ADDISABEBA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SCIENCES

WATER RESOURCE POTENTIAL EVALUATION OF BERGA RIVER CATCHMENT, WEST SHEWA ZONE, OROMIYA REGIONAL STATE

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A THESIS SUBMITED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABEBA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTERS IN HYDROGEOLOGY

BY
HUSSEN ENDRE
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ABSTRACT

Berga river catchment is located in west part of Addis Abeba with SW to NE stretch of $8^0$57'58" N to $9^0$18'35" N latitude and $38^0$20'49" E to $38^0$29'33" E longitude. It is a sub-catchment of Awash basin, found at water divide of Awash and Abbay drainage basins. It has a total area of 303km^2.

The study area is characterized by irregular undulated physiographic features. The main rocks in the catchment are basalt, ignimbrite, trachytes/rhyolites and alluvial deposits.

From long term mean monthly meteorological data, the catchment has 1119.26mm, 898.68mm, and 664.25mm annual rain fall, potential evapotranspiration and actual evapotranspiration respectively. The estimated annual relative humidity, wind speed at 2m above the ground, sunshine hour, and temperature range are 64.4%, 1.64m/s, 6.5hr/day, and 14.05—16.73^{O}c respectively. 92.73 million Cubic meter water leaves the catchment annually in the form of river flow (runoff).

The main aquifer in the catchment is weathered and fractured basalt. From borehole log, and field observation of hand dug wells and springs, in low land parts of Berga river catchment 3—15m depth is potential for hand dug well(except at Kimoye site) and shallow groundwater. This area is also potential for borehole with maximum depth of 150m. At present, the most available water source in the catchment is springs and streams. Ignimbrite, rhyolite/trachyte are aquifers with moderate to low ground water potential zone. 82.71mm water is used to recharge groundwater reservoir annually.

Ground water is generally a localized flow system controlled by topography and geology. Water in the catchment is mainly of Ca-Mg-HCO_3 and Ca-Na- HCO3 type. Almost all water in the study area are hard to very hard and TDS is generally below

480mg/l. the sum of Ca^{2+} and Mg^{2+} is grater than the sum of Na^{+} and K^{+} in all water sources.

All water in the catchment is fresh which is suitable for almost all purposes. Almost all parameters are with in the limits of acceptable values of WHO and Ethiopian water quality standard/guide line except some hand dug wells showing bacterial pollution.

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CHAPTER ONE: INTRODUCTION

1.1. Back ground

Water is the most abundant substance on earth. It is the principal component of all living things & a major force constantly shaping the surface of the earth. The need for water is strongly ascending, which is not only important for domestic purpose but also vital for the development activities in both agricultural and industrial sectors. The need of water is more complex due to population growth, urbanization and industrialization. Any developmental activity is related, either directly or indirectly, with water utilization.

Having huge water resource, Ethiopia is frequently affected by drought and the people are not food secured. This problem, to some extent, is related to under utilization of the existing water resource. It is obvious that for the full utilization of the existing water resource good understanding of hydrogeological system that controls the evaluation of potential water resource of a catchment is highly important. Such understanding could also help to know the impacts of climatic variability and aquifer pumping on water resource and to address varies problems related to water resource development.

The source of water on the earth is both surface and subsurface water. Subsurface water is a precious and most widely distributed resource of the earth and unlike any other mineral resources it gets annual replenishment from the meteoric precipitation. Unless the balance between recharge and discharge managed properly, extracting water greater than recharged may bring the possibility of exhausting the groundwater resource.

Fresh water is a finite and precious resource. It is essential for sustaining life and supporting economically productive activities. To use water for the proposed purpose (domestic, agricultural or industrial), the water should be analyzed in terms of quality and quantity. Water which is absolutely pure is not found in nature; even water vapor condensing in the air contains solids, dissolved salts and dissolved gases. As condensed water falls, it sweep up other material from the air, and becomes more contaminated on reaching the ground, running on the surface and moving through the various strata of the soil and rock. Some contamination may be removed by passing through the soil as the result of infiltration and exchange reaction.

The communities living in Berga River catchment use both surface and groundwater mainly for domestic and to some extent for agricultural purposes. Even though the water demands for different development activities with in the catchment have been increasing, surface and groundwater potential of the area is not studied. Utilization of surface and groundwater with out basic understanding of the hydrogeological setting and surface and groundwater potential of the area may lead to reversible problems, various environmental impacts.

This study tries to address the hydrogeological setup of the catchment, the effective utilization of the water resource of the catchment by giving attention to the potential water resource and recommending possible developmental activities and evaluate mainly groundwater resource based on available hydrometeorological and hydrogeological data by applying conventional methods so as to come out with reliable results. It is belied that this research will play an important role to wards the sustainable use of water resource in the catchment.

1.2 Objective of the study

The general objective is to study the hydrogeology of Berga river catchment with particular emphasis on water resource potential evaluation.

Specific objectives:-

- To evaluate the components of hydrologic cycle in the catchment
- To estimate the water balance
- To produce hydrogeological map
- To study surface and groundwater interaction
- To suggest possible measure for sustainable utilization of water resource.

1.3 Methodology

- Literature review, which include published and unpublished reports.
- Collecting hydrometeorological data, borehole log, hydrochemical, vertical electrical survey (VES) and pumping well results.
- Analysis of the topographic map (1:50,000) for the drainage map
- Conducting in situ physical parameter measurement and collecting water samples for laboratory analysis during field work
- Site investigation to map the soil and land use conditions
- Preparing geological map based on the site investigation and published reports
- Water sample chemical laboratory analysis.

CHAPTER TWO: GENERAL OVERVIEW OF THE STUDY AREA

2.1. Location

The study area is located in Oromiya Regional state, West shewa administrative zone, around Addis-Alem town (Berga River Basin). It is about 60km from Addis-Abeba on the way to Ambo city and 80km on the way to Mugger. More proportion of the catchment lays in the northern part of the Asphalt road, but the road to Enchiny (Mugger) passes through most part of the catchment. Berga River Catchment is about 303km^2. The average elevation of the catchment area ranges from 2080m to 2920m above mean sea level. The area is enclosed with in the geographical coordinate of $8^0$57'58"N –$9^0$18'35"N latitude and $38^0$20'49"E –$38^0$29'33"E longitude.

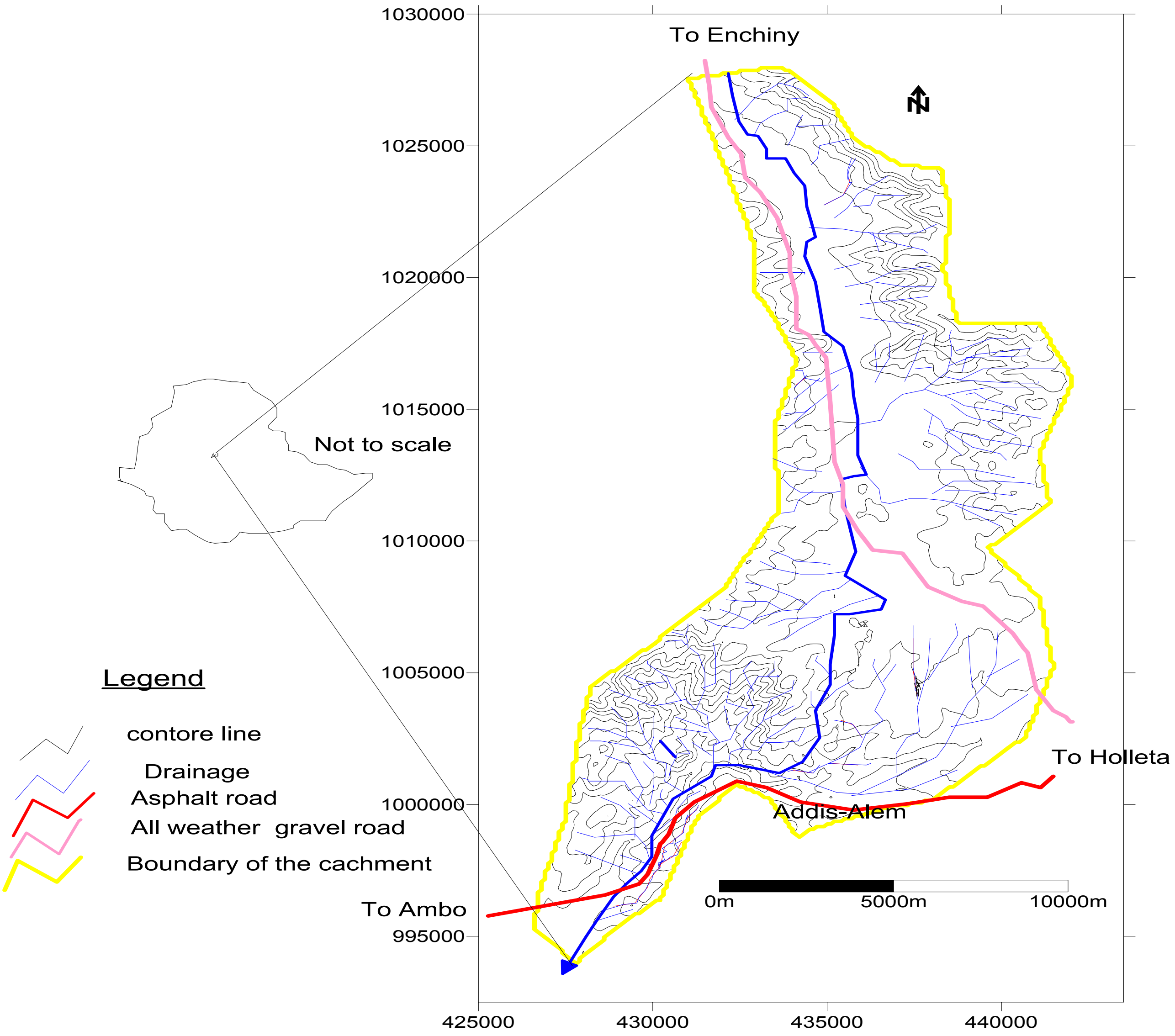

Fig 2.1 Location, Drainage and Topographic map of Berga river catchment

2.2 Accessibility and public services

One asphalt, and one all weather roads pass through the area in southern and northern parts respectively. Only one town is enclosed in the study area, but Enchiny and Holleta are the closest towns to the catchment. All towns get electric, telephone and postal services. The all weather road passes through most part of the study area and easily accessible for most parts of the study area.

