALANCE IN EVALUATION OF GROUNDWATER RECHARGE

The major chemical behavior of chloride ion includes: they do not significantly enter in to oxidation or reduction reactions; they form no important solute complexes with other ions unless the chloride concentration is extremely high, do not form salts of low solubility, they are not significantly adsorbed on mineral surfaces, play few vital biochemical roles, and the circulation of chloride ions in the hydrologic cycle is largely trough physical processes. Chloride ions moved with the water through most soils tested with less retardation or loss than any of the other tracers' tested-including tritium that had actually been incorporated in to the water molecules. This conservative behavior should not be expected where movement is through compact clay or shale, however (Kaufman and Orlob, 1956). Chloride ions may be concluded characteristically to be retained in solution through most of the processes that tend to separate out other ions (Mairs, 1967).

The method is based on the assumption of mass between the input of atmospheric chloride and the chloride flux in the sub-surface.

Ignoring the direct inputs of pollution, the fluxes for a catchment can be interpreted in terms of a mass balance equation: (Drever and Clow, 1995)

Application of the Chloride mass balance follows the following assumptions:

1. The only source of chloride in groundwater is from precipitation falling directly on the aquifer material;
2. Concentration of chloride in groundwater is by evapotranspiration with in the unsaturated zone, not from recycling, dissolution of minerals containing chloride, or inflow from adjacent aquifers;
3. Chloride is not retarded by adsorption nor accelerated by anion exclusion
4. Chloride is conservative and its mass flux has not changed over time
5. Chloride application rate is constant and known
6. There is no appreciable chloride run off or run on from the sampling sites and
7. Steady state conditions prevail.

The general equation for mean annual recharge estimation from chloride data and attributes is:

$$R = PPT * [Cl^-_p] / [Cl^-_{GW}]$$

Where R=mean ground water recharge in mm/year

PPT= mean annual precipitation depth in mm

$[Cl^-_{GW}]$ = average concentration of chloride in ground water in mg/l

$[Cl^-_p]$=Concentration of chloride in precipitation in mg/l

PPT = 938.97 mm/annum

$[Cl^-_{GW}]$= 7.27 mg/l

$[Cl^-_p]$= 5 mg/l

R = 645.542 mm/annum

The recharge value obtained by using this method is substantially higher that the 6th assumption is thought to be violated in the specific catchment under investigation. The total amount of precipitation that carries the chloride ions is not retained with in the soil; however, part of it runs off leaving the catchment. And direct input of pollution is observed due to higher amount of concentration Cl^- in the falling Precipitation over the catchment.

4. GEOLOGY

4.1 REGIONAL GEOLOGY

The central Ethiopian plateau is mainly covered with thick trapean volcanic forming mountains, ridges and plateaus. Even though the dominant are the tertiary volcanic rocks, there are also thin sequences of Mesozoic and Tertiary sedimentary rocks. The sediments exposed in deep river valleys and gorges.

The Mesozoic sedimentary rocks include the Antalo limestone, Mugher mudstone and Debre Libanos sandstone (Getaneh, 1991). These sediments are formed by the transgression and regression of the Indian Ocean during Triassic to Cretaceous.

Tertiary volcanic rocks in the central Ethiopia were formed by tectonic activity during time of weak volcanism (Zanettin et al., 1978). As a result of the tectonic process, the northwestern Ethiopia plateau as whole is a great horst narrowing northwards and gently dipping from eastern boarder (3000-4000 m.a.s.l) to western border (1000-1500m.a.s.l) (Marla, et. al, 1979)

Ashangi formation

The pre-Oligocene Ashangi formation (54-40 Ma) is tilted to the south or southwest (Zanettin et al.1978 and Mengesha et al., 1996). The type of volcanism is characterized by fissural. This group consists predominantly alkaline basalts with inter bedded pyroclastics and rare rhyolites erupted from fissures. They are injected dololarite sills, acidic dykes, and basic gabbro 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 (Kazmin, 1975).The out crops of Ashangi basalts are restricted to the northern central part of Ethiopian plateau and very often turn out to be crushed by tectonics and the large-scale erosion probably removed the upper portions (Zanettin and Justin–Visentin, 1974).

Aiba Basalt

The Aiba Basalts (34-28 Ma: Middle-upper Miocene) is a thick cover of flood basalts outpoured on the Ashangi penplained basalt (Zanitine and Justine- Visetine, 1973).The basalts of this formation were produced by fissural eruptions and attain a thickness of 200 to 600m meter. They are generally aphanitic and columnarly jointed. The Aiba basalts pinch out southward and westward (Merla et al, 1979).

Alaji formation

The Alaji Series contains interbedded layers of rhyolites and basalts with an age of 32 - 16 Ma (Oligocene- Miocene) overlying the Aiba Basalts. The Alaji is also aphyric flood basalts with association of rhyolites, ignimbrites, and minor trachytes. According to Zanettin and Justin-Visentin,(1973 in kazmin,1979) the acidic rocks (interbedded with greater or lesser amounts of stratiform basalts) of central-eastern Ethiopian plateau form a large and continuous cover extending from Amba Alaji to Debre Berhan and Mugher areas.

Tarmaber basalt

The Tarmaber basalts (28-13 Ma) which are products of central type volcanism, locally covers the Alaji series .The Tarmaber basalts that cover the Oligocene Alaji are termed as Tarmaber – Guassa basalts and those that cover the Miocine Alaji are Tarmaber Megezez basalts. Except the Tarmaber basalts, the Alaji volcanics and Aiba basalts are formed by fissural types of volcanism (Zanitin et al, 1974). 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.

Rift series

After a period of erosion, another cycle of basalts (*Fursa basalts*) and/or ignimbrites (*Balchi rhyolites*) were deposited unconformably over the older volcanics. The Pleistocene movements, which slightly tilted and severely faulted the original Balchi plain, reduced the Ethiopian rift to its present dimension. Since then, volcanism has taken place almost exclusively in the Afar rift, and in the floor of the Ethiopian rift. Emission of basalts, called *“Bishoftu”*, in the zone to the south of Addis Ababa and, locally, in the plateaus (Mts. Salale, Choke, Amba Farit) are also documented.

The general evolution of Tertiary volcanism in central Ethiopia is controlled by the processes of uplifting and up warping. According to Zanittin et al, 1977, the Aiba, Alaji and Tarmaber formations (Oligo-Miocene) are wide spread over large flat area whereas the Fursa, Balchi and Bishoftu formation (Mio Pliocene) are confined to the escarpment and rifts. Both formations began with voluminous fissural basalt volcanism, continued with fissural silicic and/or basaltic volcanism and ended with central type basaltic volcanism. These authors also described that the decreasing age of volcanism from north to south of the central Ethiopian plateau is correlated with the uplift movements which affects the northern regions and then propagated to the southern regions.

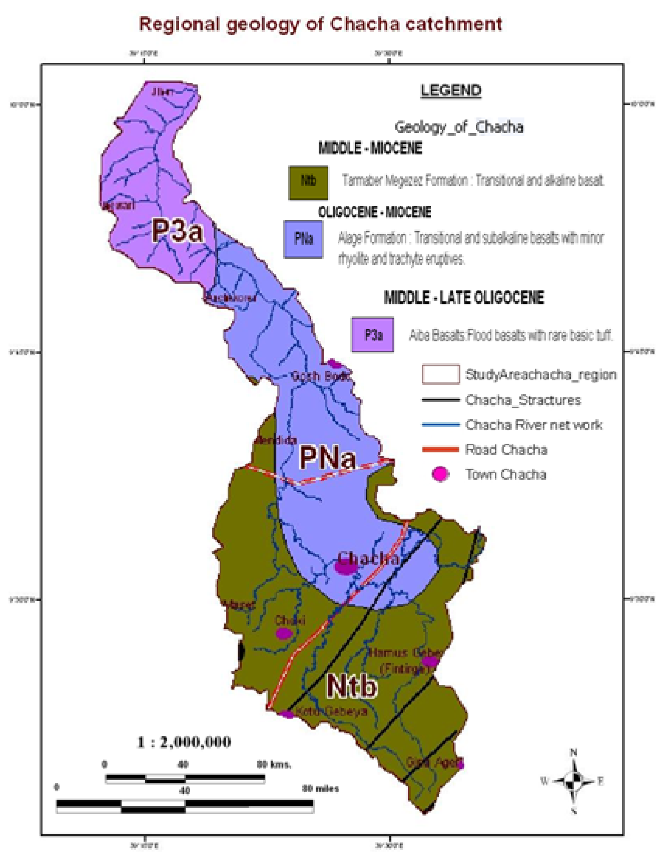


Figure 4.1 Regional geology of Chacha catchment.

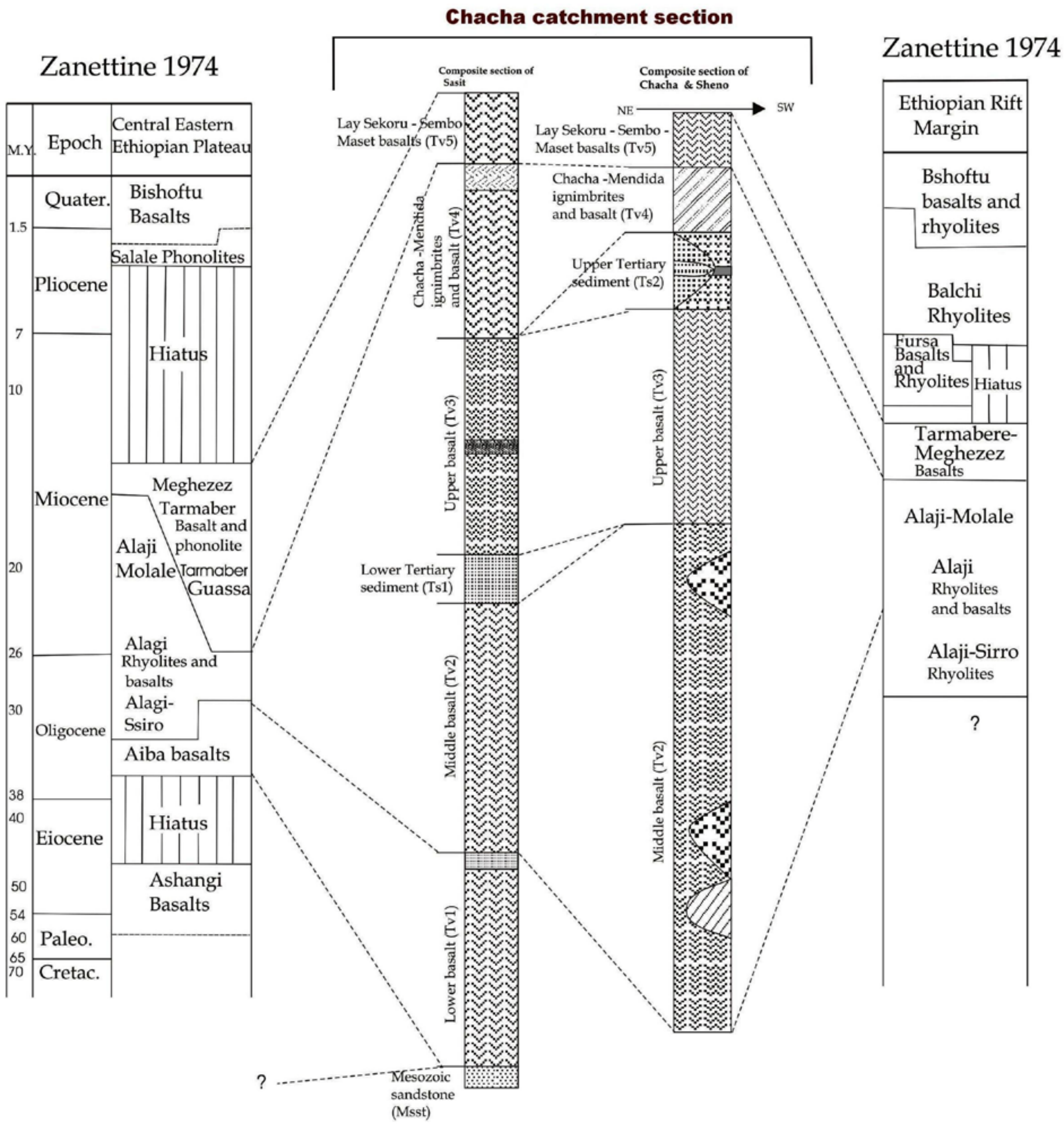


Figure 4.2 Correlation of the units of the study area with the regional stratigraphy (after Zanattine et al, 1974).

4.2 STRATIGRAPHY

Recent Quaternary deposits, Tertiary Rhyolites and Ignimbrites, Basalts, Tertiary sediments, Mesozoic Sandstone constitute the stratigraphy of the area from the youngest to the oldest. The following Table refers to the stratigraphy of the area.

Table 4.1 Stratigraphy and brief summary of all map units in Chacha catchment

Relative age	Major groups	Mappable units	Short description
QUATERNARY	Recent deposit	Alluvial soil (Qal)	Characterized by silty to clay soils that are dominantly black in color (Black cotton soil).
TERTIARY	Basic to acidic volcanics with intervolcanic sediments	Kotu Gebeya ignimbrites (Tv6)	Dark grey to light grey ignimbrite With some ash deposits.
		Sembo basalts (Tv5)	Characterized by dark grey aphanitic and olivine-plag – phyric basalts.
		Chacha Ignimbrites and basalts (Tv4)	Light grey Ignimbrite which consists of phenocrysts of sandine/ orthoclase with Subordinate Trachytes& basalts.
		Upper Tertiary sediment (Ts2)	Mostly contains reworked sediment (tuffaceous sediment) at the top and Sandstone (Greywacke) at the bottom.
		Upper basalt (Tv3)	Characterized by dark gray aphanitic to plage - phyric and Vesicular to scoraceous basalts.
		Lower Tertiary sediment (Ts1)	Intercalation of reddish brown to light yellow, medium grained, moderately to well sorted sandstone and massive reworked Sediment.
		Middle basalt (Tv2)	Association of glassy and aphanitic basalts with subordinate ignimbrite and plage – phyric basalt.
		Lower basalt (Tv1)	Irregularly jointed, slightly to Highly weathered aphanitic basalt.
MESOZOIC	Sediment	Mesozoic sandstone (Msst)	Light pink or white, fine to medium grained, compacted, thickly bedded and laminated Sandstone.

4.3 LITHOLOGY

The units exposed in the study area mainly include volcanic succession, with minor mappable Tertiary sediments, Mesozoic sandstone and superficial deposits (fig.4.3).Based on texture, compositional variation and relative stratigraphic position the rocks that are found in the area are divided in to ten major mappable units. These are , from older to younger , Mesozoic sandstone(Msst), Lower basalt(Tv1), Middle basalt (Tv2),Lower Tertiary sediment(Ts1), Upper basalt (Tv3), Upper Tertiary sediment(Ts2),Chacha ignimbrites and basalts(Tv4), Sembo basalts (Tv5), Kotu Gebeya ignimbrites (Tv6) and Quaternary deposit(Qal).

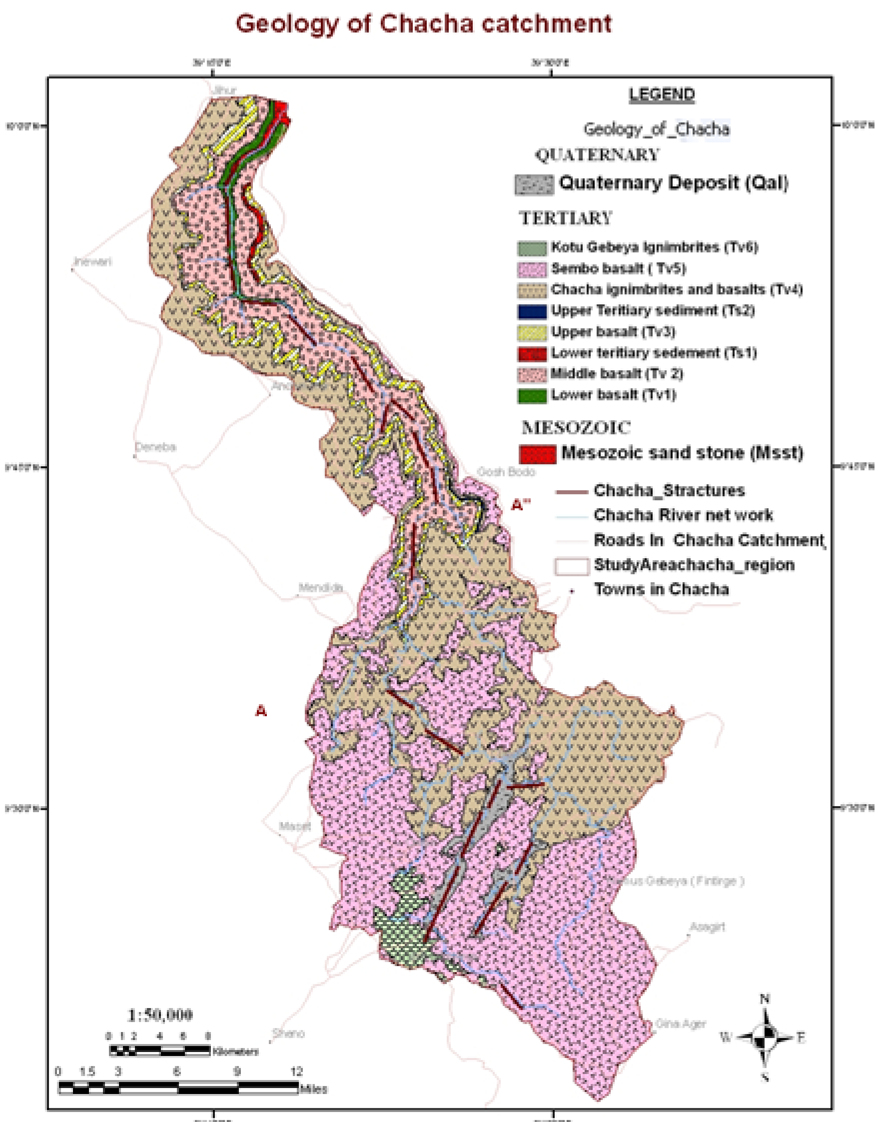


Figure 4.3 Geological map of the study area.