2.3Climate

The climate of any area is mostly depends on altitude. Berga river catchment has 1119.26mm,15.4^{O}c, 60.1%, 1.16m/s and 6.5hr/d annual rainfall, average temperature, relative humidity, wind speed and sunshine hour respectively. About 70% of precipitation is received in the months June to September, showing unimodal rainfall distribution in the catchment. According to Ethiopian Mapping Agency (1981) the climate of Berga river catchment ranges from temperate to cool-temperate (Weinadega to Dega) (see chapter 4 for the details).

2.4 physiographic setting and drainage

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

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

The elevation of the area generally decreases to the south and south west. The peak altitude is estimated to 2920m asl in NE of the area and lowest is about 2080m asl at SW (mouse of the catchment) .Numerous streams originate from hills and ridges and merge subsequently to form Berga perennial river. Dobbi, Addama, Fachi and Kerbo are among the most tributaries of Berga River. Berga River flows to Awash River. Small valleys originated from ridges and hills forming dendritic drainage pattern in the area, especially at NE and SW part of the area. The area has nearly northeast—southwest oriented drainage (Fig 2.1).

2.5. Soil and land use

2.5.1 Soil type

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

Its topography can broadly group under sloppy area with few plains around the river. The drainage can be related with its topography i.e. the slopped part with well drained conditions, which favor extreme leaching while the plain is poorly drained which facilitates limited leaching but more deposition. From field observations and according to Awash Basin master plan study (Hal crow, 1989), the dominant soil type of the study area is classified in to three(table 2.1 and Fig 2.2) :-

a. **Lithosol**: - this soil is formed at high relief hillside slops and highly susceptible to erosion. It is highly drained and found on steep hills. It is not well developed. Dominated by boulder and coble size.

b. Nitosols:-this soil unit is characterized by reddish residual soil having an average of 20—50cm thickness with ignimbrite, rhyolite/trachyte origin rock fragment. This soil is formed mainly on cultivated land of the area. It is dominated by sand size soil.

c. Fluvialsol:-this soil is developed along flat land areas (flood plains). As observed from well logs it has up to 30m thickness at some localities. Its color is different at different locations (black, brownish& reddish). It is dominated by clay size soils.

Table 2.1 soil type of Berga river catchment

soil type	area(km2)	location
Lithosol	25.75	Chirecha, Duffa, and Danissa
Nitosol	209.02	most cultivated area
Fluvisol	66.2	low land area
town	2.3	Addis-Alem
Total	303.27	

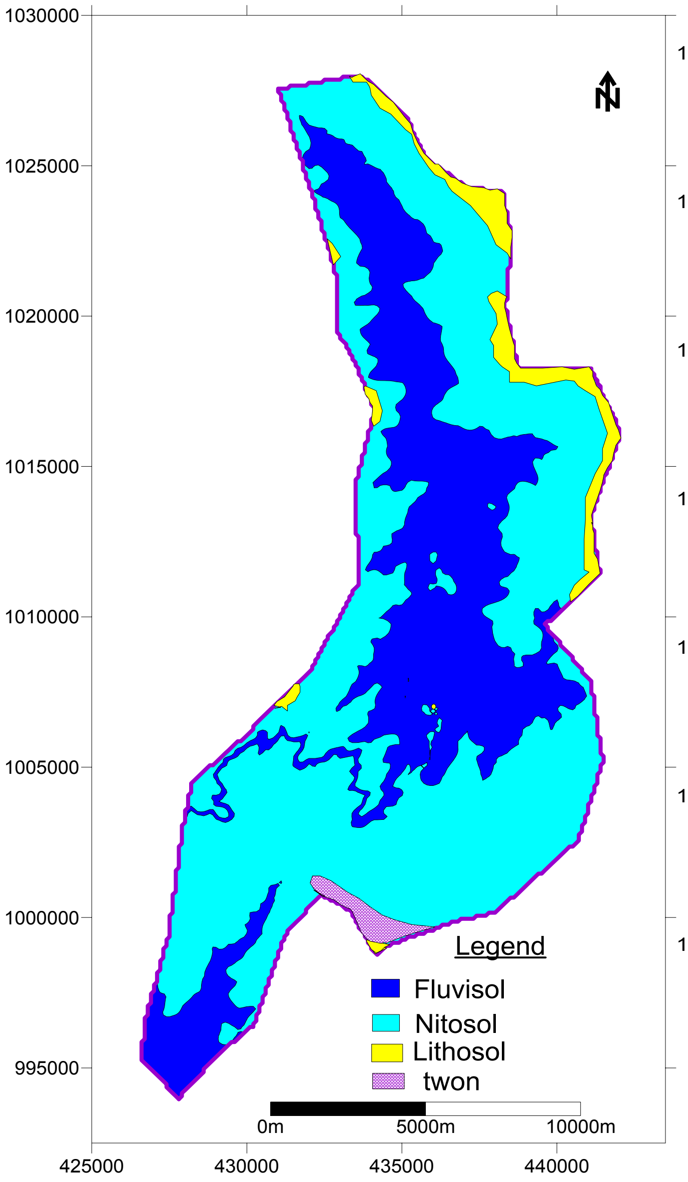

Fig : 2.2 Soil type map of Berga river catchment

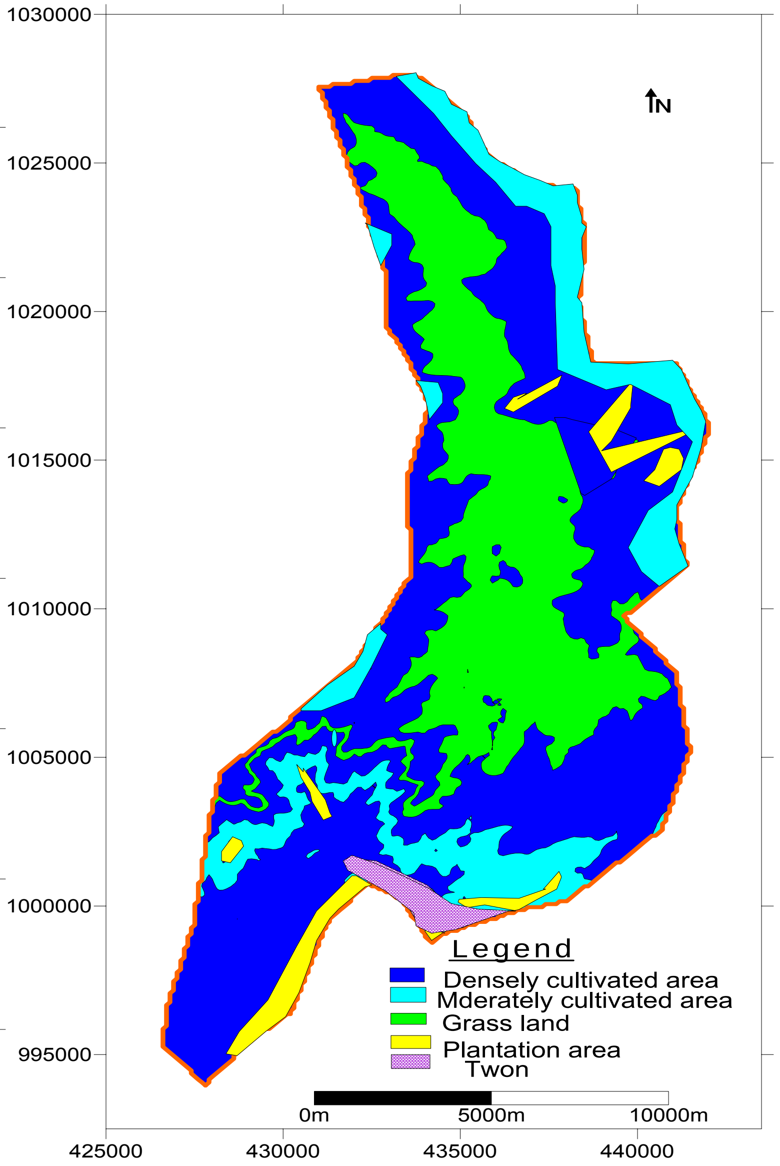

Fig:2.3 Land use map of Berga river catchment

2.5.2 Land use

Land use/land cover of an area depends on climatic factors, land escape, land use practice and agricultural activities of the area. Accordingly, the land use of the study area is mainly classifies as cultivation, grass & grazing (swampy area) and plantation (Eucalyptus tree, shrubs &bushes). The plantation species is mostly found in some valleys and near settlements, where cultivation is impossible (table 2.2 and Fig 2.3).

Table: -2.2 Land use land cover of Berga catchment

Land use/Land cover	Area(km2)	Area (%)
Densely cultivated area	196.44	64.77
Moderately cultivated area	23.78	7.75
Grass land	76.35	25.17
Plantation	4.67	1.55
Town	2.3	0.76
Total	303.27	100

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

2.6 Existing water development and use

2.6.1 Urban water supply

There are two basic problems of water in the study area, quality and quantity. In Addis-Alem town boreholes,97m, drilled in 1968E.C (for town water supply) was becomes dry and another bore hole drilled(at a depth of 147m at Dobbi well field) in 1995 E.C can not also produce enough amount of water for the town. In this year another borehole is drilled (at a depth of 221.5m at the same site). Arb-Gebeya (a small town) has not get any developed handdeg well, spring or shallow well, the people uses unprotected and undeveloped springs and rivers for drinking. Peoples living at Rob-Gebeya and Bekete (small towns) use newly developed handdug wells and undeveloped springs.

2.6.2 Rural water supply

Peoples in the rural area use improper water quality. Even though springs found here and there at the sloppy and top of hills and ridges, they are not well protected and developed. Both people & cattle functions the same stream and spring in most parts of the area. In the urban area the main problem is quality than quantity.

CHAPTER THREE: GEOLOGY

3.1 Regional Geology

3.1.1 General

The study area is located in shewa plateau, part of the Ethiopian high lands. Ethiopian high lands were recognized and mapped as flood basalt province and dominated by Tertiary volcanic (Mohr, 1983; Abebe et al, 1997).

According to numerous studies on volcanic rocks of Ethiopia, two main series are distinguished; the Trap and the Aden series (Kazmin, 1972; Mohr, 1962; Mengesha Tefera et al, 1996). Volcanic rocks along the Yerer-Tullu wellel Volcano tectonic Lineament have two successions; lower and upper volcanic sequences (Abebe et al, 1997).

3.1.2 Volcanism of the Trap series

At the beginning of Tertiary period the Ethiopian land mass was up lifted. The force that caused this uplift was strong enough to cause break in the basement complex and the overlying Mesozoic sediments. It is through this break such as fissures and vents that very fluid basaltic lavas poured out in immense quantities (Mesfin Weldemariam, 1972).