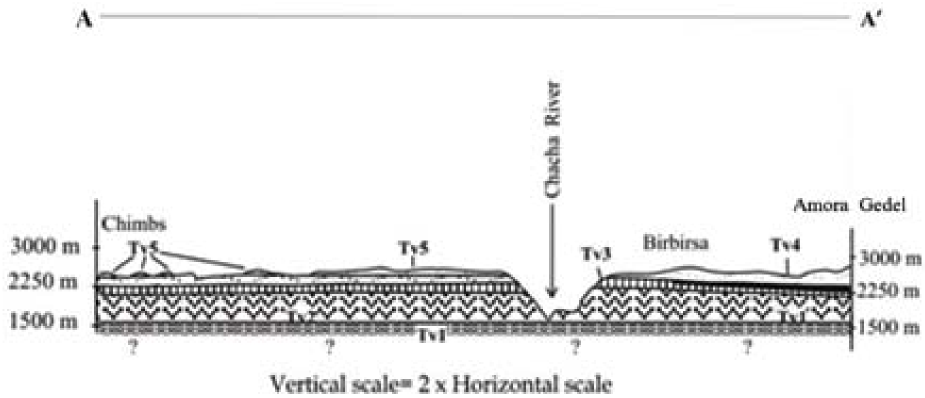


Figure 4.4 Cross section along A-A`

4.3.1 The Mesozoic sandstone (Msst)

This unit is exposed in the north corner of the study area (in Chacha valley). It covers an area of about 4.9 sq. km that accounts 0.4% of the map area (Fig. 4.3). This sandstone unconformably underlies the Lower basalt and it forms vertical cliff with a maximum thickness of about 30 m. Laterally, it is continuous to the north without significant variation. The unit is characterized by light pink and/or white, fine-medium grained, compacted, thickly bedded and laminated texture and structure. Some beds that are found on the top part show coarsening upward nature. In the middle part of the unit, there are some beds that contain sub rounded to rounded quartz pebbles which have up to 5 mm diameter. Petrographically, the sandstone is with well sorted, and the cementing material is dominantly clay mineral.

4.3.2 The Lower basalt (Tv1)

The Lower basalt is mainly exposed in the NW part of the study area especially in lower Chacha valley, covering about 15.9 sq.km area, and constitutes 1.3% of the map area (Fig. 4.3). The unit is found unconformably overlying and underlying the Mesozoic sandstone (Msst) and the Middle basalt (Tv2), respectively. The contact with the underlying unit is sharp and shows some baked dark brown soil horizon just above the sandstone, while the upper contact with the Middle basalt is marked by conglomeratic bed or friable sandstone. The basalt usually forms vertical cliff and some times steep slope topographic features. The unit can be characterized by irregularly jointed, highly weathered aphanitic basalt. On the basalt, there are floats of ignimbrites that came from the upper part of the section.

Plate 4.1 Mesozoic sandstone (Msst) and Lower basalt (Tv1) (around Tija sar area).

4.3.3 The Middle basalt (Tv2)

The middle basalt mainly exposed in the northern part of the area. It covers an area of about 142.4 sq. km that accounts 11.9% of the map area (Fig. 4.3). This unit is found unconformably overlying the Lower basalt. Generally the unit can be characterized by glassy/ shiny and aphanitic basalts with subordinate ignimbrites and olivine - plage- phyric basalts. The aphanitic basalt is more dominant and it is usually collumnarly jointed and mostly forms very steep cliffs. The top part of the unit is dominated by the glassy basalt with pyroclastic material that contains fragments of glassy basalt. The unit also contains some layers of highly weathered plag-phyric basalts at different places. The bottom part contains 60-80 m thick ignimbrite that contains basaltic clasts, some crystals and fiammes. Tuff is the least abundant rock type.

4.3.4 The Lower Tertiary sediment (Ts1)

This unit is well exposed in Chacha river section. It covers an area of about 3.5 sq. km that represents 0.3% of the study area (fig.4.3). The unit is found unconfrmably overlying and underlying the Middle basalt and the Upper basalt respectively. This unit can be characterized by alternating layers of sand stone and tuffaceous sediment. In the lower Chacha river section, the unit is 10m thick and contains fine-medium grained sandstone.

4.3.5 The Upper basalt (Tv3)

The Upper basalt is exposed in Chacha river section overlying the Lower Tertiary sediment(Ts1) or Lower basalt and underlying the Chacha Ignimbrites and basalts (Tv4). It covers an area of about 64 sq. km which constitutes 5.4% of the map area (Fig. 4.3). This unit is separated from the overlying unit, (Tv4), either by the Upper Tertiary sediment (Ts2) or by paleosoils. The paleosols are 1m-10 m thick. They are red to reddish brown, gray, light yellow, sandy to silty clay soil. The Upper basalt is characterized by vertical cliff forming, columnaly jointed dark grey aphanitic to plag- phyric and vesicular to scoraciuos basalts. Sometimes the bottom of the unit contains pyroclastic deposit/crystal to vitric tuff/ and agglomerates that have basaltic fragments whose diameter ranges from 1 mm to 30 mm. The agglomerates and pyroclastic horizons have a maximum thickness of 5m. Mostly the basalt undergoes spheroidal type of weathering.

4.3.6 The Upper Tertiary Sediment (Ts2)

This unit is exposed in the upper part of Chacha river valley especially east and west of Goshe Bado village and covers an area of 1.1 sq. km that accounts nearly 0.1 % of the map area (Fig.4.3). The unit is found underlying the Chacha ignimbrites and basalts (Tv4) and overlying the Upper basalt (Tv3). It is dominantly characterized by tuffaceous sediment with some layers of sand stone. It has a maximum thickness of about 65 m and pinches out towards north and south.

The top part of the unit contains tufaceous sediment layers and cut by N 30°E trending, 50 cm wide basaltic dyke. Towards north, the unit becomes conglomeratic and cross bedded sandstone. This sandstone is 10 m thick, friable and contains pebble to gravel sized basaltic clasts. In areas where the sediment is not deposited or exposed, there are paleosols between Tv3 and Tv4.

4.3.7 Chacha Ignimbrites and Basalts (Tv4)

The Chacha Ignimbrites and Basalts are mainly exposed in the central and northeastern part of the area. It covers about 418 sq. km that accounts 35.1% of the map area (Fig. 4.3). This unit is found unconformably overlying and underlying the upper basalt (Tv3) and the Sembo basalts

(Tv5), respectively. This unit dominantly consists of ignimbrite and basalts with subordinate trachytes and ash deposits. The ignimbrites mostly found on both sides of the Debre Birhan-Mendida all weather road and also on both sides of the Chacha – Debre Birhan aspalted road. They form small, rounded and isolated ridges/ hills, sometimes capped with basalts (Tv5). This unit is also exposed along the Chacha river valley. The basalts of this unit are found mostly below the Ignimbrites. The ignimbrite is fine graded and massive to bedded, sometimes vesicular and rarely contain secondary minerals. The basalts of this unit are aphanitic and collumnarly jointed. Below the basalts, there are agglomerates that contain basaltic blocks in a fine grained matrix. The trachyte that form columanarly jointed vertical cliff is normally found below the ignimbrite. The ash deposits are found west of Goshe Bado village interbedded with the rhyolites and/or ignimbrites.

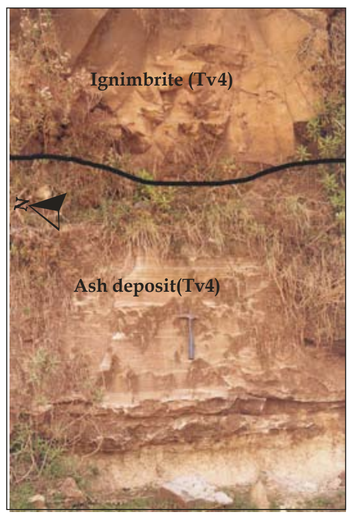


Plate 4.2 Ash deposit with in the Chacha Ignimbrites and basalt (Tv4) (south of Kotu Gebeya town).

4.3.8 Sembo Basalts (Tv5)

This unit is found mainly in Sembo, Lay Sekoru and Maset areas forming prominent basaltic ridges and in the central part (around Chacha and Mendida) as small and separated erosion remnants capping the Chacha- Mendida rhyolites and basalts (Tv4). It covers an area of 487.7 sq. km that accounts about 40.8% of the study area. The basalt is dominantly aphanitic and some plag-phyric, with few olivine- phyric verities. The plag- phyric one is well exposed in the south eastern part of the study area, along the foot of mount Megezez. The aphanitic one is dominantly found around Sembo, Chacha, and Mendida and in other places together with the plag-phyric and olivine- phyric varieties.

In this unit, there are at least 3 paleosoils between different successive flows of basalt. These paleosoils are 0.5- 8 m thick and is composed of fine sandy to silty soils. With in the unit, north of Sheno and at Kotu -Hageremariam road, scoria deposit are found caped with aphanitic basalt. This basalt sometimes undergoes onion type of weathering and the aphanitic verities are sometimes colomnarly jointed. South of Mendida town, there is trachytic/ tracy basalt flows and domes on top of the ignimbrites (Tv3). There is also about 2m thick paleosoils near Mendida town that separates the unit with the underlying one (Tv3).

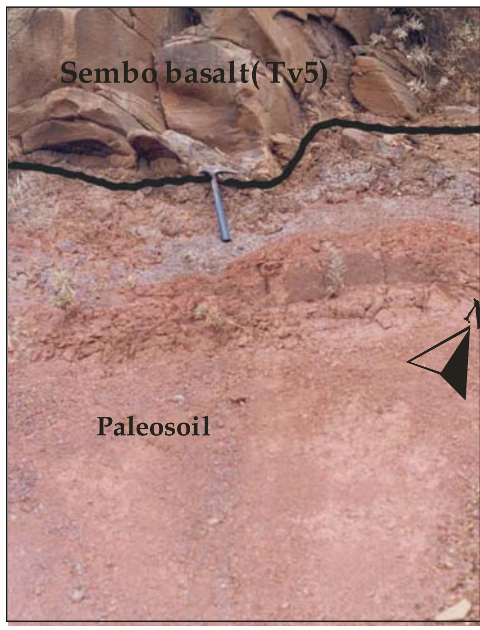


Plate 4.3 Paleosoil that separates the Chacha Ignimbrites and basalt (Tv4) with the Sembo basalts (Tv5) (near Mendida town).

4.3.9 Kotu Gebeya ignimbrites (Tv6)

This unit covers an area of about 23.9 sq. km that represents 2% of the map area. It is found dominantly in areas around Kotu Gebeya and Cheki towns. They are found as remnants of erosion forming small and isolated hills and sometimes on foots of the basaltic ridges. Around Kotu Gebeya and Cheki town they are found on relatively plain areas overlying the Sembo basalts (Tv4). Around Lay Sekoru area the ignimbrites are found at the foot of the basaltic ridges (Mount Megezez). The unit can be characterized dominantly by fine grained ignimbrites (crystal-vitric tuff) and with some ash deposits. The ash deposits are found in Cheki town and shows laminations.

4.3.10 Quaternary deposits (Qal)

This unit mainly occupies north east of Kotu Gebeya and Northwest of Mendida following steams and river channels that are found on plain areas (fig. 4.3). This unit covers an area of about 32 sq. km that represents 2.7% of the map area. It is characterized by alluvial soils varying in thickness from a few cm to about 19m in which black cotton soil is the predominant type.

4.4 STRACTURES

The main structures, joints, fractures, and normal faults, are all related to the extensional rift tectonics in the area. The structures found in the study area can be classified in to Diastrophic and Non-diastrophic structures. The main diastrophic structures are identified from imagery and DEM (Digital Elevation Model) interpretation as well as from field observation. These include photo lineaments, fractures and joints. The non- diastrophic structures include beddings and laminations (in the sedimentary rocks), columnar joints, and vesicles in the volcanic rocks.

4.4.1 Non- diastrophic structures

Planer beddings and laminations are found mainly in Mesozoic sandstone, Lower Tertiary and Upper Tertiary sediments. Some cross beddings are also observed in the Upper Tertiary sediment. Columnar joints are found almost in all the basalts that are found in Tv1, Tv2 and Tv3. Vesicles are also observed in some ignimbrites and basalts and most of them are empty with rare amygdales.

4.4.2 Diastrophic structures

Joints and fractures

Various types of joints and fractures are observed in the mapped area and most of them have irregular nature. However, some horizontal joints that are dipping 30° towards SE and vertical sets of joints trending N-S and N10°E are also observed in the ignimbrites that are found in Tv2 are Tv1, respectively.

Imagery lineaments

From imagery and DEM (Digital Elevation Model) interpretation as well as from field observation, nearly NW - SE and NE – SW trending lineaments are recognized. All streams/river valleys developed along these lineaments. Generally NW – SE trending lineaments are more dominant in the northern part whereas the NE –SW trending ones are more dominant in the southern part (Fig. 4.8).

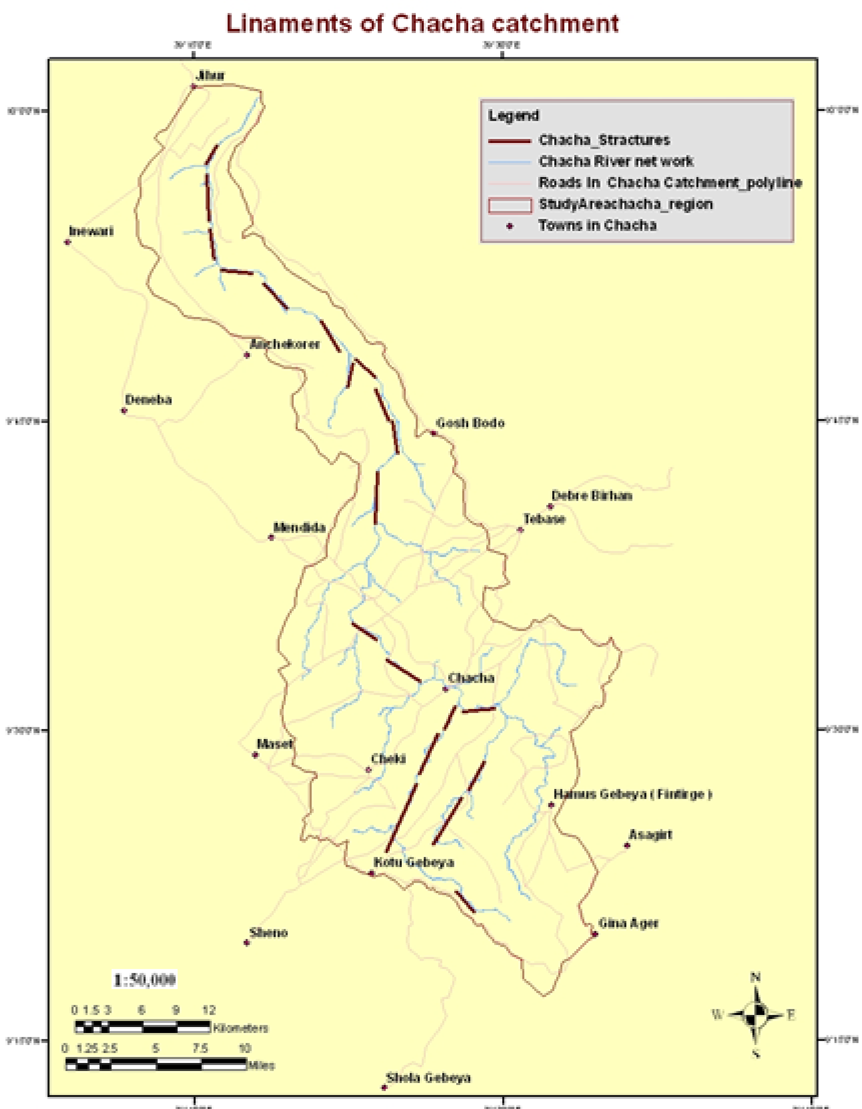


Fig.4.5 Structural map of the study area

4.5 GEOLOGIC HISTORY

The geological history of the map area might have started from the last event of regression of the Indian Ocean towards SE Ethiopia which deposited the Mesozoic sandstone (Msst). According to Getaneh, (1991) the sandstone (in our case the Debre Libanos sandstone) deposited in braided stream system. Following the Late Mesozoic-Early Tertiary transgression regression cycles there was a strong epireogenic uplift of the whole East Africa together with Arabia (Kazmin, 1972). As a result, there was eruption of fissural volcanism that covers a wide area in the plateau. According to Zanettine et al., (1974) these volcanisms erupted in cyclic manner rather than one prolonged eruption. In the map area the first fissural eruption was marked by the Lower basalt

(Tv1). This was followed by uplifting and deposition of conglomerate or friable sandstone. As clearly visible in the lower Chacha rive section, after some time gap there was another fissural eruption. From the end of Oligocene until the upper-middle Miocene (25 -15 Ma), south of 10° 30’ silcic and basaltic fissural magmas were erupted (B. Zanettine et al., 1978). The Middle basalt (Tv2), the Upper basalt (Tv3) and the Chacha and basalts (Tv4) are the results of this silcic and basaltic magma. But from our observation with in the eruption of these silcic and basaltic magmas, there were local tectonics and time gaps which generate the local basins for the accumulations of Tertiary sediments (Ts1 &Ts2). So after the eruption of the Middle basalt (Tv2), there was uplifting and local tectonics in the upper part of the study area. This also followed by the formation of local basin and deposition of the Lower Tertiary sediment (Ts1). After the eruption of the Upper basalt (Tv3), there might also be another uplifting with the accompanying tectonics which forms local basin in the central eastern part of the study area. This activity followed by the deposition of the Upper Tertiary sediment (Ts2). The deposition of the Upper Tertiary sediment there was followed by another cyclical fissural eruption which began and ended with basaltic and silcic magmas, respectively. This eruption gave the Chacha ignimbrites and basalts (Tv4). After this stage the fissural volcanism might be radically changed to central type and gave the Sembo basalts (Tv5) whose center could be mount Megezez and another small center that is found around Maset. After certain time gap the Kotu Gebeya ignimbrites (Tv6) erupted from centers, probably located around Addis Ababa, and were unconformably underlain by the Sembo basalts.

The general evolution of Tertiary volcanism in central Ethiopia is controlled by the processes of uplifting and up warping. At the beginning of each stage the volcanism occurred with in a large, elongated basin (Zanettin, 1974). During the pre-Oligocene stage, Ashangi formations were deposited. In this stage, basalts with transitional, tholeiitic affinities and/or alkaline basalt were emitted. Extensive crustal extension resulted in the fracturing of the 'peneplain of ashangi' and outpouring of *fissural Aiba* basalts whose composition is transitional between tholeiitic and alkaline basalt. The fissural volcanism then continued with the emission of large quantities of ignimbrites (*Alaji rhyolites*). Afterwards, the volcanism of the plateau changed its mode of eruption to central type (*Termaber basalts*). This basalt is different from the older ones by its association: phonolites (Mt. salale phonolites), tuffs, ultramafics, and paleosoils. After a period of erosion, another cycle of basalts (*Fursa basalts*) and/or ignimbrites (*Balchi rhyolites*) were deposited unconformably over the older volcanics. The Pleistocene movements, which slightly tilted and severely faulted the original Balchi plain, reduced the Ethiopian rift to its present dimension. Since then, volcanism has taken place almost exclusively in the Afar rift, and in the floor of the Ethiopian rift. Emission of basalts, called "*Bishoftu"*, in the zone to the south of Addis Ababa and, locally, in the plateaus (Mts. Salale, Choke, Amba Farit) are also documented..

5. HYDROGEOLOGY

5.1 GENERAL

Owing to its location along the western margin of the MER, the hydrogeological setup of the Chacha catchment is an integral part of the evolution and development of the Ethiopian Plateau and the rift system. The catchment is covered by tertiary volcanic rocks overlain by fluvial and residual soils, varying in thickness from a few cm to about 19 m in which black cotton soil is the predominant type. The main lithologies include basalts, ignimbrite, and tuffaceous sediment, vesicular to scoraceous basalt and thickly bedded and laminated sand stone and massive reworked sediment (Figure 4.3). These highly weathered, fractured lithologies favor the circulation and storage of subsurface water.

The main structures, joints, fractures, and normal faults, are all related to the extensional rift tectonics in the area. The aquifer properties in the Chacha catchment are controlled by the litho-stratigraphy of the volcanic rocks and the structures that affect them. More specifically, the hydraulic complexity of these volcanic rocks is caused by their complex spatial distribution, their different reciprocal stratigraphic relationships, their significant compositional, structural and textural variability, and their different levels of tectonization and weathering (Vernier, 1993).

The fractured and jointed Ignimbrite and Basalts are permeable and facilitate the infiltration amount and rate. Weathering horizon occurring at the contact between basaltic lava flows of slightly different age is a productive aquifers zone. Hence the major potential rock unit for the storage and movement of groundwater in the study area is fractured volcanic rocks and Sandstone.

5.2 HYDROGEOLOGICAL CLASSIFICATION/CHARACTERIZATION

Qualitative division of lithological units is based on hydrogeological characteristics of various rock types. These were divided into units with dominant porous and/or fissured permeability and impermeable rocks. Hydrogeological units of the study area are classified into aquifer/aquitard system based on hydrogeological characteristics found during the investigation /desk study and field inventory/. Quantitative classification of aquifer types is made by using water point inventory data and the various boreholes pump test data obtained from regional water offices. Since quantitative data such as permeability, aquifer thickness and yield are not adequate and evenly distributed to make detailed quantitative potential classification; qualitative assessment was made by analogy for some rock groups without water points. Hence, the hydrogeological characterization of the study area reveals the following Aquifer/Aquitard system:

Units with porous permeability: where groundwater accumulates in the pores of an unconsolidated or semi-consolidated material. Porous materials of Quaternary and Tertiary age are represented by alluvial and colluvial sediments developed in depressions and/or along Chacha river valley. The pyroclastic rocks between lava flows are generally porous but usually less permeable due to poor sorting. Layers of paleosoil of various thicknesses in between of lava flow are also less permeable and consist usually clay material. Mesozoic sediments represented by sandstone form a medium permeability with good porosity. The laboratory tested porosity of selected rock types of the study area are summarized in Table 5.1. Generally the porous aquifers are only locally developed and scattered within the study area. The units with porous permeability forming aquifers are expressed in the hydrogeological map (Fig 5.1).

Units with fissured permeability: the groundwater is accumulating in the weathered and fractured portion of young volcanic rocks. The porosity of lava flows may be high, but the permeability is largely a function of a combination of the primary and secondary structures within the rock, in addition the permeability of lava flows tend to decrease with geological time. Pyroclastic rocks associated with lava flows as well as paleosoisls in between lava flows are generally porous but not very permeable because of poor sorting and an abundance of fine materials. Hence, volcanic ash beds of large extent may form semi-horizontal barriers to water movement resulting in low productivity of lower basalts. The units with fissured permeability forming aquifers are expressed in the hydrogeological map (Fig 5.1).

Impermeable units: Ignimbrites/Rhyolites forming domes which are compact and massive with relatively few structures have low effective porosity forming the impermeable layers of the studied area. The impermeable units form aquitards and are expressed in the hydrogeological map (Fig 5.1).

Table 5.1 Porosity of rock units in the study area

Porosity (%)	Rock Units
42.1	Tertiary sediment
36.2	Ignimbrite (Ignimbrite & Rhyolite)
19.4	Kotu Gebeya Ignimbrite
3.6	Basalt Ginager
3.1	Sembo Basalt
2.4	Plag. Phyric Basalt
2.0	Middle Basalt
1.9	Aphanitic Basalt (Bas, Ign & Rhy)
1.4	Basalt (chacha basalt.& Ignimbrite)
1.2	Upper Basalt

Source: Physical lab results of engineering geology field data 2007

5.3 ELEMENTS OF HYDROGEOLOGICAL SYSTEM OF THE AREA (AQUIFERS AND AQUITARD)

Based on the hydrogeological character of lithological units and their topographical position the study area (1194 Km^2) can be divided into aquifers and aquitard of different occurrence of groundwater as follows:

- Porous aquifer developed in alluvial and colluvial sediments and in Tertiary sediments and pyroclastics outcrop.
- Fissured aquifer developed in basalts on plateau.
- Mixed aquifer developed in fissured Ignimbrite, Rhyolite, Trachyte, Basalt and sediments intercalating volcanic rocks on plateau.
- Fissured aquifer developed in basalts outcropping in deep valleys.
- Porous and fissured aquifers developed in Mesozoic sandstone in deep valleys.
- Aquitards developed in ignimbrites forming water shed mountains along plateau – rift valley edge.

The hydrogeology map shows aquifers and aquitards of which definition was done based on character of groundwater flow (pores, fissures) and yield of springs, boreholes and dugwells found during field water point inventory. The following aquifers and aquitard were defined:

1. Extensive (larger than 100sq.km), locally developed and highly productive porous aquifers (T=10-100 sq.m/d and well Q=1-5 l/s). Aquifer units are shown in fig 5.2.
   Aquifer units consist of Quaternary deposits, Tertiary sediments, pyroclastics and Mesozoic sediments.
2. Extensive (larger than 100sq.km), locally developed and highly productive fissured aquifer (T=10-100 sq.m/d and well Q=1-5 l/s). Aquifer unit is shown in fig 5.3.
   Aquifer unit consists of Tertiary basalts with outcrops on plateau
3. Extensive (larger than 100sq.km), locally developed and highly productive aquifer of mixed fissured and porous permeability (T=10-100 sq.m/d and Q=5-1l/s). Aquifer is shown in fig 5.4.
   Aquifer unit consists of Tertiary Ignimbrites, Basalts, Rhyolite, Trachyte intercalated with sediments with outcrops on plateau
4. Extensive (larger than 100sq.km) and fissured aquifer that have low productivity because of its thick overburden, but are known as aquifer of moderate productivity (T=1-10 sq.m/d and Q=1-0.5 l/s) from other areas. Aquifer is shown in fig 5.5.
   Aquifer consists of Tertiary volcanics (dominating basalts) with outcrops in deep valleys.
5. Aquitards and/or Minor aquifers with local and limited groundwater resources (T = 0.1–1 sq m^2/d and Q = 0.05 - 0.5 l/s)
   Aquifers consist of Tertiary volcanic rocks (dominating Ignimbrite and Rhyolite) of a limited extend with outcrops forming water shed mountains along plateau – rift valley edge. Aquitard is shown in fig 5.6.

The following detailed hydrogeological characteristics of aquifers – aquitards and hydrogeological characteristics of individual lithological units are described based on water points inventoried in the catchment and ENGDA /GSE, Version 201/.

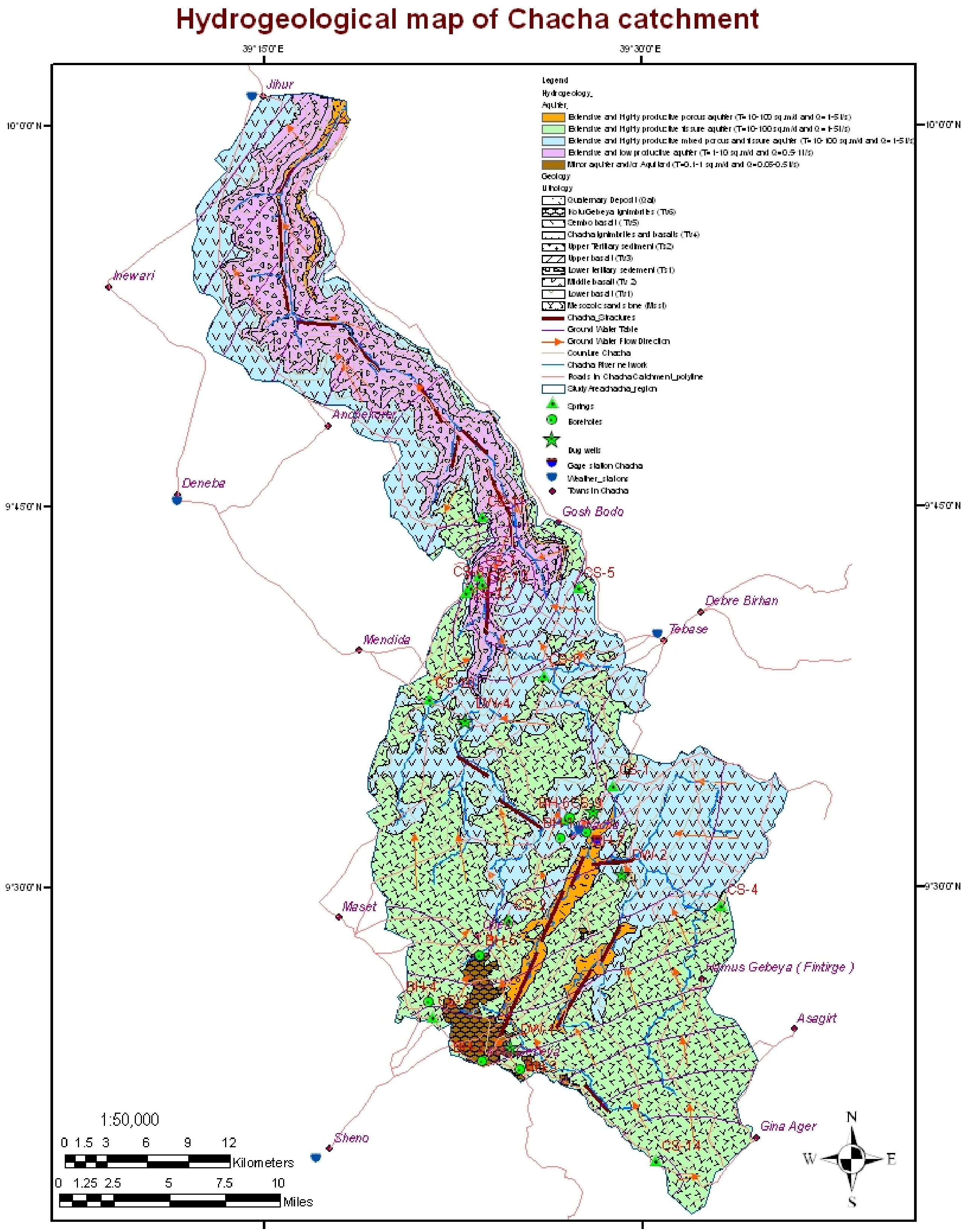


Figure 5.1 Hydrogeological map of Chacha catchment.

5.3.1. Extensive and highly productive porous aquifers

The porous aquifers altogether makes 41.5 km^2, where 36.9 km^2 is covered by Quaternary and Mesozoic sediments and 4.6 km^2 is covered by Tertiary sediments. The aquifer is expressed in deep yellow color (Fig 5.2).

Quaternary deposits (Qal)

The general distribution of the deposits with porous permeability in the study area is localized to gentle undulating plateau of the upper Chacha catchment along Hadewa, Beliti and Germ perennial tributaries of Chacha river. The area covered by quaternary deposits with porous permeability is 32 km^2. The thickness of the alluvium along Chacha river is variable from place to place. The alluvium reworked and seems less compacted and relatively more porous. The alluvial sediments are represented mainly by porous-sandy-gravels to silty sand which can be exploited by shallow dugwells. Aquifer in alluvial sediments is recharged directly by infiltration of rain. Alluvial sediments can be also recharged by rivers during their high discharge. Groundwater of aquifer in alluvial sediments is drained by rivers. Plateau Quaternary deposits also recharge underlying aquifers.

Dugwells sunk on the plateau Quaternary deposits supply local community with groundwater of low TDS. The groundwater fluctuation of several meters is common. Groundwater is under water Table condition.

Some perennial springs with variable yield depending on the sediment thickness, degree of consolidation and local catchments of Alluvial were seen on some of inter-mountain plains. Safe yield of wells sunk into Quaternary deposits is estimated to be about 0.5 l/s. The thicker cover by Quaternary sediments should be located by simple geophysical measurements e.g. VES.

Tertiary sediments (Ts1 and Ts2)

Tertiary sediments form outcrops in Valley of Chacha River. The extent of the sediments is not over 4.6 km^2, Intercalation of reddish brown to light yellow, medium grained, moderately to well sorted sandstone (Greywacke) at the bottom and massive reworked Sediment (tuffaceous sediment) at the top is observed in the eastern part of catchment. The sediment consist of various rocks permeable as well as impermeable (marl and clay) and represents lake sediments and/or fluvial and colluvial sediments of wide valleys and shallow depressions of plateau. No visible springs were observed because the outcrops of Tertiary sediments are located in upper parts of deeply dissected valleys near at the edge of valleys and contact of sediment with underlying basalt is covered by slope sediments. The sediments are not acting as independent aquifer but when they are developed by drilling together with volcanic rocks they can contribute to the safe yield of a well. Aquifer is recharged indirectly by groundwater of overlying aquifers. Groundwater is probably drained into deep rivers valleys and it also recharges underlying aquifers. Groundwater is probably under water Table condition.

The Mesozoic sandstone (Msst)

The sandstone outcrop of the study area is found occupying 4.9 km^2 at the northern corner of the catchment. Despite the fact that the unit being highly porous, springs were not emerging at contact with the lower basalt; however springs emerge at the foot near the contact with lower unit, the ‘Mugher’ mudstone. In most cases the mudstone below the sandstone serves as an impermeable layer reflected by the emergence point of springs. The yield of these springs remains almost constant throughout the year; the mean dry season discharge was 2.03 l/s.