The Trap series dominates the Ethiopian Volcanic Province (EVP) and pre-dates the rift faulting. It contains a very thick series of lava flows chiefly flood basalts (Traps), but with trachyte and rhyolite occurring especially near the top of the series (Abebe et al, 1997; Kazmin, 1962&1979; Mohr, 1972 & 1983; Mengesha Tefera et al, 1996).

Volcanic rocks belonging to Trap series includes Ashangi basal, Aiba basalt, Alaji and Tarmaber formations.

3.1.2.1 Ashangi Basalt

Ashangi basalt is chronologically belongs to Eocene to Paleocene with the oldest reported age of 54my and representing the earliest fissural flood basalt volcanism on north western plateau (Kazmin, 1979; Mengesha Tefera et al, 1996).

Ashangi basalts are characterized by fissural eruption type, thick strongly weathered (usually up to 1km), crushed, tilted and lies below the major pre-Oligocene unconformity. Their out crops are usually restricted to the north-central parts of the Ethiopian plateau. This group of basalt consists predominantly alkaline-basalts with interbeded pyroclastic, ignimbrites, and rare rhyolites and is commonly injected by doleritic sill, acidic dykes and gabbroic intrusions .The upper part of Ashangi basalt is more tuffaceous and contains interbeded lacustrne deposits with lignite seams and acidic volcanics and locally over lies the older parts of the group with angular unconformity (Kazmin, 1979; Tenalem Ayenew and Tamiru Alemayehu, 2001)

3.1.2.2 Aiba Basalt

Aiba basalt represents the second major volcanic cycle on Ethiopian plateau. They were produced by fissure eruptions and unconformably overlie Ashangi basalt and attain a thickness of 200 to 600m. They are usually aphyric-compact rocks, in places showing clear stratification. They show a distinctive tholeiitic nature with transitions to mildly alkaline varieties. The absolute age of Aiba basalt ranges from 34 to 24 ma, placing them in Oligocene (Kazmin, 1979; Mengesha Tefera et al, 1996).

Basalts of this age were recognized along Ambo lineament with their age decreasing south ward overlying the cretaceous upper sand stone unconformably. The top of the section is represented by 26my old basalt which forms 30—40m high cliff (Wolde-Gabriel et al 1990).

Aiba basalts are flood basalts with rare tuffs. The flows are always evident with columnar joints and pinch out south and west wards. The base of the overlying Alaji formation is defined by the first rhyolitic ignimbrite, but where such ignimbrite are absent ,no distinction between the two formations can be made on either lithological or geochemical ground(Mohr,1983).

3.1.2 .3. Alaji formation

On the Ethiopian plateau Alaji formation is represented mainly by aphyric stratoid basalt associated with rhyolites, ignimbrites and subordinate trachytes. This formation ranges in age between 36---13ma which belonging them in late Oligocene to early Miocene (Kazmin, 1979; Mengesha Tefera et al, 1996).

Alaji formation makes the bulk of volcanic succession on both northwestern and southeastern plateau. On the northwestern plateau they rests conformably on Aiba basalt but in some places (eg:-kassem gorge, mugger canyon) and in most out crops on the southeastern plateau it directly overlies on Mesozoic sediments. Alaji basalts are transitional to tholeiitic in nature and an increase in alkalinity is observed in the younger members of the formation. Thus Miocene Alaji basalts are more alkaline and associated with sub alkaline acidic members (Mengesha Tefera et al, 1996).

According to Zanettine et al, 1974a (cited in Kazmin, 1979), acidic rocks of central eastern Ethiopian plateau form a large and continuous cover extending from Ambo-Alaji to Debre-Berhan and mugger areas. These acidic rocks lie on the Aiba flood basalts and are over lied by the Tarmaber basalts which are the products of a central type volcanism. North west of the line joining Ambo and Fiche, on Addis Abeba—Dessie road, Alaji basalts are of Oligocene age, from 36—34 to 38—26 my (Alaji Moll ale), while to the south east of this line they are lower to middle Miocene, from 26 to 16—13 my (Alaji sirro). Thus migration of the Alaji type volcanism from north to south is established.

According to Abebe.T et al (1997), two sequences have been recognized in the volcanic succession of Yarer—Tulu wellel Volcano tectonic Lineaments (YTVL):-the lower and the upper volcanic sequences. The lower volcanic sequence, exposed mainly in the western and central areas, consists of flood basalt with associated trachytes to phonolite domes &necks. It is strongly eroded and dissected by faulting and locally it is unconformably covered by the products of the upper sequence and has ages Oligocene to lower Miocene.

3.1.2.4 Tarmaber formation

Tarmaber formation represents Oligocene to Miocene basaltic shield volcanism on the north western and south eastern plateaus. The central type Tarmaber formation basaltic volcanism was followed by fissural eruptions particularly along the escarpments of north western and south eastern plateaus. Tarmaber basalt in contrast to the tholeiitic and mildly alkaline nature of the earlier flood basalts are typically alkaline in nature. It superimposed on the fissure flood basalts and represent the last major volcanic episodes on the plateau falling in to two known age groups;-26—22my (Tarmaber—Gussa formation) on the northern part of the western plateau and 15—13 my (Tarmaber—Megezez formation) on the central part and eastern plateaus, indicating that the Tarmaber shield volcanoes can become progressively younger from north to south (Mohr, 1983; and Mengesha et al, 1996). The upper age limit of the Tarmaber Megezez formation is lower to 7 to 8 ma when the large basaltic center of Arba-Gugu with the same alkaline nature is considered as the youngest episode of Tarmaber type volcanism (Mengesha Tefera et al, 1996).

Tarmaber formation is represented by varies basalts;-femic pyroxene-olivine porphyritic varieties to plagioclase porphyritic type, also contains large amounts of tuffs, scoracoeus lava flows, and red paleosols, usually individual flows area easily recognizable (Kazmin, 1979).

According to Mengesha et al, (1996) the Tulu wellel trachytes, having an absolute age of 8 ma are correlated with Tarmaber—Megezez formation. The upper volcanic sequence consists mainly of several volcanoes and associated small domes and cones, all of which are roughly aligned east to west has ages late Miocene to recent in the YTVL (Abebe et al, 1997).

3.1,3 The Rift Series

The quaternary volcanics in Ethiopia can be roughly subdivided in to three groups:-volcanics of the plateau, marginal complexes of the Afar and the volcanics of the Ethiopian rift (main along the Afar margin) and volcanics of the Axial ranges built along NW extension faults (Kazmin, 1972&1979; Mohr, 1971).

The quaternary alkaline basalts and trachytes were erupted along pre-existing structures on the NW and SE plateaus. The quaternary basalt flow is characteristically alkaline and represent the final pulse of basaltic volcanism 0n the Ethiopian plateau (Mengesha Tefera et al, 1996).

After the formation of the escarpment of the Ethiopian rift, fissural volcanism becomes confined to the rift and along the escarpments. At the foot of the escarpment tilted and eroded lavas of the preceding stage were covered unconformably by transitional flood basalt (Fursa-basalt, 12—10My), with its eruption related to the first stage of rift formation, thickens towards rift (Kazmin, 1979). Eruption in the interval of 18—15 MY to recent is characterized by localization of volcanism, due to the effects of tectonic events volcanism mainly restricted to Axial zones of the wengi fault belt and the Axial ranges of Afar, spreading zone(kazmin,1979; Mengesha Tefera et al,1996).

The Aden volcanic series are the youngest quaternary volcanics having rock series:-obsidian flow, ignimbrite, pumice deposits associate with rhyolitic flow, pyroclastic surge deposits, basaltic lava flows and spatter cones. This series is almost all exposed in parts of the Ethiopian rift and is intensively affected by tectonism (Tenalem Ayenew and Tamiru Alemayehu, 2001).

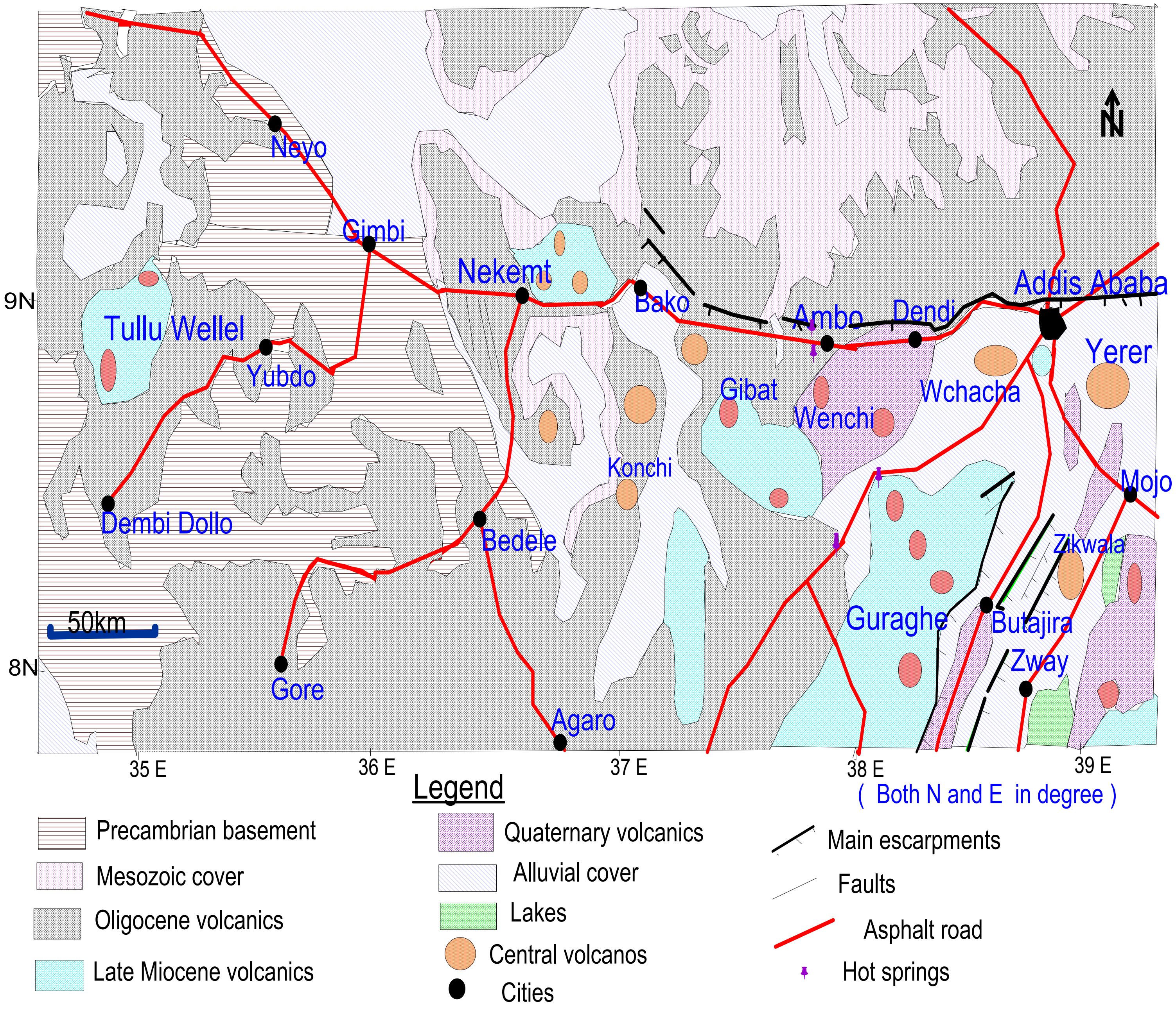

Fig:- 3.1 Regional geological map (Source :- Abebe et al , 1997)

3.2 Local Geology

3.2.1 General

Considering previous work, it is not possible to get large scale geological maps which show the geology of Berga river catchments except 1:2850000 approximant scale which have been done by Halcrow (1989) during the preparation of Awash Basin master plan and 1:2500000 developed by Abebe et al (1997) during the study of Yerer-Tulluwellel Volcanotectonic Lineaments.These maps have certain limitations to indicate the local geology of the study area.

According to Abebe et al (1997) in the Yerer-Tulluwelel-Volcanotectonic Lineaments, extending from the western margin of the Ethiopian main Rift (EMR) through Ambo to Nekemt, there are two volcanic successions:-the lower volcanic sequence (Oligocene to lower Miocene) that corresponds to Aiba and Alaji basalts and the upper volcanic sequences (Late Miocene to Recent) which corresponds to Tarmaber and quaternary formations.

3.2.2 Lithologic units

In the study area four Lithologic units are identified from their out crops .these units are discussed as follows and mapped in (fig .3.2).

3.2.2.1 Lower Basalt

The lower most part of the Lithologic unit of study area is characterized by basalt. This formation is out cropped at Dobbi river gorge, north of Addis-Alem, forming a steep cliff at the southern part of the study area and at some places in Berga river gorge. It has up to 10m maximum exposure, forming it unmappeable, at Dobbi River forming a fall. This rock unit is highly jointed and fractured at its exposed area. It has dark gray color and aphanitic texture. This rock is very similar with the Aiba basalt described in the regional geology (section 3.1.2.2)

3.2.2.2 Ignimbrite, Rhyolite/Trachyte

On the top of the lower basaltic unit the volcanic products of ignimbrite, rhyolite/trachite have been out cropped in the area as the second major volcanic rock units. It covers most part of the area forming ridges and hills. It is fractured, jointed and weathered. The coarse grained ignimbrite, rhyolite/Trachyte rock contains phenocrysts of quartz or feldspars. This unit is strongly eroded and shows a tilted lamination at some out crops. These rock units are similar to Alaji formation discussed in regional geology (section 3.1.2.3).

3.2.2.3 UPPER BASALT

In the catchement the youngest visible rock overlying on the top of ignimbrite, rhyolite/trachyte is basalt. Its thickness varies locally and it forms some cones in the study area. This rock unit is highly weathered and fractured. It has aphanitic and porphyritic texture and shows vesicular at its top (vesicles filled with plagioclase, calcite or quartz) and forms a pillar like structure at some out crops, the main phenocrysts are plagioclase feldspars. Its textural feature is very similar with Tarmaber basalt described in section 3.1. 2.4.

3.2.2.4 ALLUVIAL AND RESIDUAL SILTY CLAY SOILS

Thin deposits ranging from boulders to clays characterized the main river beds in Awash basin (Hal crow, 1989). Due to highly undulated topographic nature of the area, most stream beds out crops rock units. On gentle slope of the hills, there is a wide area of cultivated land having mostly reddish silty clay residual soils with an average depth of 0.50m overlying on ignimbrite, trachite and rhyolite bed rock. This thin residual soil unit is mapped according to the bed rock Lithologic type. But the alluvial soils which cover a relatively wider area adjacent to the main river (Berge plain) and flat area near kimoye village can be mapped separately. This soil has mostly a black cotton color and contains some lithic components and is cracked.

3.2.3 Geological structures

In the study catchment and adjacent area, different authors reported the occurrence of an E—W trending faults, joints and other structures with in different volcanic rocks (Abebe et al, 1997; and Giday.W et al, 1990) naming Yerer-Tulluwellel Volcanotectonic Lineament and Ambo fault belt respectively .

Major faults are oriented E---W in the southern part of the study area near Addis-Alem town forming a ridge bounding the study area. Different sets of joints are observed along the stream beds and rock out crops, having different orientations locally. Fractures with orientation mostly E—W and at some places SE—NW and N—S are observed in the study area.

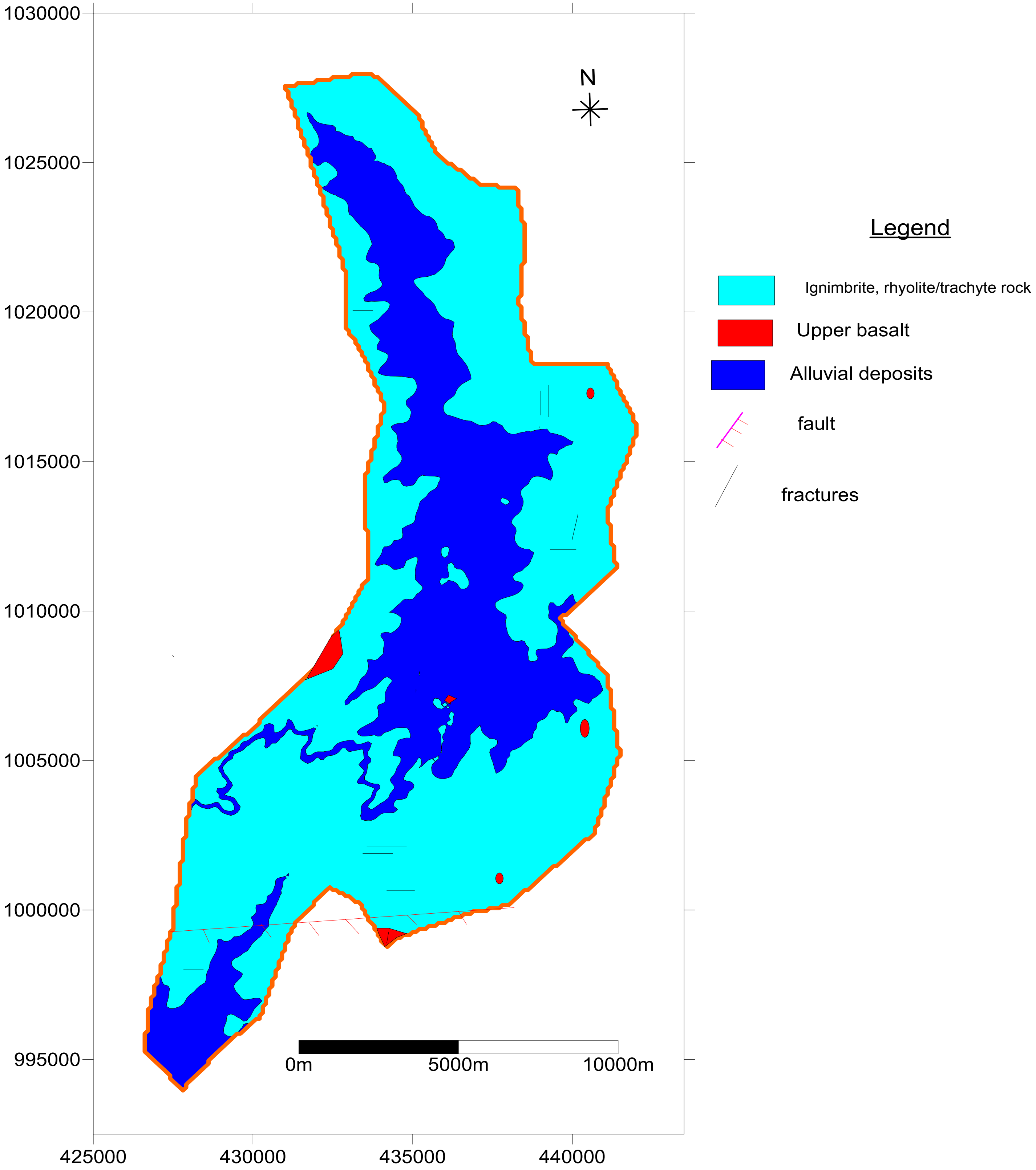

Fig:3.2 Geological map of Berga river catchment

CHPTER FOUR: HYDROMETEOROLOGY

4.1 General

Hydrometeorology is a science which links hydrology and meteorology. It studies the hydrological cycle which involve processes in the atmosphere and at the earth's surface (Shaw, 1985). Hydro-meteorological data are required to determine the water balance of a basin for developing and managing its water resource. The most use full hydrometeorological elements are precipitation, evaporation, evapotranspiration, solar radiation (sunshine hours), humidity, air temperature and stream discharge.

4.2. Meteorological parameters

In Berga River catchment there is only one meteorological station located at Addis Alem town. It records 0nly rainfall and temperature. Enchiny station is the most nearest one in the northern part of the catchment which records only rainfall. The other stations are Wellenkomy and Holleta with class 3 & 1 respectively. The over all meteorological parameters available in the study area are rainfall, temperature, relative humidity, wind speed, and sunshine duration. For different stations the duration over which the parameters are averaged varies.

For the analysis of various components of hydrologic cycle long term meteorological data have been taken from Ethiopian National Meteorological Service Agency (ENMSA) and Holleta agricultural research center for the stations in the study area and in the vicinity.

In this work, the main objectives of analyzing hydrometeorological data is to compute evaporation and evapotranspiration and the results of the analysis further used to calculate water balance of the catchment.

4.2.1. Precipitation analysis

Precipitation which is the main source of all fresh water in hydrologic cycle falls nearly every where, but its distribution is highly variable. Of all the components of hydrological cycle, precipitation is the most commonly measured (Shaw, 1985). Bing located in tropical region; rainfall is the main form of precipitation in Ethiopia.

Physiography and topography of the drainage basin, together with the vegetation, influences the relationship between precipitation over the catchment and the water drained from it.