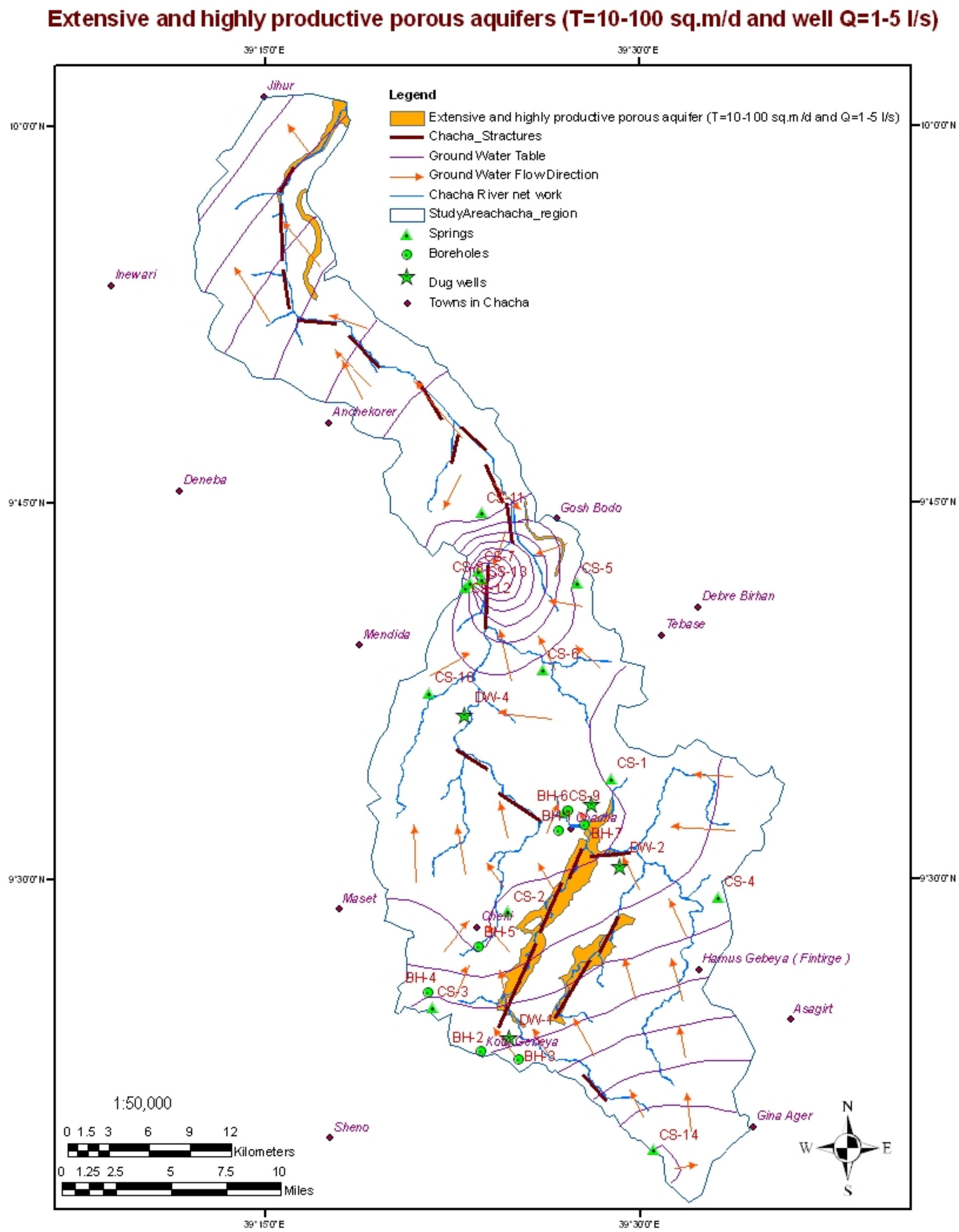


Figure 5.2 Extensive and highly productive porous aquifers.

5.3.2 Extensive, locally developed and highly productive fissured aquifer

The fissured aquifers on the plateau covers 487.7 km^2, the aquifer is expressed by light green color Fig 5.3.

Sembo basalt (Tv5)

The plagioclase-phyric basalt is tectonically affected by the NNE-SSW trending boundary normal fault running from Ankober to Tarmaber and downthrows the basalts towards the Afar rift. This formation has large proportion of scoraceous lava flows which is highly pervious favoring groundwater storage and movement. The springs from this aquifer show low variation in yield throughout the year. Most of the springs of this unit are fracture controlled usually emerging at the intersection points of N-S and NE-SW striking fractures or faults with topography. The dry period discharges of 0.042-12.76 l/s are observed for springs emerging in the area. CS-3, CS-4, CS-5, CS-6, CS-10 and CS-12 emerge at the contact between the phyric basalt and underlying volcanic rock. And there is also a spring at Gudoberet with the discharge of > 17 l/s (ENGEDA). Due to the relatively good yield and constant discharge rate of springs emerging from this unit they are widely used for small scale irrigation purpose apart from sustainable community water supply. This aquifer is being recharged directly by infiltration of rainfall and/or infiltration from porous aquifer developed in Quaternary sediments covering plateau area and by non perennial rivers and their tributaries. Recharge is enhanced along rift related NE-SW structures. The plateau sediments retains rainwater for longer time, creates favorable condition for infiltration through highly weathered, jointed and permeable upper layer. Groundwater is drained by shallow rivers and it also recharges underlying aquifers. Groundwater is probably under water Table condition.

Boreholes (BH-5 and BH-7) sunk in Cheki and Chacha at Sembo (Tv5) basalt with a yield of 2.9 and 5 l/s respectively are good examples showing the high potential of the aquifer in the study area. The Jalissa spring (CS-9) which is emerging at flat plain surrounded by small hills of Sembo basalt yields 12.75 l/s indicating high potential of the aquifer at the center of the study area.

The static water level measurements of boreholes in the Basalt are in the range of 6.6 to 51.39 m below ground surface for BH-7 and BH-5 respectively.

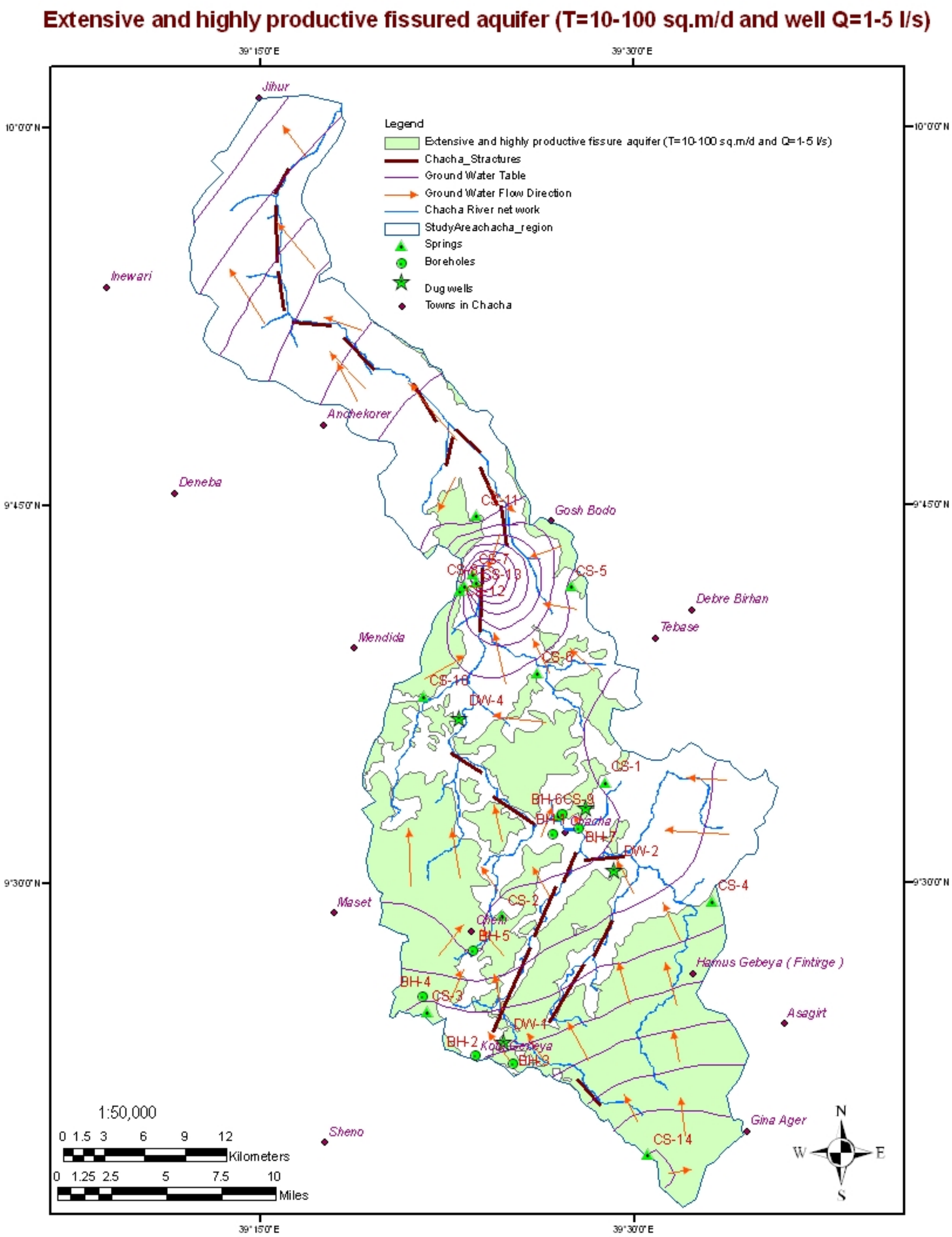


Figure 5.3 Extensive and highly productive fissured aquifer.

5.3.3. Extensive and highly productive fissured and mixed aquifers

Generally the highly productive fissured and porous mixed aquifer covers an area of 418.7 km^2 and represented by light blue color (Fig 5.4).

Chacha Ignimbrite and basalt (Tv4)

The highly fractured Ignimbrite and/or Trachyte of the Alaje formation are one of the major water bearing formation of the area. It covers large gently undulating areas of plateau. Ignimbrite as well as Trachyte form non-homogeneous hydrogeological environment, though the amount of groundwater in these rocks is variable from place to place depending on the frequency, intensity and distribution of the fracturing system. On the basis of production wells drilled for Debre Birhan water supply study, the inter-bedded volcanic rocks of the Alaje group contains semi confined aquifers. This aquifer is being recharged directly by infiltration of rainfall and/or infiltration from porous aquifer developed in Quaternery sediments covering plateau area. The formation is drained by perennial and seasonal rivers like Chacha and Beresa. Discharge of springs is 0.4-1 l/s on the Ignimbrite.

Boreholes sunk in the fractured Ignimbrites for the most part have transmissivity value between 10-100 m^2/day. Mean transmissivity is 95.8 m^2/day (Dalecha well fields data) therefore; the fractured Ignimbrite /Trachyte/ unit generally has high permeability and productivity. Transmissivity, hydraulic conductivity and storativity data of few wells located mainly in the fractured Ignimbrite and basaltic rocks of Debre Birhan area were obtained and summarized in Table 5.2.The boreholes through fractured Ignimbrite/Trachyte have static water level between 6 and 51 m below ground surface.

Table 5.2 Beresa and Dalecha well fields data

Borehole ID	Transmissivity (m^2/day)	Hydraulic Conductivity (m/min)	Aquifer Thickness (m)	Storativity
BH-1	98.2	$1.87*10^{-3}$	36.59	$2.96*10^{-1}$
BH-2	165.6	$2.36*10^{-3}$	48.9	$1.93*10^{-8}$
BH-3	10.8	$2.1*10^{-4}$	35.74	3.71*10
BH-4	98.1	$1.79*10^{-3}$	37.99	$6.68*10^{-4}$
BH-5	0.05	$7.23*10^{-7}$	54	$5.01*10^{-3}$
BH-6	224.6	$5.05*10^{-3}$	30.99	10
BH-7	266.4	$4.34*10^{-3}$	42.66	3.13
BH-8	76.9	$1.25*10^{-3}$	42.59	7.04*10

Source : Yadot engineering plc

Drilling data from Debre Birhan area shows important contribution of permeable Tertiary sediments upon safe yield of wells.

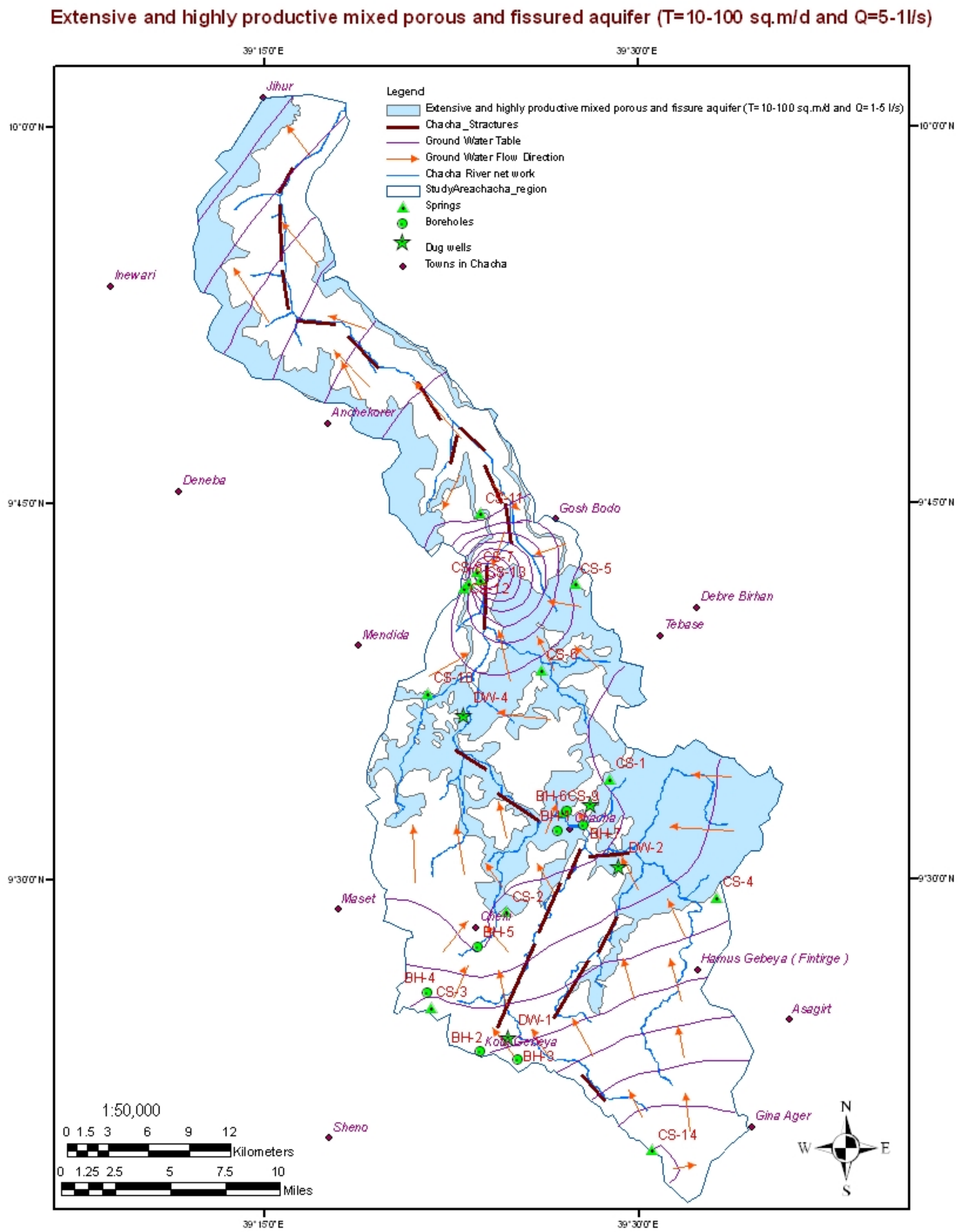


Figure 5.4 Extensive and highly productive mixed porous and fissured aquifer.

Contribution of Tertiary sediments in aquifers drilled into Tertiary volcanic rocks mixed with permeable sediments is between 1 – 10 l/s. However, direct contribution of the sediments to safe yield is not known.

5.3.4 Extensive and low productive fissured aquifer

A total of 222.3 Km^2 area, accounting 18.6% of the study area is covered by low productive aquifer type. The units are mapped by light pink color (fig 5.5).