In general, the rainfall distribution of the study area and neighbors are more or less similar to that of the Ethiopian central plateau. The temporal rainfall distribution indicates that the occurrence of two main seasons, the dry and wet seasons. As displayed in precipitation bar graph (Fig: 4.2), the maximum and minimum rainfall is recorded in the month of August and December respectively. The majority of rainfall in the catchment is obtained in the months June to September covers about 70 % of the total annual rainfall (table 4.2 and 4.5).

Precipitation is the most commonly measured meteorological data. Accordingly there are four meteorological stations within and around the study area (table 4.1).

Table 4.1 meteorological stations with in and around Berga river catchment

No	station	UTM(m)		Altitude(m)	Annual rainfall(mm)	recording period
		Latitude	Longitude			
1	Addis-Alem	434750	999850	2340	1141.9	1962—2004 2*
2	Holleta	444250	1001300	2380	1050	1980—2005 1*
3	Enchiny	432800	1029750	2690	1204	1975—2004 3*
4	Wellenkumy	417650	995200	2140	980.11	2000—2004 3*

Where:-

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

2* Records of rainfall and temperature

3* Records of rainfall only

Table 4.2 long term average monthly rainfall at different stations

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
Addis Alem	21.17	41.57	69.08	81.61	77.66	142.1	258.5	249.1	140.2	32.34	15.85	12.73	1141.91
Enchiny	29.46	31.04	70.33	82.35	65.1	139.2	277.3	274.5	139.7	48.21	22.72	24.09	1204
Wellenkomy	27.58	4.525	71.3	90.1	45.53	178.2	245.7	194.6	95	16.44	7.2	3.933	980.108
Holleta(RS)	23	40	63	84	65	115	246	253	125	20	6	10	1050
Average	25.3	29.28	68.43	84.52	63.32	143.6	256.9	242.8	125	29.248	12.943	12.69	1094

4.2.1.1. Determination of aerial depth of rainfall

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

a. an arithmetic mean: - this method is the simplest and reliable to calculate the average rainfall over a relatively flat topography and closely and evenly spaced gauging stations.

It is computed as the arithmetic mean of the amounts measured by gauges enclosed with in the area. Therefore, Addis-Alem station is located with in the study area and it is the only station used for arithmetic mean aerial depth rainfall estimation and the result is 1141.9mm annually.

b. Theissen polygon method: - this method provides a good result for none uniformly distributed rain gauges over the area for both flat and hilly terrain by determining a weighted factor for each gauges. Even though, four stations are considered to construct Theissen polygon, only three stations are used for computing weighted annual rainfall (Addis-Alem, Holleta and Enchiny).

The method is given by

$$P_A=(P_1a_1+P_2a_2+\text{---}+p_na_n)/At \qquad (4.1)$$

Where: - $P_{A=}$ average rain fall for the total area

P_i =measured precipitation at i^{th} station

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

At = total area of the catchment

Using this method, the computed annual rainfall of Berga river catchment is 1119.26mm (Table-4.3 and Fig-4.1).

Table 4.3 Theissen polygon method to calculate the annual rainfall of the Berga river catchment

No	station	mean annual rain fall(mm)	area of influence(km2)	Weighted area (%)	weighted rain fall(mm)
1	Addis-Alem	1141.9	156.53	51.62	376.43
2	Enchiny	1204	101.67	33.53	396.71
3	Holleta	1050	45.05	14.85	346.12
Total			303.25	100	1119.26

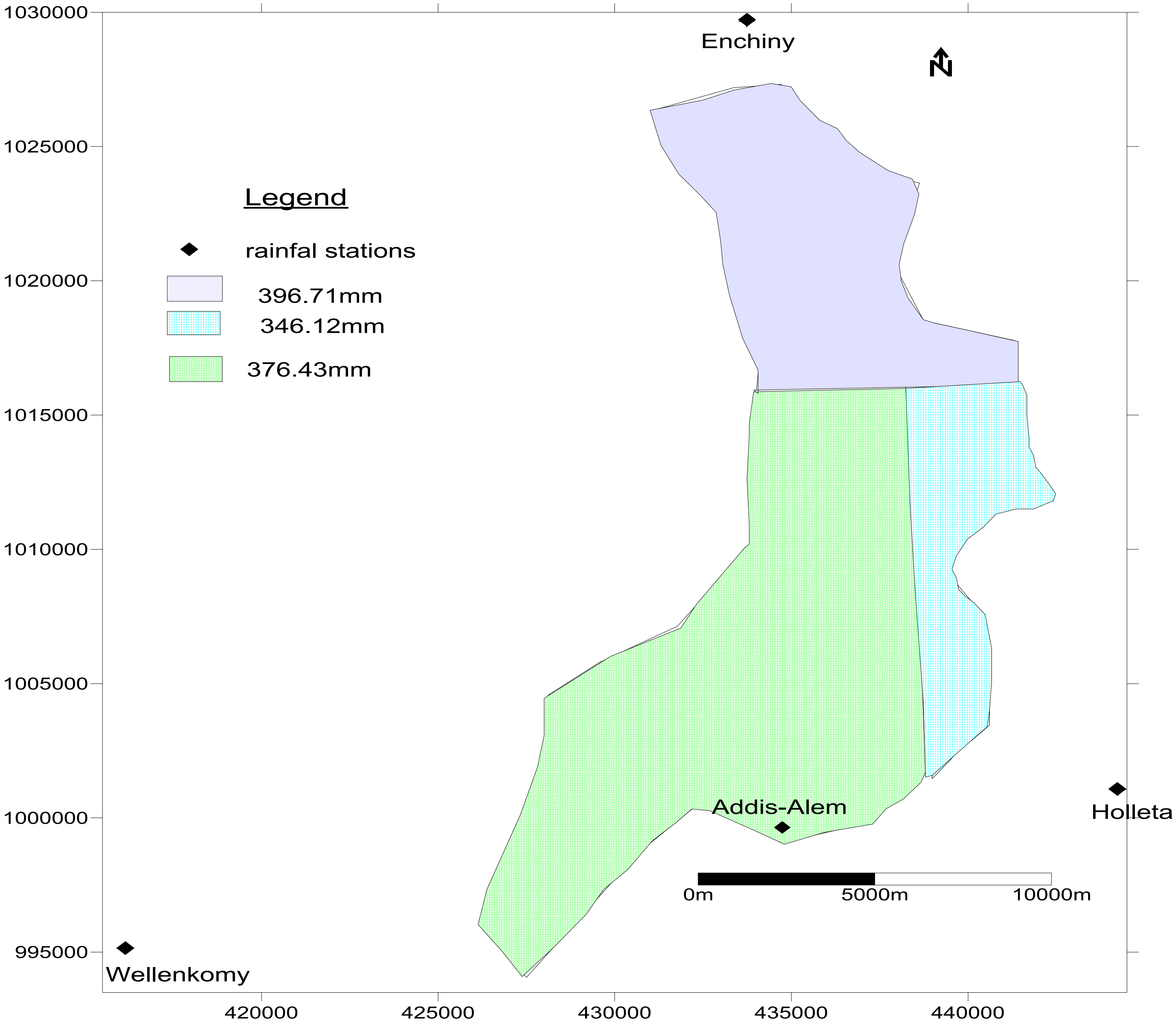

Fig: 4.1 Theissen polygon map of Bega river catchment

The calculation of mean annual rainfall computed by arithmetic mean method over estimate the value. The case may be due to uneven distribution of stations or undulating nature of the topography or both. Where as the result of mean annual rainfall computed by Theissen polygon method is 1119.26 mm. This indicates that the topography has an effect on rainfall. Therefore, it is logical to take 1119.26 mm Theissen polygon value as the mean annual rainfall of Berga river catchment.

4.2.1.2 Characterization of rainfall

The amount of rainfall increases with altitude increases. Its amount and frequency are greater on the wind ward sides of the orography (Tenalem Ayenew and Tamiru Alemayehu, 2001). As it is indicated in table 4.1, the annual rainfall generally increases with altitude.

To compare monthly rainfall distribution and to identify dry and rainy seasons, rainfall coefficient (R.C) should be employed. Rainfall coefficient is the ratio between mean monthly rainfall and one twelfth of the annual mean of the total rainfall (Daniel Gemechu, 1977, cited in Debebe Muleta, 2005).

$$R.C=12(P_m/p_a) \tag{4.2}$$

Where; - R.C=Rainfall coefficient, it is unit less

P_m=mean monthly rainfall

P_a=annual total rainfall of the year

Table 4.4 classification scheme of monthly rainfall values (source Daniel Gemechu, 1977, cited in Debebe Muleta, 2005)

No	Designation	Rainfall coefficient
1	Dry months	<0.6
2	Rainy months	≥0.6
3	small rains	0.6—.0.9
4	Big rains	≥1.0
5	Moderate concentration of rain	1.0—1.9
6	High concentration of rain	2.0—2.9
7	Very high concentration of rain	≥3.0

Table 4.5 mean monthly rainfall & rainfall coefficient for the study area and classification of dry and wet months

parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall(mm)	24.14	42.9	66.36	81.3	68.11	129.9	252.29	258.58	132.73	32.96	15.3	14.62	1119.26
R.C	0.26	0.46	0.71	0.87	0.73	1.4	2.71	2.77	1.42	0.35	0.17	0.16	
Designation	dry	dry	small rain	small rain	small rain	Big rain	Big rain	Big rain	Big rain	dry	dry	dry	

The study area has four big rainy, three small rainy and five dry Months in a year. It gets very high rainfall concentration during the months of August and July. The months of June and September are categorized under moderate rainfall concentration where as the months November, December and January are the driest months.

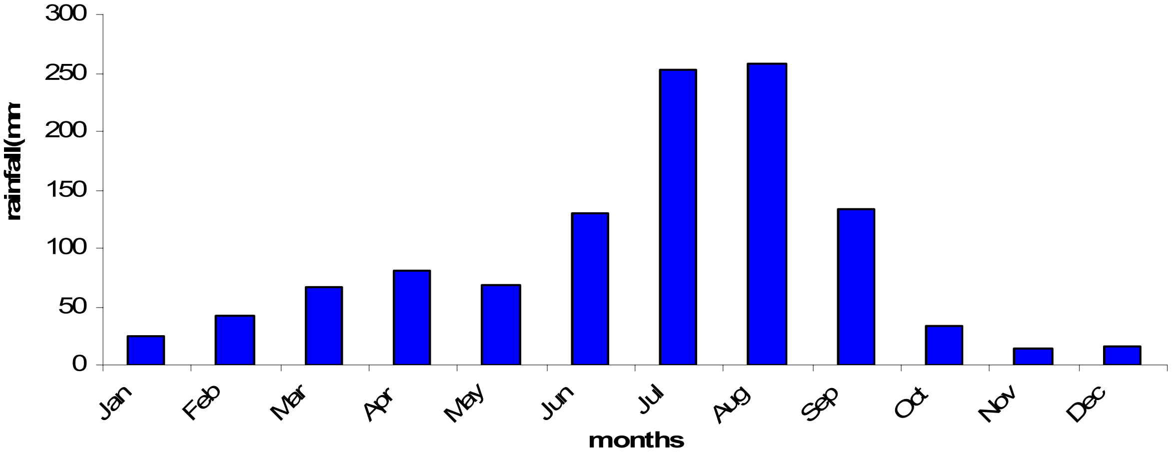

Fig:-4.2 monthly rainfall distribution of Berga river catchment (rainfall in mm)

4.2.2Temperature

Temperature enhances evapotranspiration through making the environment hot and favors the passage of liquid state of water to vapor state. Air and water temperature are dependent on solar radiation and has direct influence on evaporation.

From four meteorological stations used for this work, only two stations have records of monthly maximum and minimum temperature .The least minimum and the most maximum air temperature is recorded in the month of December and march respectively (table 4.6)

Table 4.6 indicates that temperature decreases with increase of elevation. Holleta is found at a bit higher elevation and both its minimum and maximum temperature records are some what less than that of their respective records at Addis Alem. The average value of the mean monthly maximum and minimum of the two stations were considered to characterize the temperature of the study area.

Table4.6 max and min temperature of the two stations and the average for the study catchment (^{O}c)

station	^{O}c	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	average
Addis-Alem	Max	24.7	25.2	25.4	25.4	25.4	24.2	21.9	21.2	22.4	23.8	23.9	24.3	23.983
	Min	7.4	8	9.3	9.4	9.6	10	9.9	10.3	9.9	9.2	7.4	6.9	8.9417
Holleta	Max	23.2	24.1	24.1	23.6	24	22.3	19.6	19.4	20.4	21.8	22.5	22.8	22.317
	Min	3.7	5.4	7.3	8.5	7.9	7.7	9	9	7.5	4.6	2.2	2.2	6.25
Mean of	Max	23.95	24.7	24.8	24.5	24.7	23.25	20.75	20.3	21.4	22.8	23.2	23.55	23.15
	Min	5.55	6.7	8.3	8.95	8.75	8.85	9.45	9.65	8.7	6.9	4.8	4.55	7.5958
Average of max &min		14.75	15.7	16.5	16.7	16.7	14.8	14.88	15.5	15.8	15.1	14.2	14.05	15.388

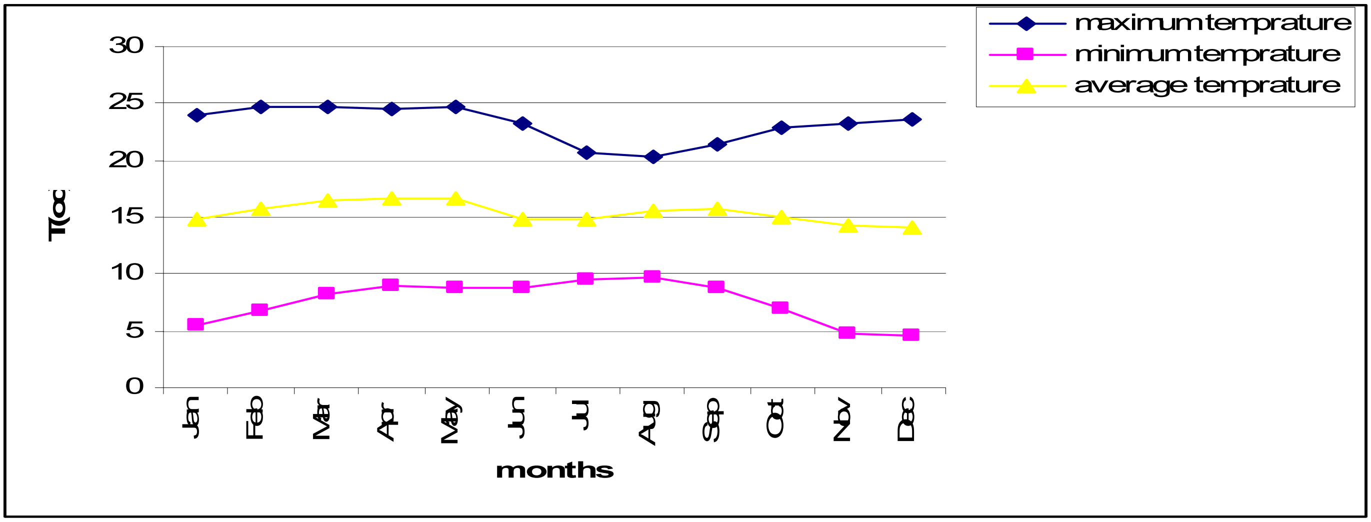

Fig 4.3 monthly average maximum, minimum and mean temperatures at Addis Alem and Holleta stations (8 and 26 years respectively)

4.2.3 Relative humidity

Relative humidity is the relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature ed/ea represents as a percentage (Shaw, 1985)

$$RH=(e_{d}/e_{a})\ 100 \qquad (4.3)$$

Where: - RH is relative humidity

e_d is actual vapor pressure at the dew point, Td

e_a is saturated vapor pressure at air temperature, Ta

As air humidity increase, its ability to absorb water vapor decreases and evaporation rate slows down. For evaporation to take place there must be a difference in humidity (Tenalem Ayenew and Tamiru Alemayehu, 2001; Fetter C.W, 1994)

Of four stations used for this work, only Holleta station has relative humidity records. The mean monthly relative humidity attains maximum in July& August and minimum in December and January (Table 4.7). In general, this change is related to the rainy and dry seasons of the country which it raises during summer (kiremt).

Table 4.7 Monthly mean relative humidity (%), wind speed (m/s) and sun shine hour (hr/d) at Holleta station

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	average
humidity	54.24	55.36	57	62.62	58.93	71.22	81.71	83	77.13	60.39	56.28	54.5	64.37
wind speed	1.17	1.64	1.42	1.39	1.36	0.97	0.86	0.8	0.89	1.08	1.14	1.17	1.16
sunshine	8.45	8.13	7.36	6.62	6.99	5.13	2.93	3.1	4.68	7.52	9.44	8.39	6.56

4.2.4 Wind Speed

The movement of air and moisture transfer depends on wind speed and turbulence. Evaporation has a direct relation with wind speed and turbulence (Tenalem Ayenew and Tamiru Alemayehu 2001; Shaw, 1985). Wind speed and air temperature removes water vapor molecules from the air in contact with the water holding surface and enable evaporation to proceed at maximum rate governing with the existing main factors, temperature and humidity condition.

Evaporation is greater in exposed areas that enjoy plenty of air movement than in sheltered localities where air tends to stagnant (Shaw-1985)

Wind speed varies with the height above the ground. Its result is obtained at a given height above the surface. The wind speed data of the study area, i.e. at Holleta station is measured at 2m above the ground surface. The average wind speed value reaches maximum and minimum in months of February and August (Table 4.7). Its general trend shows that increment during the dry period of the year and decreases with increasing rain fall.

4.2.5 Sunshine

Sunshine hour is the time in hours of sunshine in a day .It is the main evaporation factor and has direct relationship with evaporation. When the day is cloudy, sunshine hour's decreases and evaporation rate also decreases with the existing other meteorological factors being constant.

As shown from table 4.7 the area gets maximum and minimum average sunshine hour during the months of November and July respectively. It has a direct relationship with dry and rainy seasons. During rainy seasons the cloud coverage is greater and the mean sunshine hour is relatively small.

4.2.6 Methods of estimating evapotranspiration

Evaporation is the transfer of water in to the atmosphere, where water is temporally stored, from a free water body, bar soil, or interception on a vegetal cover .Transpiration is a form of evaporation loss from vegetation surface. Over land areas, it is difficult to separate the effects of evaporation and transpiration. Therefore, evapotranspiration is usually thought as the total loss by both evaporation and transpiration from a land surface and its vegetation (Shaw, 1985; Fetter C.W, 1994).

It is not possible to measure evapotranspiration directly from an appreciable area under natural conditions, but lysimeters are used to measure it in limited volume containers (WMO, 1994). Evapotranspiration is generally depends on different factors:-climate (temperature, relative humidity, solar radiation …), plant physiology, water quality, etc. The nature of evaporating surface affects evaporation by modifying wind pattern. Over a rough irregular surface, friction reduces wind speed but has a tendency to cause turbulence and evaporation is affected predominantly by horizontal velocity (Shaw, 1985).

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

4.2.6.1 Penman-combined method of evaporation (Eo) estimation

The physical principle to calculate evaporation from open water body combines two approaches, the mass transfer and energy budget methods. The basic equations are modified and rearranged to use meteorological constants and measurements of variables made regularly at climatological stations (Shaw, 1985; and Bruce J.P and Clark R.H, 1966).

Assuming that other variables in energy balance are negligible, the simplified equation is given as:-

$$H= Eo + Q \tag{4.4}$$

Where H is the available heat

EO is energy for evaporation or rate of evaporation

Q is energy for heating the air

The values of EO and Q can be defined by mass transfer (or aerodynamic) equations:

$$Eo=f(u)(e_s-e_d) \tag{4.5}$$

and

$$Q=\gamma f(u)(Ts-Ta) \tag{4.6}$$

$$Ea=f(u)(ea—ed) \tag{4.7}$$

$$\Delta=de/dT=(es—ed)/(Ts—Td)=(ea—ed)/(Ta—Td)\text{(if gradients are small)} \tag{4.8}$$

Then from equation 4.6:-

$$\begin{aligned} Q&=\gamma f\ (u)\ (Ts—Ta) \\ &= \gamma f\ (u)\ [(es\text{-}ed)/\ \Delta — (ea\text{-}ed)\ /\Delta] \\ &=(\gamma Eo/\Delta)—(\gamma Ea/\Delta) \end{aligned} \tag{4. 9}$$

Ta is easily measured, then ea is easily obtained from table against Ta, and ed is calculated from equation (4.3).

Substituting equation 4.9 in equation 4.4 gives,

$$Eo=H— (\gamma Eo/\Delta) + (\gamma Ea/\Delta)$$

$$\Delta Eo+ \gamma Eo= \Delta H+ \gamma Ea$$

$$Eo= [(\Delta/\gamma)H+Ea]/[(\Delta/\gamma)+1] \tag{4.10}$$

Where: ea-ed is saturated deficit

es is saturation vapor pressure of the air at water surface (mmHg)

ea is saturated vapor pressure at air temperature (Ta) ed is saturated vapor pressure at dew point temperature (Td)

f (u) is a function of wind speed

γ is the hygrometric constant (0.27mmHg/$^{O}{}_{F}$)

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

Equation (4.10) is the basic Penman formula for open water evaporation. It requires the values of H, Ea and Δ for its application.