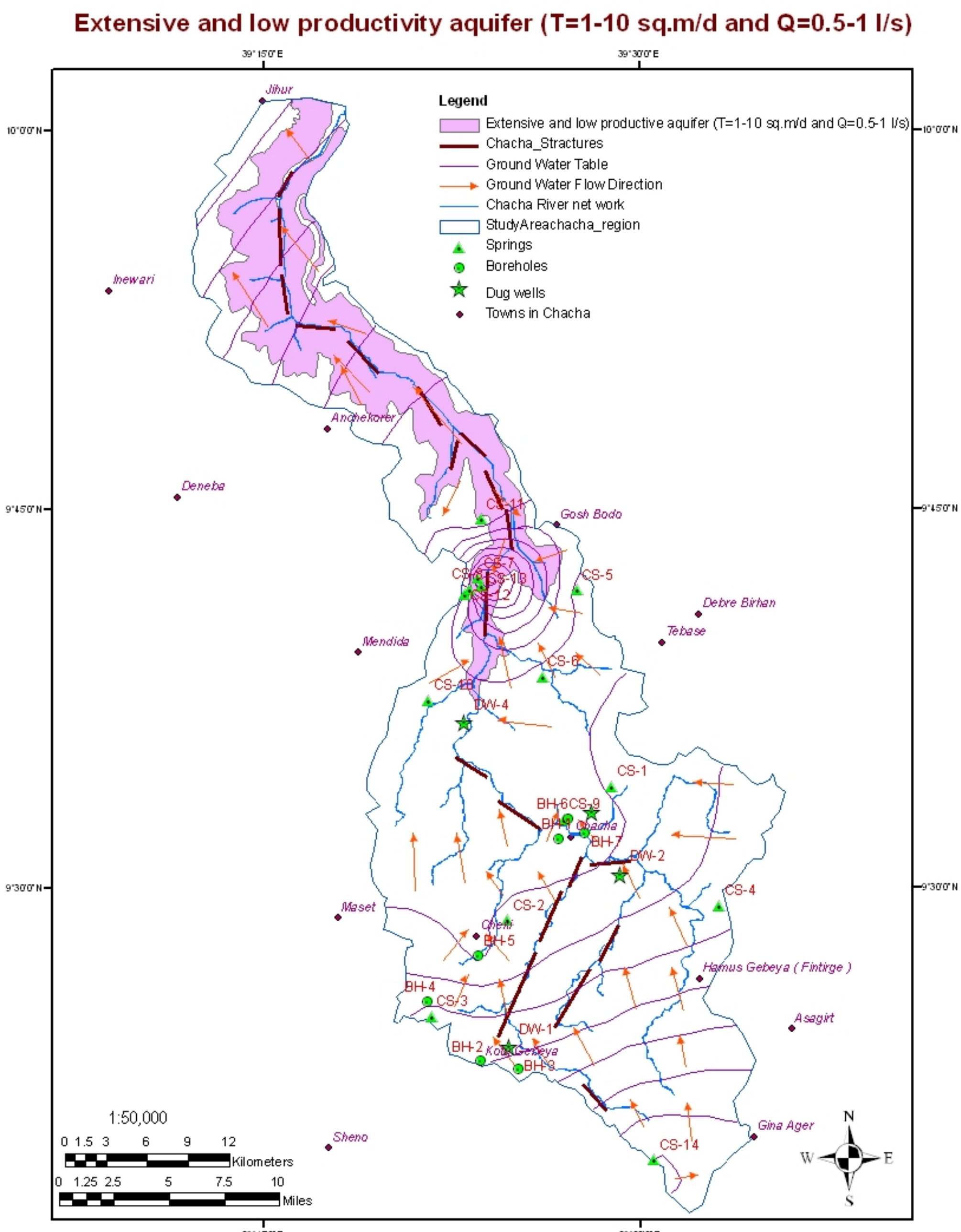


Figure 5.5 Extensive and low productive fissured aquifer.

Lower basalt (Tv1), Middle basalt (Tv2) and Upper basalt (Tv3)

The hydraulic conductivity, groundwater storage and yield of springs of this aquifer are variable from place to place. The spring discharge measurements taken from this aquifer type ranges from 0.09-0.7 l/s with mean yield of 0.31 l/s during dry period. Most of the springs are located on hill side as topographic breaks. The steep gradient topography of the location of this aquifer type favors more of runoff than infiltration, as most parts forms highly dissected terrain, groundwater storage in those areas that form very irregular surfaces is expected to be low. Hence the impact of topography is significant for the low aquifer yield in highly tectonized and irregular geomorphic terrains of lower Chacha river catchment.

The intercalated pyroclastic deposits between different successions of basaltic flows hinder the vertical circulation of water, and hence no springs could be located in the valleys of Chacha in the lower, middle and upper basalts around.

5.3.5 Aquitard and/or Minor aquifer with local and limited groundwater resources

The elevated dome forming upper Ignimbrite cover an area of 23.9 km^2 forming the aquitard and is represented by brown color in Fig 5.6

Kotu Gebeya Ignimbrite (Tv6)

Aquitards developed in ignimbrites forming water-shed mountains along plateau – rift valley edge. This unit covers small elevated area and no springs are emerging from this unit. Quantitative data is not available from this unit. Hence, the hydrogeological classification of the unit is qualitative based on the geologic information. The unit forms domes, fine grained and hydro-structures such as joints and fissures are poorly developed. Generally the recharge, permeability and storage of water are believed to be minimal hence this unit is considered to be aquitard.

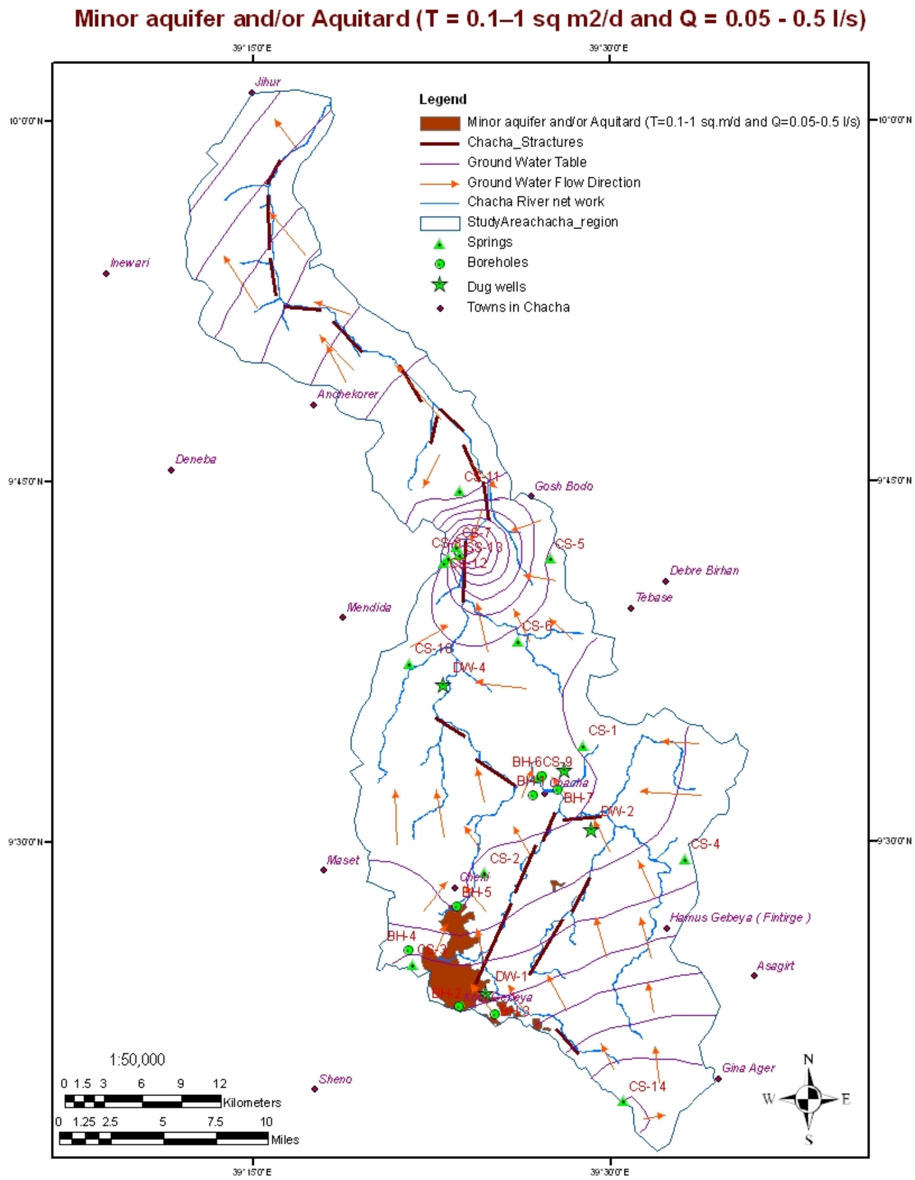


Figure 5.6 Minor aquifer / Aquitard (Tv6).

5.4 GROUNDWATER POINTS

Groundwater point inventory were taken to collect hydrogeological information and directly measured data such as coordinates, dynamic or static water level, field water quality measurements such as specific electrical conductivity, water temperature and pH. Inventory data sheets (Annex-1) were mostly completed during the field survey.

A total of 30 water points were inventoried, out of which 7 are boreholes with variable depth, 14 cold springs from different formation, 4 shallow depth hand dug wells, 3 river points (up stream, Down stream and lower stream) and 2 rain water.

Water samples were collected from representative water points for chemical analysis. Chemical analyses were conducted for 25 water samples in the central geological survey laboratory.

Table 5.3 Summery of Inventory

Sample Type	Sampled	Not Sampled	Total Inventory
Borehole (BH)	7	0	7
Cold Spring (CS)	11	3	14
DugWell (DW)	4	0	4
River Water (RV)	2	1	3
Rain Water (RW)	1	1	2
Total	25	5	30

5.4.1 Spring

Totally fourteen springs data were collected with varying yield. The springs of the area dominantly are depression and fracture type. Most of them are oozing out from basalt formation at hill side and slope breaks. However, springs were also found at the flat land with considerable amount of discharge for instance Jalissa spring. The springs in the catchment have dry period discharges of 0.1-1 l/s on Basalt and 0.11-12.76 l/s on Ignimbrite. Most of the springs on the flat land are well developed for community use, Jalissa spring (Q=12.76 l/s) with relatively good discharge are used for small scale irrigation schemes.

Plate 5.1 Irrigation scheme at Jalissa spring.

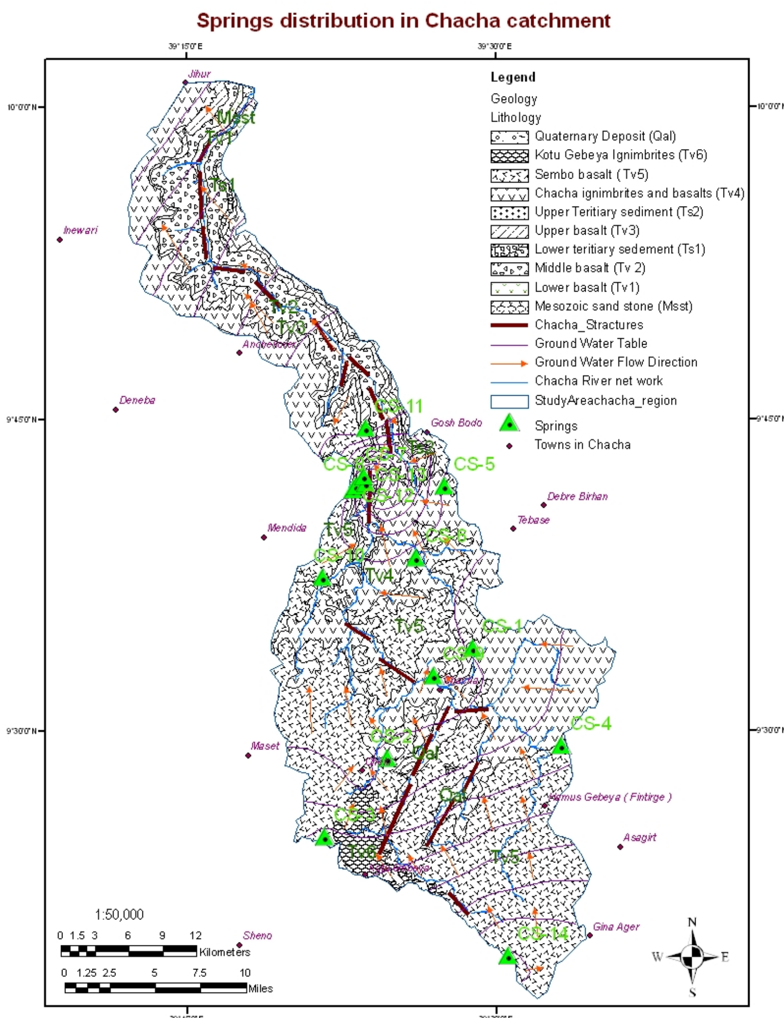


Figure 5.7 Springs distribution in relation with lithology, structures and topography.

5.4.2. Borehole

Most of the boreholes of the study area penetrate through fractured Ignimbrites/Trachyte and Basalts with variable depth. The boreholes have depth range 50-115 m.b.g.s for the ignimbrite (Tv5) shallow wells in average and 80-96 m.b.g.s for the basalt (Tv4) in average deeper well. The static water level (SWL) measurements of BH-3 and BH-5 in the ignimbrite are 13.8 and 51.39 m.b.g.s respectively and BH-7 in Basalt has SWL=6.6 m.b.g.s. All the boreholes are functional and domestic water supply for the towns like Chacha, Cheki, Kotugebeya and Sembo.

The log diagrams of the boreholes with well completion data are presented in annex 3 using GDbase outputs.

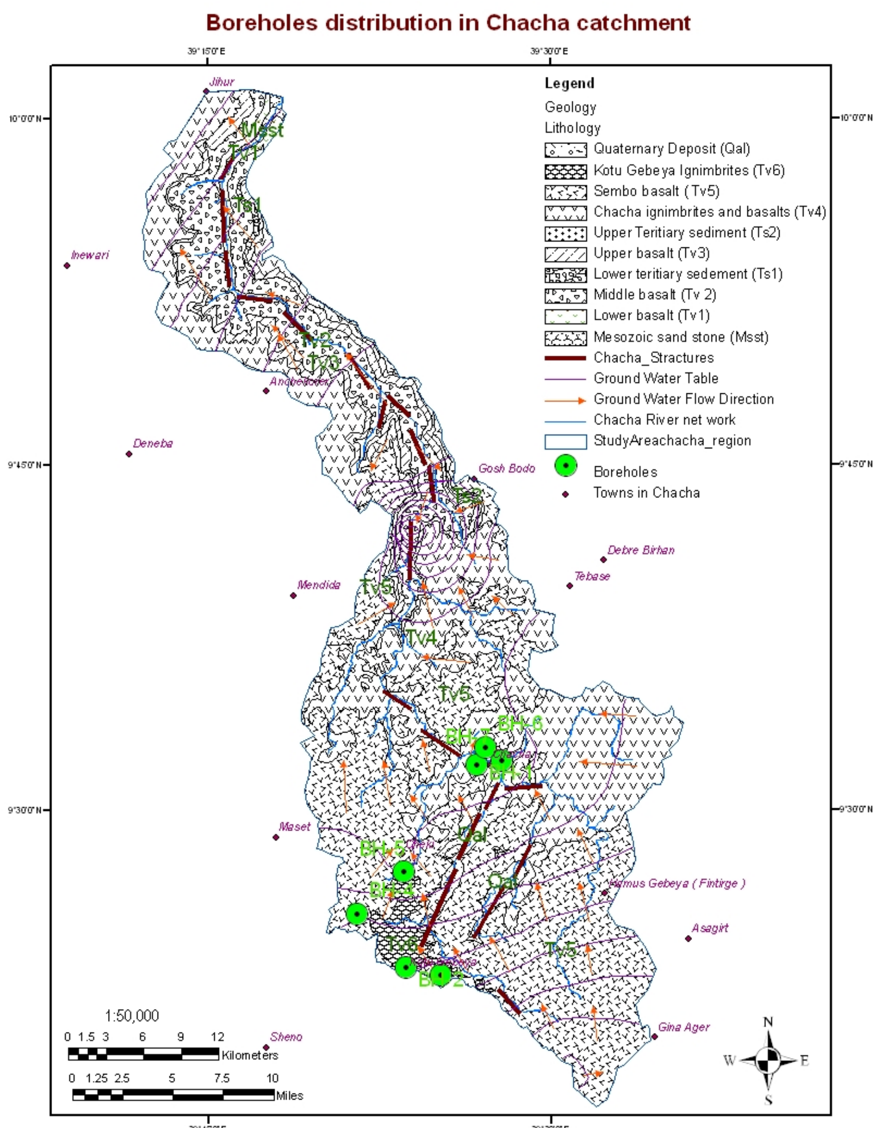


Figure 5.8 Boreholes distribution in relation with lithology, structures and topography.

5.4.3. Dug well

The hand dug wells of the area are sunk on the flat or gently sloping terrain on the recent deposits. Depth of these wells is in the range of 3 to 13.6 m.b.g.s. Most of the wells are not open to measure the static water levels. DW-1 has SWL of 1.5m.b.g.s.