If net radiation measurements are available, then H can be obtained directly .Moreover, H is calculated from incoming (R_I) and out going (Ro) radiation determined from sunshine records, temperature and humidity, using:-

$$H=R_I(1-r)-Ro \tag{4.11}$$

Where r is the albedo and equals 0.05 for water

R_I is a function of Ra, the solar radiation (which is fixed by latitude and season) modulated by a function of the ratio, n/N, of measured to maximum possible sunshine duration.

Ratio, n/N, using r=0.05 gives:-

$$R_I(1-r)=0.95Ra\,f a(n/N) \tag{4.12}$$

Penman used $fa(n/N)=0.18+0.55n/N$ in his original work , but later studies have shown that the function $fa(n/N)$ depends on the clarity of the atmosphere and latitude (MAFF,1967 cited in Shaw,1985).They uses :-

$fa\ (n/N)=0.16+0.62n/N$ for latitude south of 54.5^0

The term Ro in equation (4.11) is given by:-

$$Ro=\delta T_a^4(0.56-0.09\sqrt{ed})(0.10+0.90n/N) \tag{4.13}$$

Where δT_a^4 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)

n is bright sunshine hours over the same period

N is mean daily duration of maximum possible sunshine hours

Ra is solar radiation

N and Ra, expressed in mm/day, are obtained from standard meteorological table, for this work N and Ra are taken from Shaw (1985) at 10^0 north latitude

Then, H in equation (4.10) is obtained from values found through equations (4.12) and 4.13) in to equation (4.11)

Ea in equation (4.10) is found using coefficients derived by experiment for open water

$$Ea=0.35(0.5+u_2/100)\ (ea—ed) \qquad (4.14)$$

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

Knowing open water evaporation of the study area has a multidisciplinary importance for dam design in the area, irrigation, hydropower and water supply purposes. Accordingly, the annual open water evaporation rate calculated with in the catchment is 1210.84mm (table 4.10).

Table 4.8 calculated open water body evaporation of Berga river catchment using Penman combined method

parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total
T(Oc)	14.75	15.68	16.53	16.73	14.63	16	14.8	14.88	15.53	15.75	15.05	14.18	
ea(mm/d)	12.74	13.46	14.14	14.3	12.49	13.65	12.73	12.81	13.4	13.79	12.21	12.38	
RH(%)	54.28	55.36	57	62.62	58.93	71.22	81.71	83	77.13	60.39	56.28	54.5	
ed(mm/d)	6.92	7.45	8.06	8.96	7.36	9.72	10.4	10.63	10.34	8.33	6.87	6.75	
U2(mil/d)	66.78	88	76.19	74.58	73	52.05	46.14	43.46	47.75	57.95	61.17	62.78	
Tk(Ok)	287.8	288.7	289.5	289.7	287.6	289	287.8	287.9	288.5	288.8	288.1	287.2	
n(hr/d)	8.45	8.13	7.36	6.62	6.99	5.13	2.93	3.06	4.68	7.52	9.44	8.39	
N(hr/d)	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5	
n/N	0.73	0.69	0.61	0.54	0.55	0.4	0.23	0.25	0.39	0.64	0.81	0.73	
fa(n/N)	0.61	0.59	0.54	0.5	0.5	0.41	0.3	0.32	0.4	0.56	0.66	0.61	
Ra(mm/d)	12.8	13.9	14.8	15.2	15	14.8	14.9	15	14.8	14.2	13.1	12.5	
RI(1-r)(mm/d)	7.42	7.79	7.59	7.22	7.13	5.77	4.25	4.56	5.62	7.55	8.21	7.24	
δT_a^4	13.38	13.55	13.7	13.73	13.34	13.6	13.38	13.4	13.51	13.56	13.43	13.27	
Ro	3.29	3.07	2.71	2.35	2.53	1.75	1.12	1.18	1.65	2.77	3.68	2.86	
H(mm/d)	4.13	4.72	4.88	4.87	4.6	4.02	3.13	3.38	3.97	4.78	4.53	4.38	
Ea(mm/d)	2.38	2.93	2.69	2.33	2.21	1.4	0.78	0.71	1.05	2.06	2.08	2.22	
Δ/Γ	1.37	1.53	1.59	1.75	1.56	2.06	1.39	1.69	1.79	1.58	1.37	1.37	
Eo(mm/month)	101.8	120.4	120.9	118.4	110	99.91	64.4	71.62	88.7	111.8	104.89	104.1	1210.84

Where Ta air temperature (O_c)

ea saturation vapor pressure (mmHg)

RH relative humidity (%)

ed actual vapor pressure (mmHg)

U_2 wind speed at 2m above the ground (mile/day)

Tk Temperature in Kelvin

n daily mean bright sunshine hour (hr/day)

N maximum possible sunshine hours determined by latitude and season (10^0N for the Study area, taken from standard tables)

$ƒa$ a function of sunshine hour

Ra solar radiation which depends on latitude and season (10^0N is taken from standard table)

R_l in coming solar radiation (mm/day)

r albedo (reflection coefficient for incident radiation=0.05 for water)

δ Stephan-Boltzman constant

Ro out going solar radiation (mm/day)

H available heat (mm/day)

Ea energy for evaporation (mm/day)

δT_a^4 Theoretical black body radiation (mm/day)

Δ slop of saturation vapor pressure plotted against temperature

γ hygrometric constant ($0.27 mmHg/o_F$)

E_O open water evaporation (mm/day)

4.2.6.2. Estimation of Potential Evapotranspiration (PET)

Potential Evapotranspiration (PET) is evapotranspiration from vegetable cover if sufficient water is supplied to obtain optimum growth or the maximum amount of vapor which might be transferred under existing meteorological condition, water is not the limiting factor (Thornthwaite, 1944 cited in WMO, 1994; Bruce.J.P and Clark.R.H, 1966). Potential evapotranspiration is dependent on the evaporative capacity of the atmosphere or it is a theoretical calculation based on meteorological data (Freez and Cherry, 1979). It is dependent on continuous water supply.

There are several formulae for calculating potential evapotranspiration .For this study Penman modified and adjusted Thornthwaite methods are used based on the available data.

4.2.6.2.1. Penman modified method

This method is widely used to provide a numerical evaluation of the moisture content of a catchment as well as used as a first stage in calculation of evapotranspiration (Shaw, 1985).

$$PET=[(\Delta/\gamma)Ht+E_{at}]/[(\Delta/\gamma+1)] \qquad (4.15)$$

Where the extra subscript, t, signifies inclusion of transpiration effects.

$$Ht=RI(1-r)-Ro \tag{4.16}$$

Where r =the reflective coefficient for incident radiations, albedo, from the basin depending on the nature of the surface. This value usually varies between 0.15—0.25, 0.05—0.45,and 0.05 for lands covered with crops, bare lands and water surface respectively (Subramanya,1988;cited in Debebe Muleta,2005).Thus for the Berga river catchment r is assumed to be 0.23 for the vegetated surface .Then

$$Ht=RI\ (1-0.23)-Ro$$

$$=0.77RI-Ro \tag{4.17}$$

The term E_{at} is very similar to Ea in equation (4.14), the coefficient 0.5 being represented by 1 to allow for extra roughness in the wind speed function.

$$E_{at}=0.35(1+u_2/100)(ea-ed) \tag{4.18}$$

$$RI(1-r)=0.77Ra\,fa(n/N) \tag{4.19}$$

$$fa(n/N)=(0.16+0.62n/N) \text{ for latitude south of } 54.5^0 \tag{4.20}$$

$$Ro=\delta T_a^4(0.47-0.075\sqrt{ed})(0.17+0.83n/N) \tag{4.21}$$

As it is shown in table (4.9), the annual potential evapotranspiration rate of Berga river catchment calculated using Penman combined method is 1092.96mm. Lower monthly potential evapotranspiration occurs in the months of July and August because of their higher humidity in the atmosphere, lower wind speed and lower sun shine hours due to cloudiness (tables 4.7). Maximum potential evapotranspiration occurs in the months of February and March (113.36 and 112.5) mm respectively, which corresponds to their higher wind speed.

4.2.6.2.2. Thornthwaite method

Thornthwaite produced a formula (1948) for calculating potential evapotranspiration based mainly on temperature with an adjustment being made for the numbers of day light hour and latitude correction (Tenalem Ayenew and Tamiru Alemayehu,2001).The method requires only air temperature as an index of energy available and adjusted hours of day light for evapotranspiration ,so the values tend to underestimated (Shaw,1985).

The equation is given by:-

$$PET_m=16N_m(10t/J)^a \tag{4.22}$$

Where PET_m is monthly evapotranspiration (mm)

m months:-1, 2, 3 ...12

t monthly mean temperature (O_c)

N_m monthly adjustment factor related to hours of day light. For this work, it is taken at latitude 10^0N

J annual heat index, given by

$$J=\sum ji \qquad (4.23)$$

j monthly heat index, given by

$$j_i=(t/t_n)^{1.514} \qquad (4.24)$$

t_n mean annual temperature

$$a=6.7\times10^{-7}J^3—7.7\times10^{-5}J^2+1.8\times10^{-2}J+0.49 \qquad (4.25)$$

The potential evapotranspiration calculated by this method for the Berga river catchment is 704.29mm (table 4.10), which is smaller with respect to that calculated based on Penman method (table 4.9). For Berga river catchment the estimated potential evapotranspiration is the average of the two method; Penman and Thornthwaite; having value of 898.68mm/year (table 4.11).