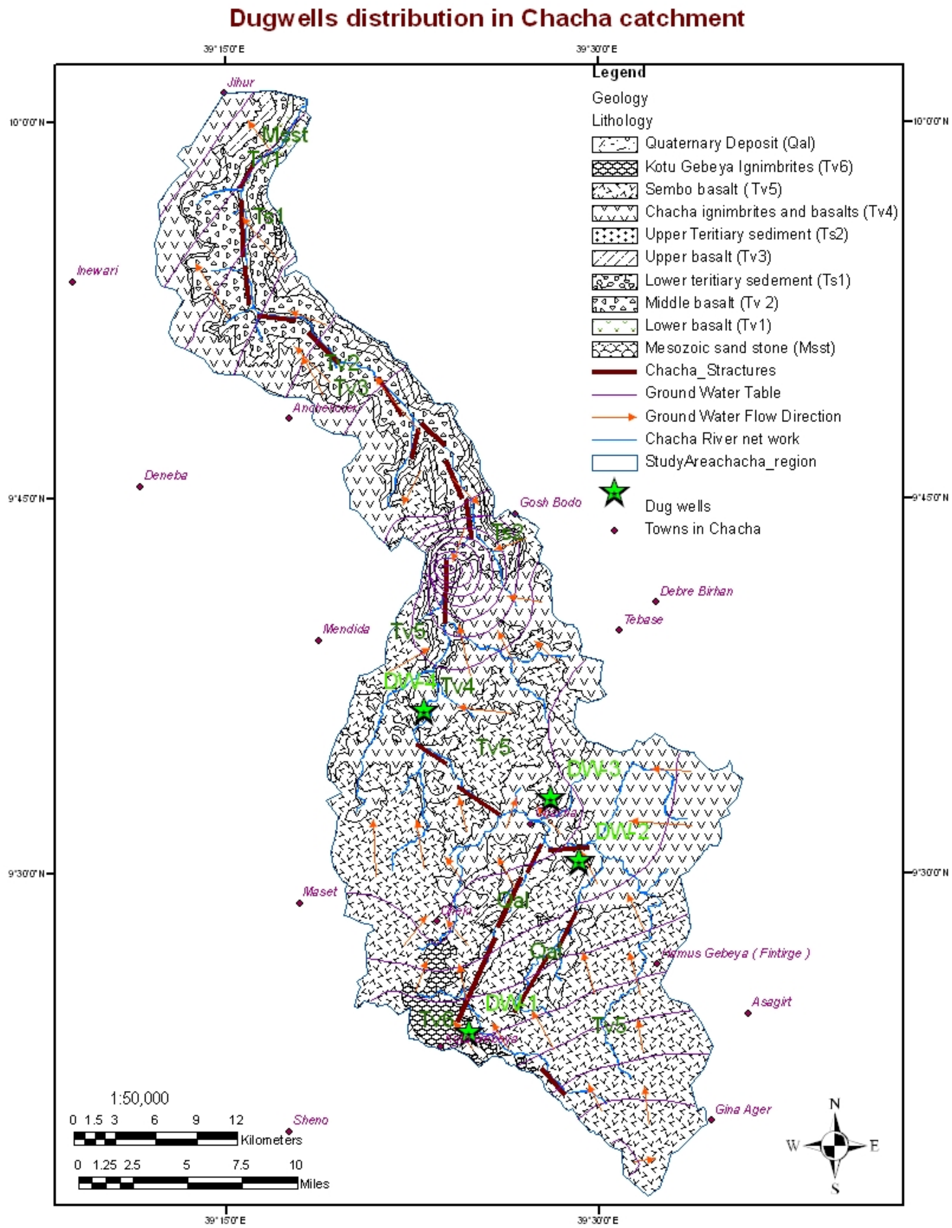


Figure 5.9 Dugwells distribution in relation with lithology, structures and topography.

5.5 GROUNDWATER FLOW, RECHARGE AND DISCHARGE

5.5.1. Groundwater flow

Groundwater flow direction in the study area is mainly controlled by structures and partly by geomorphology. Most of the springs emerge along the trend of NE-SW in the upper catchment and at the crossing of the NE-SW and S-N trends of fault system in the catchment and others emerge at the contact of different lithological units and episode of formation. High gradiant topographic setting, particularly the lower catchment has a great role in directing ground flow direction. Boreholes also aligned along NE-SW fault system in the upper catchment indicating that groundwater flow is mainly structurally controlled here.

Local groundwater flow directions vary from place to place according to local topography and may follow tributary of the drainage basins.

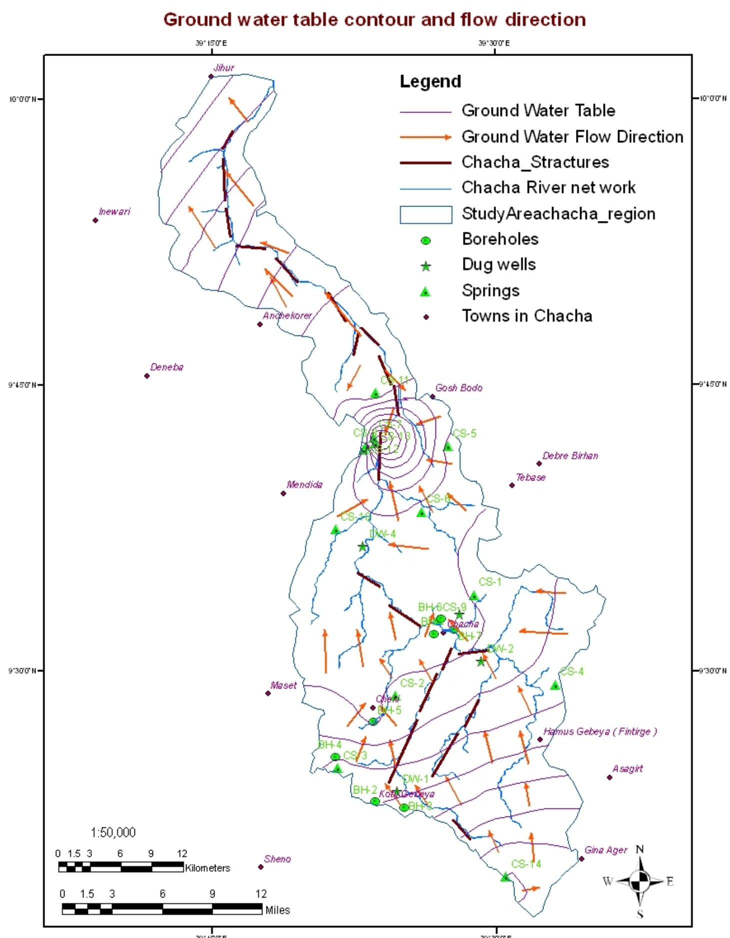


Figure 5.10 Ground water table contour and flow direction in Chacha catchment.

5.5.2. Groundwater recharge

The main source of recharge to groundwater in the area is mainly from rainfall on the plateau and moderately-gently sloping plains. Although the source of recharge is rainwater for most of the area, recharge to the groundwater is also possible along the surface flow of the perennial river Chacha. The possible recharge zone is from the upland plateau and its tributaries of rift related NE structures. The recharging plateau retains rainwater for longer time, creates favorable condition for infiltration through highly weathered, jointed and permeable volcanic layer. Groundwater from aquifers on the plateau is recharging underlying basalts and pyroclastics which outcrop in deep valleys. System of recharge and discharge of aquifers is shown in the following conceptual model.

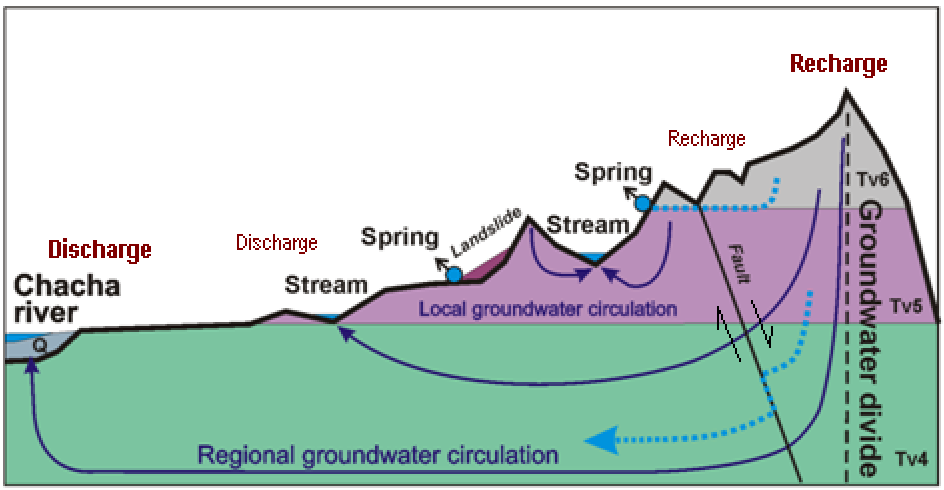


Fig 5.11 Conceptual model of recharge and discharge of aquifers on plateau/upper Chacha Catchment/ (Sectional view).

A seasonal, but significant, amount of recharge to localized aquifers is also possible from most of the intermittent streams. As the flow of many streams in the catchment is controlled by structures, localized aquifers along the structural plains will be recharged by the surface water of streams.

5.5.3. Groundwater discharge

Topographically high areas can generally be considered as recharge areas and topographically low areas can be considered as discharge areas. Since Chacha catchment is structurally, lithologicaly and topographically controlled, ground water discharges occur as springs at the highlands and seepages on the valley and escarpments. Groundwater discharge areas are formed by local moderate depressions in the plateau and steep slopes and escarpments of Chacha Valley, Groundwater discharge also occurs due to topographic breaks, most of the elevated areas are recharge areas to groundwater.

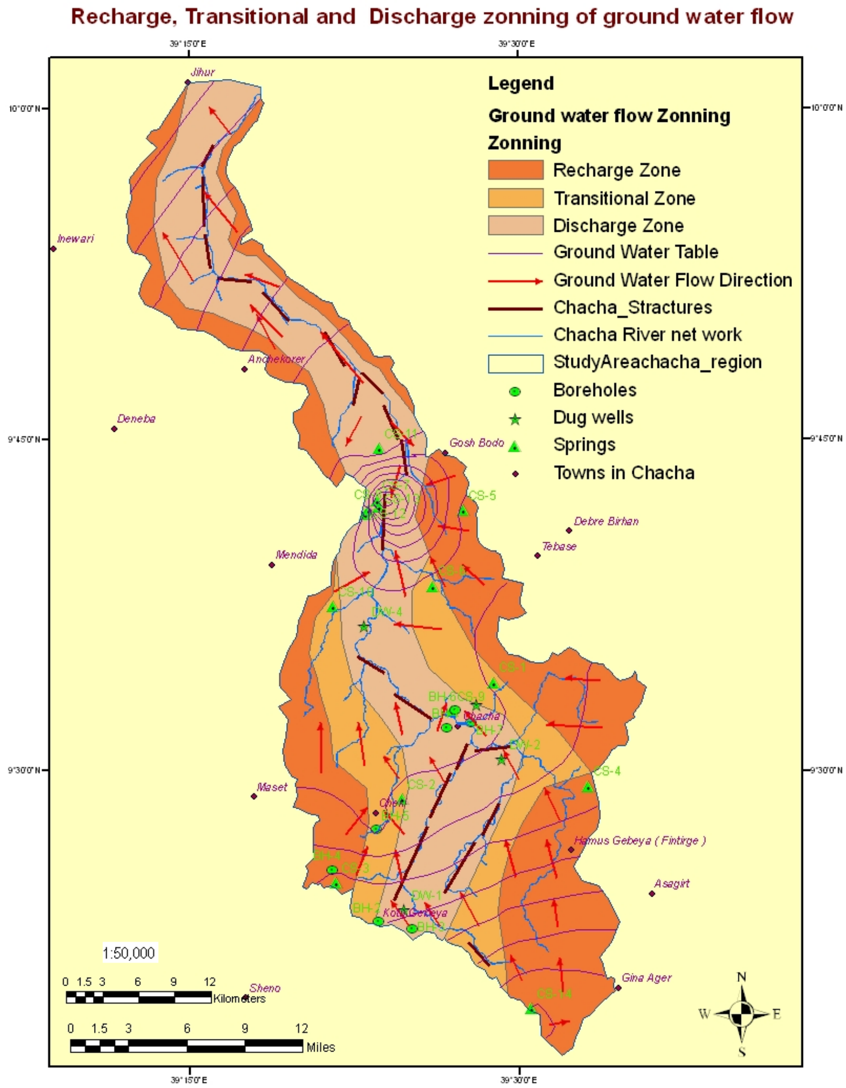


Figure 5.12 Recharge and discharge zoning of Chacha catchment (Planner view).

6 HYDROCHEMISTRY

6.1 GENERAL

Hydrochemistry is an outstanding scientific approach in the field of hydrogeological study to understand hydrochemical processes in ground water systems, and interpret how structural, geological, mineralogical, and hydrological features affect ground water flow and chemistry.

Any of water property fluctuation from the normal has to do with the environmental condition in which it exists. Hydrogeochemistry implies the physicochemical nature of groundwater as it passes through different geological media. Hydrochemical information can be used to interpret the origin and mode of ground water recharge, refine estimates of time scales of recharge and groundwater flow, decipher reactive processes, provide paleo-hydrological information, and calibrate ground water flow models. Hydrochemistry can also assist in understanding the evolution of water quality, to examine natural base line conditions against which human impacts can be recognized and to take a look at some ways in which the protection and management of groundwater resources can be achieved.

Hem (1985) listed out some important points, which governs the physicochemical nature of water these include: Climate, Geological effects, Biochemical factors, Hydrologic cycle, Particulates in the atmosphere, Composition of precipitation and Human impact.

6.2 WATER SAMPLING AND ANALYSIS

One of the major tasks of water point inventory and data collection was to survey the ground water quality of the Chacha catchment. To characterize chemical nature of groundwater representative water samples were collected on the different geological formations of the catchments. A total of twenty five water samples from boreholes, dug wells, springs, river waters and rain water were collected from the study area.

All water samples collected for laboratory examination were submitted to the Central Laboratory of the Geological Survey and analyzed for chemical composition. Chemical analysis of major constituents (Mg, Ca, Na, HCO_3, SO_4, and Cl) and secondary constituents (K, NO_3, F, HBO_2, CO_2, and SiO2), electrical conductivity (EC) and pH at room temperature were measured in the laboratory (Annex 2). Field measurements of pH, temperature and electrical conductivity were made at the time of sampling (Annex 1).

The hydrochemical results were analyzed and graphically presented to facilitate visualization of the water type and their relationship. Water types are classified using the software Aquachem 4.0 and the suitability of ground water for different purposes is assessed based on their quality standards.

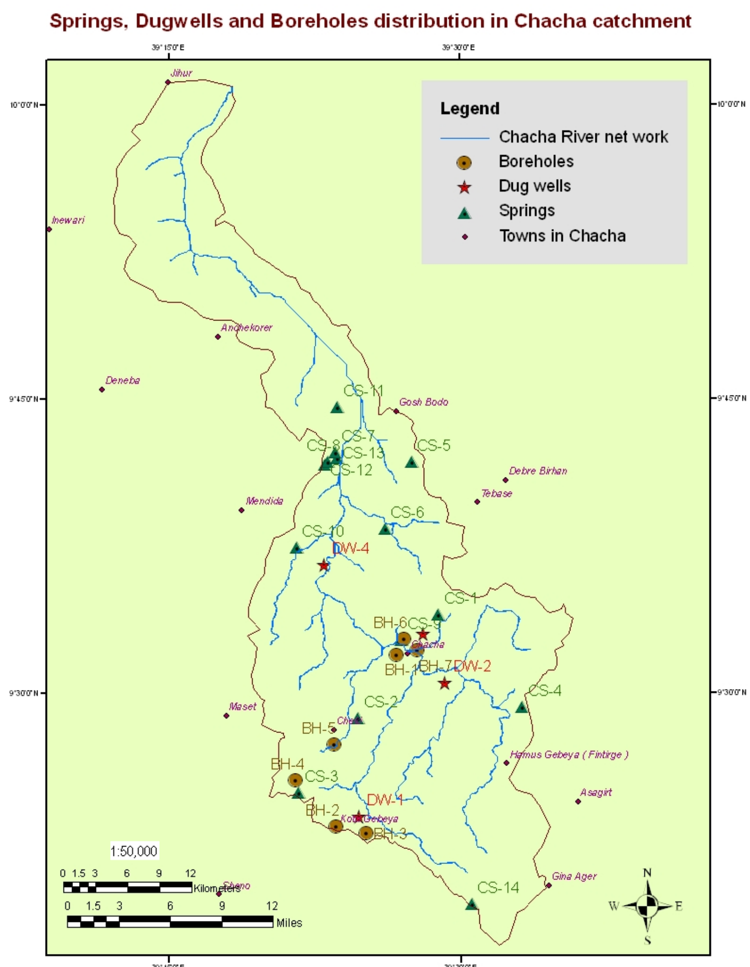


Figure 6.1 Ground water points sampling location and distribution.

6.3 CLASSIFICATION AND GRAPHICAL PRESENTATION OF NATURAL WATERS

The spatial variability observed in the composition of the major ions (as natural tracers) can provide insight in to aquifer heterogeneity and connectivity as well as the physical and chemical processes controlling water chemistry. Accordingly, classification of natural waters in the area is made on the basis of laboratory results of major cations and anions. For an easy classification of water types, the percentage of major cations and anions of the analyzed samples are plotted on different diagrams. The diagrams provide different approaches for the analysis of the water samples in the catchment.

Based on Aquachem software results, the dominant water type of the study area is bicarbonate type (Table 6.1). The bicarbonate type of groundwater indicates a fast hydrogeological regime of an area receiving a relatively high amount of rainfall where groundwater is flowing in lithologicaly homogeneous aquifers.

Table 6.1 Hydrochemical types of individual Anions and cations and water classification based on Anions.

Anion	Water type	Cation	Cold springs	Boreholes	Dugwells	River water	Rain water
Bicarbonate ($HCO3^-$)	**CaHCO3**	**Ca**	Sp-1,Sp-2,Sp-4, Sp-9	BH-1,BH-2,BH-3	DW-1,DW-2,DW-3,DW-4	Rv-1	
	Ca-MgHCO3	**Ca-Mg**	Sp-3,Sp-5,Sp-7, Sp-8, Sp-10,Sp-11	BH-4,BH-5,BH-6		Rv-2	
	Ca-NaHCO3	**Ca-Na**		BH-7			
Bicarbonate nitrate (HCO3-NO3)	**Ca-MgHCO3-NO3**	**Ca-Mg**	Sp-6				
chloride nitrate	**Na-Mg-Cl-NO3**	**Na-Mg**					RW

Graphical presentations

Most of the graphical methods are designed to simultaneously represent the total dissolved solid concentration and the relative proportions of certain major ionic species (Hem, 989) and all the graphical methods use a limited number of parameters of the laboratory major anion and cation results.

Piper diagram

Piper diagram scheme for classification of samples of natural waters are shown below. The diagrams display the relative concentrations of the major cations and anions on two separate tri-linear plots, together with a central diamond plot where the points from the two tri-linear plots are projected. The central diamond-shaped field (quadrilateral field) is used to show overall chemical character of the water (Hill, 1940; Piper, 1944).

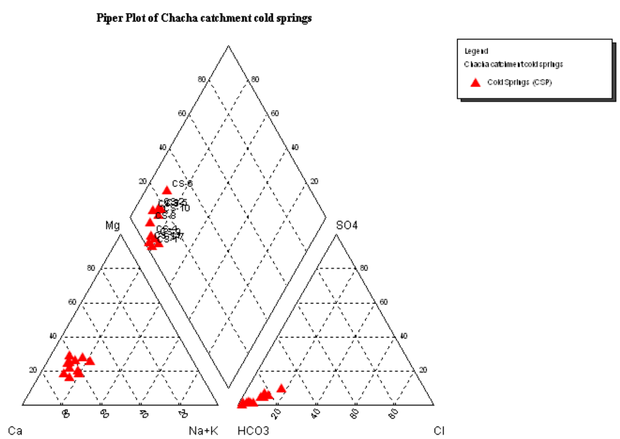


Figure 6.2 Piper Plot of Spring water

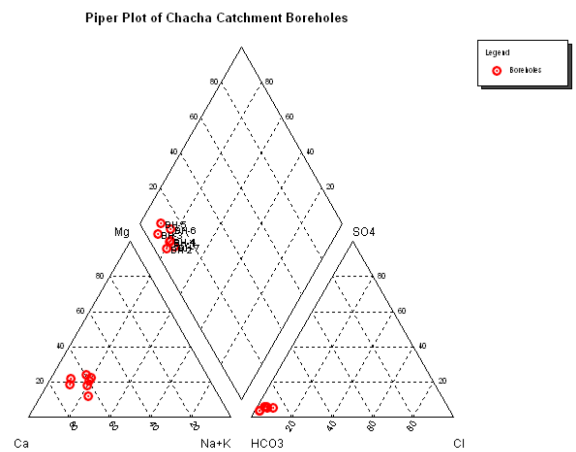


Figure 6.3 Piper Plot of Borehole water

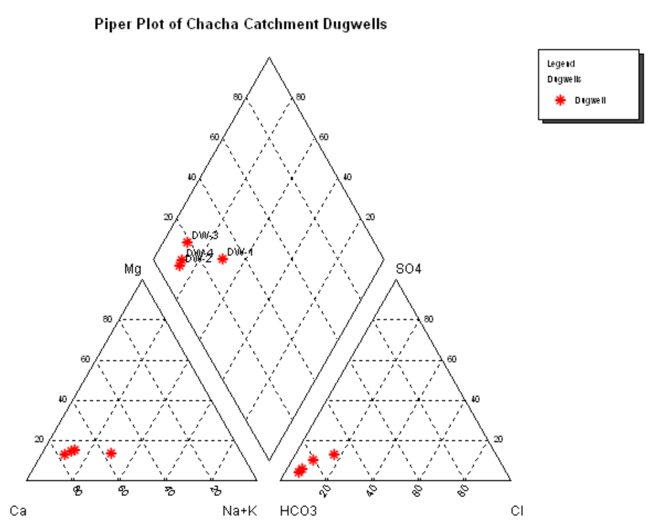


Figure 6.4 Piper Plot of Dugwell water

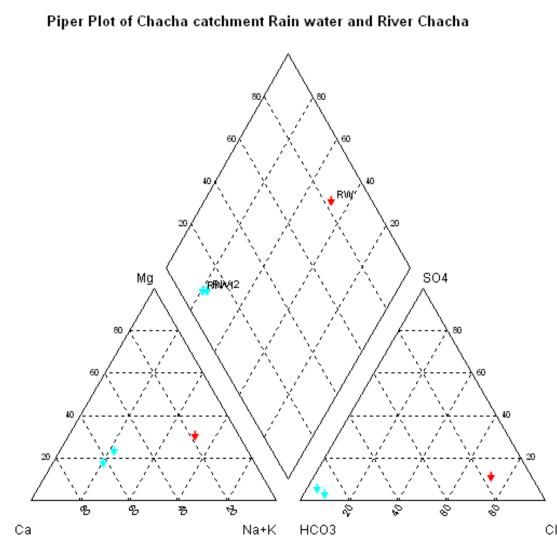


Figure 6.5 Piper Plot of Rain and River water

Schoeller semi-logarithmic diagram

The Schoeller diagram shows the total concentration of major ions in log-scale, and it allows the major ions of many samples to be represented on a single graph, in which samples with similar patterns can be pointed out easily.

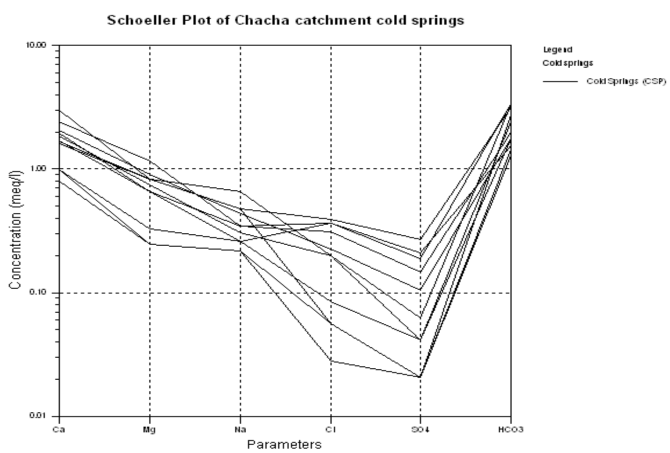


Figure 6.6 Schoeller diagram of spring water

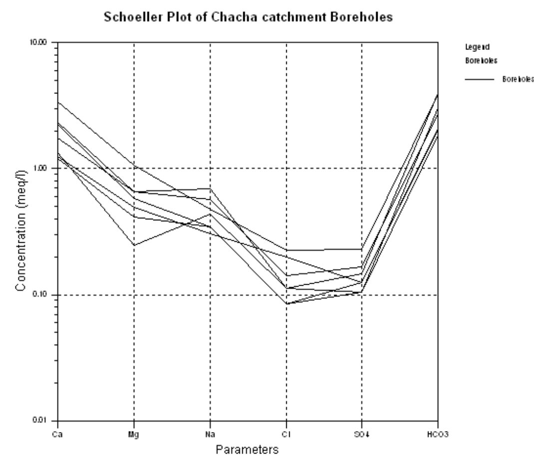


Figure 6.7 Schoeller diagram of Borehole water

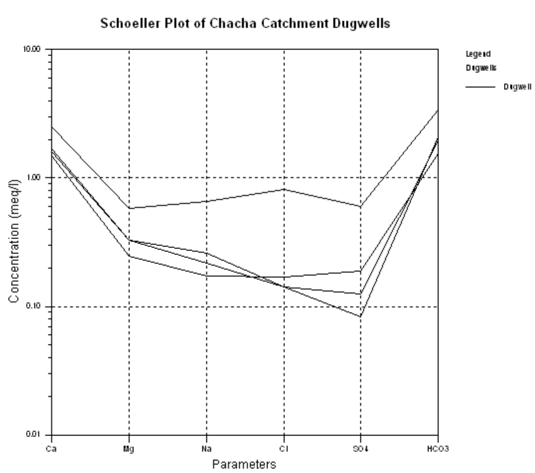


Figure 6.8 Schoeller diagram of Dugwell

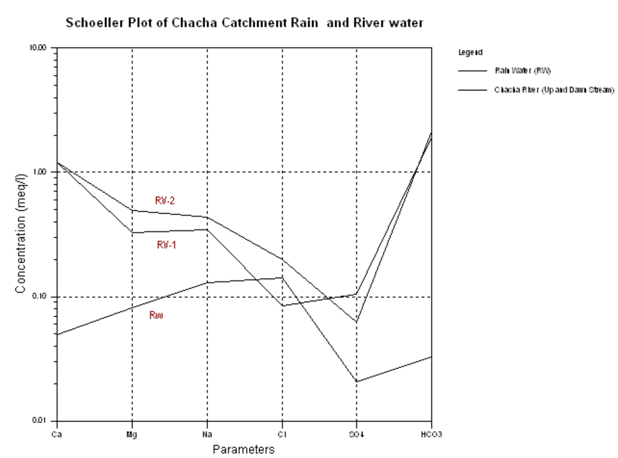


Figure 6.9 Schoeller diagram of Rain and River

6.3.1 Hydrochemistry of rain water

Hydrochemistry of rainwater of the area is not known in detail; however, analysis of one rainwater sample from Sela Dingay area has been done. The hydrochemistry is shown in sample summery Report of Aquachem soft ware Table 6.2.The chemistry is typical for rainwater.

Table 6.2 Rain water sample summary of report

Sample Summary Report

Sample ID					
Sample Date					
Station	RW				
Location					
Geology					
Watertype	Na-Mg-Cl-NO3				
Temperature (°C)					
pH	5.36				
Conductivity	30.00 uS/cm				
Sum of Anions	0.29 meq/L				
Sum of Cations	0.28 meq/L				
Balance	-3.04 %				
Total dissolved solids	34.06 mg/L				
Total hardness	6.62 mg/l CaCO3				
Alkalinity	1.63 mg/l CaCO3				
Major ion composition	mg/l	mmol/l	meq/l		
Na	3.00	0.13	0.13		
K	0.50	0.013	0.013		
Ca	1.00	0.02	0.05		
Mg	1.00	0.04	0.08		
Cl	5.00	0.14	0.14		
SO4	1.00	0.01	0.02		
NO3	7.53	0.10	0.10		
HCO3	2.00	0.03	0.03		
Ratios			Comparison to Seawater		
	mg/l	mmol/l	mg/l	mmol/l	
Ca/Mg	1.00	0.61	0.319	0.194	
Ca/SO4	1.00	2.40	0.152	0.364	
Na/Cl	0.60	0.93	0.556	0.858	
Cl/Br			287	648	

DESCRIPTION:		
Company Logo	PROJECT:	PROJECT NO:
	CLIENT:	DATE:

6.3.2 Hydrochemistry of Surface water

Two surface water samples were sampled from upstream and downstream of Chacha Rivers. The chemical analysis made for the two samples show that Rv-1 (Chacha upstream) and Rv-2 (Chacha downstream) are bi-carbonate type of water with $Ca\text{-}HCO_3$ and $Ca\text{-}Mg\text{-}HCO_3$ chemical formulation respectively. The TDS of the surface water samples Rv-1 and Rv-2 are 250.9 mg/L and 262.86 mg/L respectively.

Table 6.3 Chacha upstream (Rv-1) water sample summary report

Sample Summary Report

Sample ID		
Sample Date		
Station	RV-1	
Location		
Geology		
Watertype	Ca-HCO3	
Temperature (°C)		
pH	7.69	
Conductivity	183.00	uS/cm
Sum of Anions	2.13	meq/L
Sum of Cations	1.92	meq/L
Balance	-4.98	%
Total dissolved solids	250.90	mg/L
Total hardness	76.41	mg/l CaCO3
Alkalinity	95.14	mg/l CaCO3

Major ion composition	mg/l	mmol/l	meq/l
Na	8.00	0.35	0.35
K	1.90	0.049	0.049
Ca	24.00	0.60	1.20
Mg	4.00	0.16	0.33
Cl	3.00	0.08	0.08
SO4	5.00	0.05	0.10
NO3	0.44	0.01	0.01
HCO3	116.00	1.90	1.90

Ratios			Comparison to Seawater	
	mg/l	mmol/l	mg/l	mmol/l
Ca/Mg	6.00	3.64	0.319	0.194
Ca/SO4	4.80	11.50	0.152	0.364
Na/Cl	2.67	4.11	0.556	0.858
Cl/Br			287	648

DESCRIPTION:		
Company Logo	PROJECT:	PROJECT NO:
	CLIENT:	DATE:

Table 6.4 Chacha downstream (Rv-2) water sample summary report

Sample Summary Report

Sample ID				
Sample Date				
Station	RV-2			
Location				
Geology				
Watertype	Ca-Mg-HCO3			
Temperature (°C)				
pH	8.16			
Conductivity	238.00 uS/cm			
Sum of Anions	2.40 meq/L			
Sum of Cations	2.18 meq/L			
Balance	-4.90 %			
Total dissolved solids	262.86 mg/L			
Total hardness	84.65 mg/l CaCO3			
Alkalinity	105.80 mg/l CaCO3			
Major ion composition	mg/l	mmol/l	meq/l	
Na	10.00	0.43	0.43	
K	2.00	0.051	0.051	
Ca	24.00	0.60	1.20	
Mg	6.00	0.25	0.49	
Cl	7.00	0.20	0.20	
SO4	3.00	0.03	0.06	
NO3	0.44	0.01	0.01	
HCO3	129.00	2.11	2.11	
Ratios			Comparison to Seawater	
	mg/l	mmol/l	mg/l	mmol/l
Ca/Mg	4.00	2.43	0.319	0.194
Ca/SO4	8.00	19.16	0.152	0.364
Na/Cl	1.43	2.20	0.556	0.858
Cl/Br			287	648

DESCRIPTION:		
Company Logo	PROJECT:	PROJECT NO:
	CLIENT:	DATE:

6.3.3 Groundwater in volcanic rocks

Rain water infiltrates in outcrops of volcanic rocks and flows within aquifers from recharge areas into discharge areas in shallow and deep valleys. Groundwater dissolves minerals of volcanic rocks along its flow and is enriched by various chemical compounds. Volcanic rocks forming aquifers in the catchment Chacha are represented by various types of basalts and ignimbrites. Dominant water type of these volcanic rocks is pure Ca-HCO_3 type with few Ca-Mg forms the second cation within the bi-carbonate type. Sp-6 has bi-carbonate nitrate (HCO_3-NO_3) type that can be due to nitrate contamination by human and/or animal wastes in the area.

In the catchment, there are no significant differences in groundwater types related either to basalt or to ignimbrite. Similarities in distribution to most of compounds confirm uniformity of chemical types. Groundwater in ignimbritehas slightly higher content of dissolved solids (TDS) and some chemical compounds. Slightly higher content of dissolved solids can be related to higher porosity of some parts of ignimbrite and higher vitreous constituent. Groundwater from basalt has higher content of alkali earths.

6.3.4 Groundwater in sedimentary rocks

No water point is taken from sandstone but groundwater chemistry of the aquifer is understood from regional hydrogeochemical evolution. There is an idea that ionic genetic ratios (Na/SiO_2, Na/Cl) of ground water from the sand stone aquifer are similar to the aquifer of volcanic rocks indicating that groundwater from aquifers in volcanic rocks penetrate to the depth and recharge aquifer in sedimentary rocks.

6.4 WATER QUALITY

To assess the suitability of water for drinking purposes results of chemical analyses were compared with Ethiopian standards for drinking water published in Negarit Gazeta No. 12/1990 and The Guidelines of Ministry of Water Resources (MoWR, 2002) Table 6.5.

Table 6.5 Ground water Chemistry compared with drinking water quality

Property	Ethiopian standards (1) and MoWR Guide lines (2) (mg/l)		Chacha catchment (mg/l)	
	Highest desirable level	Maximum permissible level	Range	Number of exceeding values
Na(2)	358	358	3-16	none
Ca(1)	75	200	1-68	none
Cl(1)	200	600	1-29	none
Cl(2)	533	533	1-29	none
B(2)(HBO2)	0.3	0.3	0.16-5.51	23
Dissolved free Ammonia	0.05	0.1		Not analyzed
Fe(1)	0.1	1		Not analyzed
Fe(2)	0.4	0.4		Not analyzed
Mg(2)	50	150	1-14	none
Mn(1)	0.05	0.5		Not analyzed
Mn(2)	0.5	0.5		Not analyzed
SO_4^{-2}(1)	200	400	1-29	none
SO_4^{-2}(2)	483	483	1-29	none
TDS	500	1500	34-540.53	1
Total hardness CaCO3 (1)	100	500		Not analyzed
Total hardness CaCO3(2)	392	392		Not analyzed
pH(1)	7-8.5	6.5-9.2	5.36-8.16	3
pH(2)	6.5-8.5	6.5-8.5	5.36-8.16	1
$NO3^{-1}$(1)	10	45	0.44-43.9	none
$NO3^{-1}$(2)	50	50	0.44-43.9	none
F(1)	1	1.5	0.03-1.21	1
F(2)	3	3	0.03-1.21	none

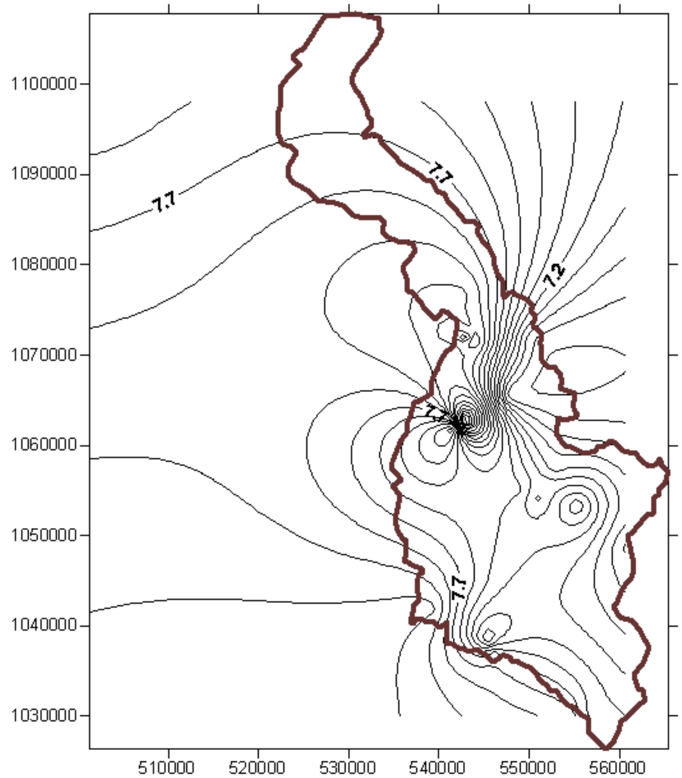


Figure 6.10 pH distribution map of the Chacha catchment.

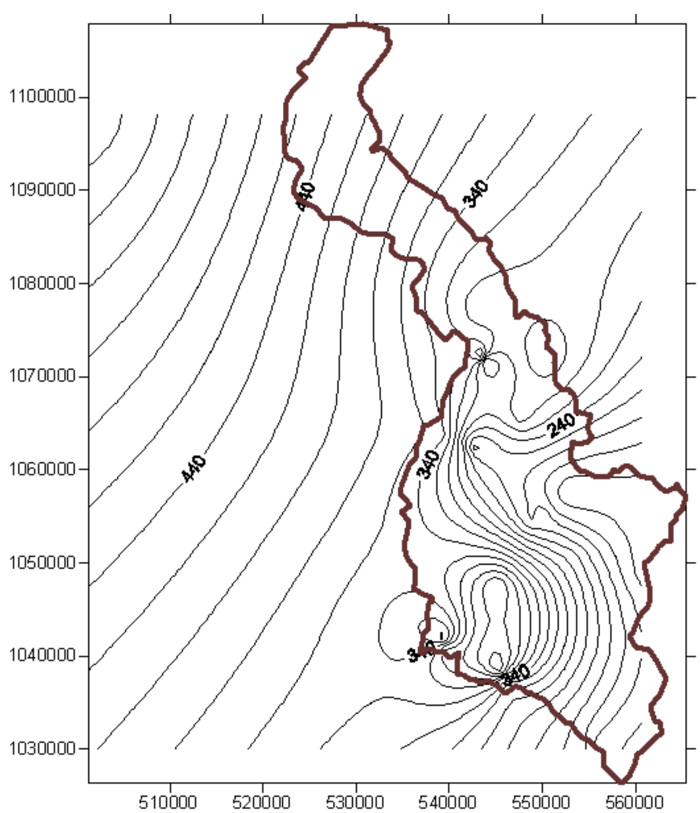


Figure 6.11 EC distribution map of the Chacha catchment.

6.4.1 Domestic use

In general Physical property of ground waters from most springs, boreholes and dugwells are colorless, odorless and tasteless, pH of the ground water ranges between 5.36 and 8.16. Temperature varies from 14^0Cto 24^0C. Although all samples show nitrate content below the threshold, water samples from CS-2, CS-5 and CS-6 shows relatively higher nitrate content with values of 42.1, 43.4 and 43.9 mg/l respectively. High content of nitrate might be due to mixing of sewerage, animal waste and agricultural chemicals to ground water. The rainwater sample RW is acidic with pH 5.36, the rest of the waters in the area are with in the permissible limit for drinking purpose. Only DW-1 has TDS greater than the permissible limit of drinking. Fluoride (F) maximum permissible concentration limit is 3 mg/l, set according to health criteria. The maximum fluoride concentration found in the area is 1.21 mg/l.

6.4.2 Irrigation use

Agriculture standards of groundwater quality used irrigation purpose is determined based on sodium Adsorption ratio (SAR), total dissolved solids and American salinity criteria (USSC). To study the suitability of groundwater for irrigation purposes the use of sodium Adsorption ratio (SAR) is used. It is defined by SAR = Na/√ [(Ca+Mg)/2] where all concentrations are expressed in mg/l.

All of water samples from the study area are found to be suitable for irrigation since all waters show the SAR value below 5.9, which is within the excellent range of water quality for agricultural purpose.

Table 6.6 Suitability of water for irrigation SAR values

Value of SAR	Water class	Number of studied cases
SAR<10	Excellent	75
10-18	Good	1
18-26	Fair	0
>26	Poor	0

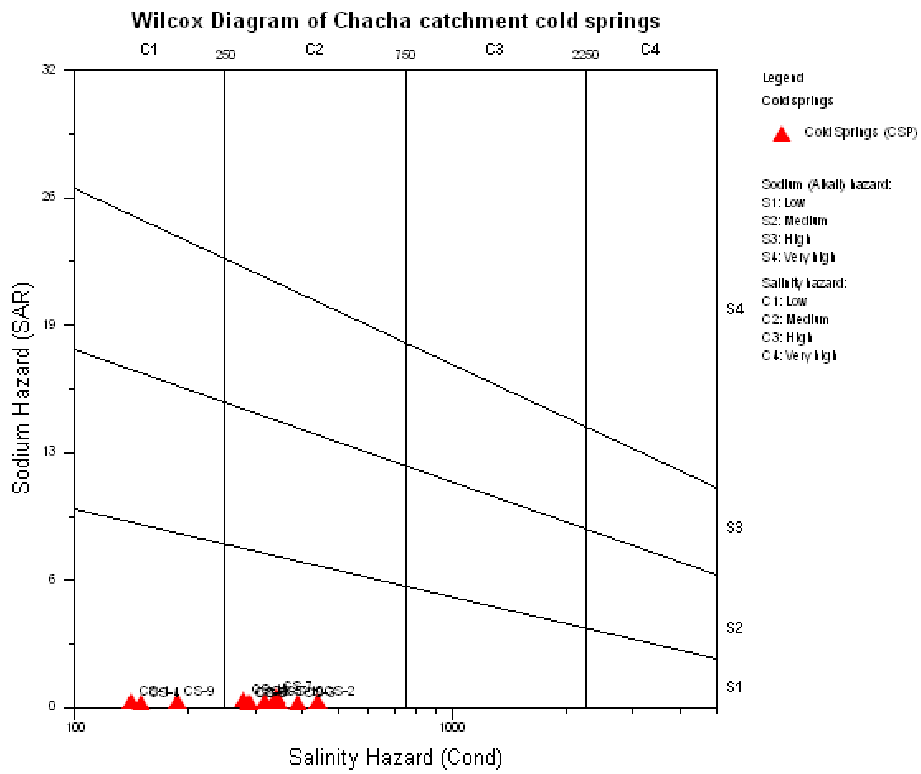


Figure 6.12 SAR and Salinity Hazard of springs

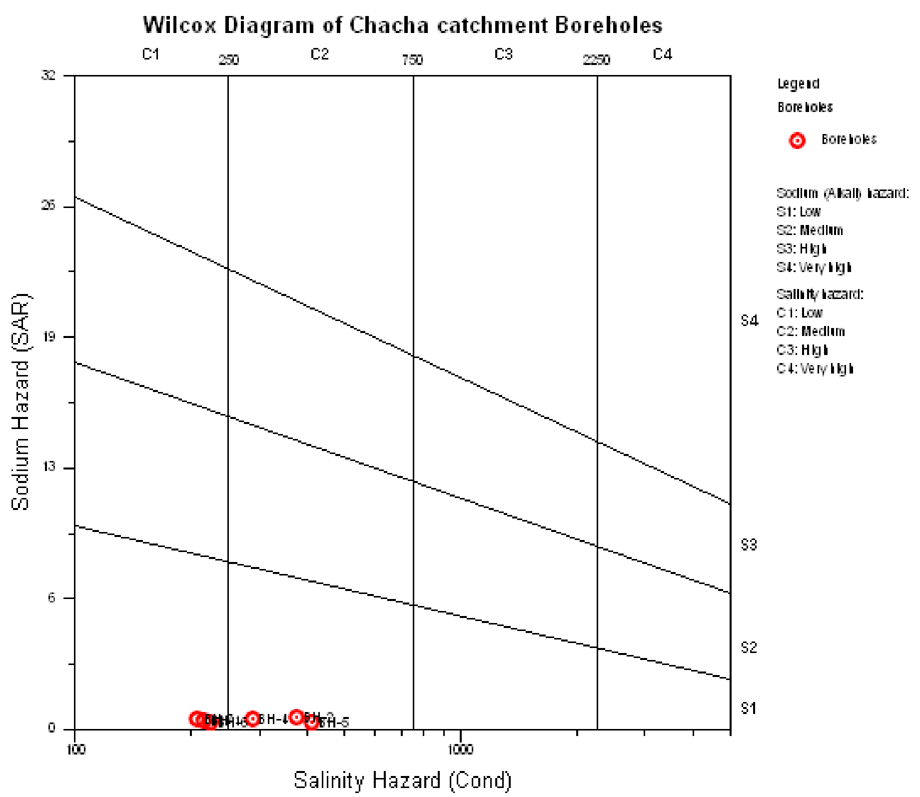


Figure 6.13 SAR and Salinity Hazard of Boreholes

7. CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

The study area is the Chacha catchment of Chacha river shade at the central dissected highland of Ethiopia which covers an area of 1194 sq.Km and geographically bounded by 39°00’E to 39°45’E longitudes and 9°15’N to 10°15’N latitude and with in 520000m - 565000m easting and 1025000m - 1110000m 37N UTM. There is a considerable elevation difference in the Chacha catchment ranging from 700-3500 m.a.s.l with an average elevation of 2728m with a physiographic zoning of Chacha River Gorge, central flat plain and gentle slopes and highlands.

The catchment gets 939mm of annual mean rainfall and 13-15.6 °c average annual temperature. Rainfall amount vary with altitude, direction of moisture bearing wind and physiographical setting of the area. The area has two rainfall regime (bimodal rainfall characteristics) that is small rain (Bulg season) in the month of March, April and June and big rain (Kiremt season) in the month of July, August and September. From the available meteorological data, potential evapotranspiration(PET) is calculated using Thornthwaite and penman combined method and the results are 678mm/yr and 1141mm/yr respectively and representative catchment’s PET is assumed to be 1141 mm/yr. Lower monthly potential evapotranspiration is occurred in the months of July and August because of high humidity in the atmosphere, lower wind speed and lower daily sunshine hours due to cloudiness while higher potential evapotranspiration in the month of may due to lower humidity in the atmosphere, higher wind speed and higher daily sunshine hours.

The lithological units exposed in the study area mainly include Tertiary volcanic succession, with minor mappable Tertiary sediments, Mesozoic sandstone and superficial deposits. Based on texture, compositional variation and relative stratigraphic position the rocks that are found in the area are divided in to ten major mappable units. These are, from older to younger, Mesozoic sandstone, Lower basalt, Middle basalt, Lower Tertiary sediment, Upper basalt, Upper Tertiary sediment, Chacha ignimbrites and basalts, Sembo basalts, Kotu Gebeya ignimbrites and Quaternary deposit. The main structures such as joints, fractures, and normal faults, are all related to the extensional rift tectonics in the area and show a general tread of NE-SW and N-S.

Fractured tertiary volcanic rocks which form the discontinuous aquifer on the plain /upper catchment/ are the main aquifer, the fissured aquifer exposed at the face of the deeply dissected valleys /lower catchment/ even though having similar composition with the tertiary volcanics on the plateau are classified as low productivity aquifer due to their limited recharge and storage. Some drilling data from study area shows the important contribution of permeable Tertiary sediments upon yield of wells hence the aquifers with the mixture of sediments and volcanic are classified as mixed type of aquifers. Alluvial and Colluvial sediments, Tertiary volcanics and Mesozoic sandstone form the porous aquifer with uneven distribution in the study area. Groundwater flow direction in the study area is mainly controlled by structures and geomorphology. Rain water infiltrates in outcrops of volcanic rocks and flows within aquifers from recharge areas into discharge areas in shallow and deep circulation.

In the catchment, there are no significant differences in groundwater types. Similarities in distribution to most of compounds confirm uniformity of chemical types. 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 spatial variation within the catchment. Dominant water type in the area is Ca-HCO_3 type with few Ca-Mg forms the second cation within the bi-carbonate type. These water types show high land water behavior. Sp-6 has bi-carbonate nitrate (HCO_3-NO_3) type that can be due to nitrate contamination by human and/or animal wastes in the area. All water samples are fresh water (TDS =34-453 mg/l) except DW-1 with TDS=541 mg/l beyond the permissible level of drinking water. Although all samples show nitrate content below the threshold, water samples from CS-2, CS-5 and CS-6 shows relatively higher nitrate content with values of 42.1, 43.4 and 43.9 mg/l respectively. High content of nitrate might be due to mixing of sewerage, animal waste and agricultural chemicals to ground water. The rainwater sample RW is acidic with pH 5.36, the rest of the waters in the area are with in the permissible limit for drinking purpose. All of water samples from the study area are found to be suitable for irrigation.

7.2 RECOMMENDATION

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

• Generally, the recommended methods for groundwater developments for village water supply are sinking dugwells and shallow wells not more than 60m depth on the plateau and valleys and developing the numerous springs on the flat plain and escarpments of the deep gorges. Drilled wells in the range of 100-150m are recommended for town water supply schemes.

• As there is groundwater pollution potential of shallow aquifers especially in the shallow wells hence, precautions must be made so as not to further pollute the resource.

• 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 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. Development activity as well as protective measures are the same as it was disused for fissured aquifer in volcanic rocks.

• Existing groundwater data handling system is poor in most of regional offices; hence centralized database system should be implemented.

• The area has enormous surface water and ground water resources. Very little has been done in the field of development of the water resources, particularly in areas of groundwater. Groundwater utilization has been limited to community water supply using shallow hand dug wells and unprotected springs. Limited deep boreholes were drilled in few rural areas. The use of deep ground water from boreholes for agriculture is almost non-existent. There is also an increasing demand for water supply, irrigation and hydroelectric power development in the area.

REFERENCES

Anteneh Girma, 1994, Hydrogeology of Akaki Area, MSc thesis, Addis Ababa University, Addis Ababa.

Atlas of Ethiopia, (1988), National Atlas of Ethiopia. First. ed. Ethiopian Mapping Agency.

Berhanu Gizaw, (2002), Hydro chemical and Environmental Investigation of the Addis Ababa region, Ethiopia, PhD Thesis.

Beza T. and G/Giorgis T. (1992) Environmental Protection Planning in the Context of Urban Development Planning in Ethiopia.

Carla W. Montgomery, (2000), Environmental Geology, 5th Edition, Mc Garw-Hill Higher Education, USA.

CSA, 2005. Statistical Abstract. Central Statistical Authority, Addis Ababa, Ethiopia.

Daniel Gemechu. (1974). Aspects of Climate and Water Budget in Ethiopia. AAU Press, Addis Ababa, 71pp.

Davis N.S., and and DeWiest J.M.R., 1966. Hydrogeology. John Wiley Sons, New York, 463pp**.**

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

Doneen, L.D. and Westcot, L.D.,1984. Irrigation practice and water management. Irrigation and drainage paper, 1 Rev.1 63pp

Doorenbos, J & Kassam, A.H., 1979. Crop water requirement, FAO Irrigation and Drainage paper 33,

Driscoll F.G. (1989). Ground Water and Wells. Johnson Filtration Systems Inc. St. Paul, Minnesota, USA, 2nd ed.

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

FAO/UNESCO, 1973. Irrigation, Drainage and salinity. An international source book. Hutchinson, London, 510p.

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

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

Glynn P.D., Plummer L., N. (2005). Geochemistry and the Understanding of Groundwater Systems: U.S. Geological Survey, Hydrogeology J. 13:263-287, Springer Verlag.

Houghton D.D. (ed), 1985. Handbook of applied meteorology. John Wiley & Sons, 1461pp.

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

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

Kazmin V. (1979). Stratigraphy and correlation of volcanic rocks in Ethiopia.

Kumar C.P., 2004. Groundwater assessment methodology. National Institute of Hydrology, India, 21pp.

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

Malin, F., and Tom C.,1989. Comparative hydrology. UNESCO, Paris, 479pp

Mohr, P.A., 1962. The Geology of Ethiopia. Addis Ababa press, Addis Ababa, 268pp.

Shaw, E.M., 1994. Hydrology in practice. Third edition, Chapman and Hall, New York, 539pp.

Sileshi Mamo (2004), Guidelines to hydrogeological investigation. Geological Survey of Ethiopia, Addis Ababa. (unpublished).

Sileshi Mamo (2006), Hydrogeological and hydrogeochemical standards. Geological Survey of Ethiopia, Addis Ababa. (unpublished) .

Tenalem Ayenew and Tamiru Alemayhu, 2001. Principle of hydrogeology. Department of geology and geophysics, Addis Ababa University, 125pp.

WMO, 1994. Guide to hydrological practices. Fifth edition, WMO No 168, 735pp.

Wright, C.E(ed), 1980. Surface water and groundwater interaction. UNESCO- Studies and reports in hydrology, No 29 , 129pp

Viale Delle Jerme Di Caracalla, (2006), Crops And Drops, Making The Best Use Of Water For Agriculture, FAO Of The United Nations, Rome.

Yohannis G. Eyesus et al, 2001, Initial National Communication of Ethiopia to the United Nations Framework Convention on Climate change (UNFCCC). National Meteorologic Service Agency. Addis Ababa, Ethiopia, pp 113.

Zenettin, B. and Justin Visenntine, E., 1974. The Volcanic succession in central Ethiopia, the volcanics of west Afar and Ethiopian Rift Margins. Memorie degli Istuti di geologiae dell Universita di podova V.31, P. 1-19

ANNEX

ANNEX 1 INVENTORY FORMS

ANNEX 2 HYDROCHEMISTRY DATA

ANNEX 3 BOREHOLE LOGS