Table.4.9 calculated PET of Berga river catchment using Penman modified method

parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total
T(Oc)	14.75	15.68	16.53	16.73	14.63	16	14.8	14.88	15.53	15.75	15.05	14.18	
ea(mm/d)	12.74	13.46	14.14	14.4	12.49	13.65	12.73	12.81	13.4	13.79	12.21	12.38	
RH(%)	54.28	55.36	57	62.62	58.93	71.22	81.71	83	77.13	60.39	56.28	54.5	
ed(mm/d)	6.92	7.45	8.06	8.96	7.36	9.72	10.4	10.63	10.34	8.33	6.87	6.75	
U2(mil/d)	66.78	88	76.19	74.58	73	52.05	46.14	43.46	47.75	57.95	61.17	62.78	
Tk(Ok)	287.8	288.7	289.5	289.7	287.6	289	287.8	287.9	288.5	288.8	288.1	287.2	
n(hr/d)	8.45	8.13	7.36	6.62	6.99	5.13	2.93	3.06	4.68	7.52	9.44	8.39	
N(hr/d)	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5	
n/N	0.73	0.69	0.61	0.54	0.55	0.4	0.23	0.25	0.39	0.64	0.81	0.73	
fa(n/N)	0.61	0.59	0.54	0.5	0.5	0.41	0.3	0.32	0.4	0.56	0.66	0.61	
Ra(mm/d)	12.8	13.9	14.8	15.2	15	14.8	14.9	15	14.8	14.2	13.1	12.5	
RI(1-r)(mm/d)	6.01	6.32	6.15	5.85	5.78	4.67	3.44	3.7	4.56	6.12	6.66	5.87	
δT_a^4	13.38	13.55	13.7	13.73	13.34	13.6	13.38	13.4	13.51	13.56	13.43	13.27	
Ro	2.85	2.66	2.4	2.09	2.25	1.61	1.1	1.15	1.52	2.41	3.09	3.4	
Ht(mm/d)	3.16	3.66	3.75	3.76	3.53	3.06	2.34	2.55	3.04	3.71	3.57	2.47	
Eat(mm/d)	3.4	3.96	3.75	3.26	3.11	2.09	1.19	1.1	1.58	3.02	3.01	3.21	
Δ/Γ	1.37	1.53	1.59	1.75	1.56	2.06	1.39	1.69	1.79	1.58	1.37	1.37	
PET(mm/d)	97.84	113.4	112.5	107.4	101	82.29	55.79	60.33	75.5	103.5	100.01	83.47	1092.96

Table 4.10 potential evapotranspiration of Berga river catchment calculated by Thornthwaite method

parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
t(Oc)	14.75	15.68	16.53	16.73	16.73	14.8	14.88	15.53	15.75	15.05	14.18	14.05	
j	0.937	1.03	1.11	1.13	1.13	0.942	0.95	1.010	1.04	0.971	0.884	0.870	J=12.003
Nm	0.97	0.98	1	1.03	1.05	1.06	1.05	1.04	1.01	0.98	0.97	0.96	
PET	52.62	59.6	66.13	67.74	67.74	53.34	57.13	59.8	58.63	55.62	53.39	52.55	704.29

Table 4.11average potential evapotranspiration (mm) for the study area

method	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
penman	97.84	113.36	112.5	107.35	101	82.29	55.79	60.33	75.5	103.52	100.01	83.47	1092.96
Thornthwaite	52.62	59.6	66.13	67.74	67.74	53.34	57.13	59.8	58.63	55.62	53.39	52.55	704.29
average	75.23	86.5	89.32	87.57	84.37	67.82	56.46	60.07	67.07	79.56	76.7	68.01	898.68

4.2.6.3. Estimation of Actual Evapotranspiration (AET)

Actual evapotranspiration is the real evapotranspiration that take place from vegetal cover under the existing soil moisture supply. A value of the actual evapotranspiration over a catchment is obtained by first calculating the potential evapotranspiration, and then modifying the answer by accounting for the actual soil moisture content (Shaw, 1985; Dunne and Leopol (1978).

Actual evapotranspiration is the amount of evapotranspiration that occurs under field conditions. If there is abundant moisture in the soil, the actual evapotranspiration rate equals to potential evapotranspiration rate. When the moisture content in the soil is limited and vegetation is unable to abstract enough water from the soil, then actual evapotranspiration becomes less than potential evapotranspiration. Thus the relationship between AET and PET depends on the soil moisture content. As soil moisture deficit increases, AET becomes increasingly less than PET. The values of AET depend on soil and vegetation types (Shaw, 1985). The values of AET become larger during dry period and less during rainy periods of the year .Always, AET≤ PET.

The actual evapotranspiration of the study area is calculated using two methods; Turk's empirical formula and Thornthwaite and Matter soil water balance method.

a) Turc method

This method is widely used to estimate annual values of actual evapotranspiration for large catchment. The formula uses only precipitation and temperature to calculate AET, since precipitation and temperature are dominant factors in evaporation (Shaw, 1985). It is given as:-

$$AET=P/\sqrt{\{0.9+P^2/[L(T)]^2\}} \quad (4.26)$$

Where AET is actual evapotranspiration

P is mean annual precipitation (mm)

T is mean air temperature (^{O}c)

$L(T)=300+25T+0.50T^3$

Using annual mean precipitation and mean air temperature 1119.26mm and $15.39^{O}c$ respectively, the calculated actual evapotranspiration of Berga river catchment becomes 699.0mm/year.

b) Thornthwaite and Mather soil water balance method

This method computes actual evapotranspiration through calculation of potential evapotranspiration. To calculate actual evapotranspiration, the proportion of vegetation cover with its soil moisture and soil type of the catchment must be known. A soil moisture budget can be made on a monthly basis for various types of vegetation classified according to their root constant (RC), which defines the amount of soil moisture (mm-depth) that can be extracted from the soil with out difficulty by given vegetation. This method needs monthly rain fall (P_m) and monthly potential evapotranspiration (PET_m) as an in put (Shaw, 1985; and Dunne.T and Leopol.B.L, 1978).

For this work the average potential evapotranspiration calculated by Penman modified and Thornthwaite methods (table 11) have been used to estimate the actual evapotranspiration of the study area. To calculate AET the study area has been classified in to two major groups of soil types (fine sand and clay) with four types of vegetation rooting depth (0.5m,0.6m,1.0m, and 1.5m).

Monthly actual evapotranspiration, AE_{Tm}, is found as:-

$$AET_m=PET_{m,} \quad \text{if } Pm > PET_m \quad (4.27)$$

$$AET_m=P_m+S_m-S_{m-1} \;,\quad \text{if} Pm < PET_m \quad (4.28)$$

Where, AET_m is actual evapotranspiration at a given month, m

PET_m is potential evapotranspiration at a given month, m

S_m is soil moisture at the end of a given month, m

P_m is monthly precipitation

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

Based on this method, the calculated annual actual evapotranspiration loss computed from four soil types and their corresponding land use units of the catchment is 664.25mm, i.e., 59.35% of the annual mean rain fall. The annual water surplus in the catchment is 513.98mm, which occurs in the months of June, July, August and September. The annual deficit is 234.64mm (table 4.16).

Table 4.12 Long term monthly actual evapotranspiration of Berga river catchment, for fine sand covered with cereal crops having 45mm field water capacity and 0.6m estimated root depth penetration. It covers 75.51% of the study area (229km^2).All values in the table are in mm.

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	24.14	42.93	66.36	81.29	68.11	129.9	252.29	258.58	132.73	32.96	14.62	15.34	1119.26
PET	75.23	86.5	89.32	87.57	84.37	67.82	56.46	60.07	67.07	79.56	76.7	68.01	898.68
P-PET	-51.09	-43.57	-22.96	-6.28	-16.26	62.08	195.83	198.51	65.66	-46.6	-62.08	-52.67	220.57
Acc.pot.WL	-212.4	-256.01	-279	-285.3	-301.5	0	0	0	0	-46.6	-108.7	-161.35	
Sm	38.71	37.36	37.27	35.92	35.14	45	45	45	45	43.56	41.8	40.26	
∆S	-1.55	-1.35	-0.09	-1.35	-0.78	9.86	0	0		-1.44	-1.76	-1.54	
AET	25.69	44.28	66.45	82.64	68.89	67.82	56.46	60.07	67.07	34.4	16.38	16.88	607.03
D	49.94	42.22	22.87	4.93	15.48	0	0	0	0	45.16	60.32	51.13	292.05
S	0	0	0	0	0	52.22	195.93	198.51	65.66	0	0	0	512.32

Table 4.13 Long term monthly actual evapotranspiration of Berga river catchment, for fine sand covered with shrubs and bushes having 150mm field water capacity and 1.5m estimated root depth penetration. It covers 2.7% of the study area (8.07km^2).All values in the table are in mm.

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	24.14	42.93	66.36	81.29	68.11	129.9	252.29	258.58	132.73	32.96	14.62	15.34	1119.25
PET	75.23	86.5	89.32	87.57	84.37	67.82	56.46	60.07	67.07	79.56	76.7	68.01	898.68
P-PET	-51.09	-43.57	-22.96	-6.28	-16.26	62.08	195.83	198.51	65.66	-46.6	-62.08	-52.67	220.57
Acc.pot.WL	-212.4	-256.01	-279	-285.3	-301.5	0	0	0	0	-46.6	-108.7	-161.35	
Sm	148.1	147.71	147.68	147.3	147	150	150	150	150	149.6	149.04	148.58	
∆S	-0.45	-0.4	-0.03	-0.4	-0.24	2.96	0	0	0	-0.43	-0.53	-0.46	
AET	24.59	43.33	66.39	81.69	68.35	67.82	56.46	60.07	67.07	33.39	15.15	15.8	682.59
D	50.64	43.17	22.93	5.88	16.02	0	0	0	0	46.17	61.55	52.21	298.57
S	0	0	0	0	0	59.12	195.83	198.51	65.66	0	0	0	519.12

Table.4.14 Long term monthly actual evapotranspiration of Berga river catchment, for clay soil covered with cereal crops having 75mm field water capacity and 0.5m estimated root depth penetration. It covers 2.11% of the study area (6.4km^2).All values in the table are in mm.

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	24.14	42.93	66.36	81.29	68.11	129.9	252.29	258.58	132.73	32.96	14.62	15.34	1119.25
PET	75.23	86.5	89.32	87.57	84.37	67.82	56.46	60.07	67.07	79.56	76.7	68.01	898.68
P-PET	-51.09	-43.57	-22.96	-6.28	-16.26	62.08	195.83	198.51	65.66	-46.6	-62.08	-52.67	220.57
Acc.pot.WL	-212.4	-256.01	-279	-285.3	-301.5	0	0	0	0	-46.6	-108.7	-161.35	
Sm	71.23	70.41	69.88	69.55	69.08	75	75	75	75	74.14	73.08	72.16	
∆S	-0.93	-0.82	-0.53	-0.33	-0.47	5.92	0	0	0	-0.86	-1.06	-0.84	
AET	25.07	43.75	.66.89	85.62	68.58	67.82	56.46	60.07	67.07	33.82	15.68	16.18	540.12
D	50.16	42.75	22.43	1.95	15.79	0	0	0	0	45.74	61.02	51.83	291.67
S	0	0	0	0	0	56.16	195.83	198.51	65.66	0	0	0	516.16

Table 4.15 long terms monthly actual evapotranspiration of Berga river catchment, for clay soil covered with grass having 200mm field water capacity and 1.0m estimated root depth penetration. It covers 19.7% of study area (59.8.km^2).All values in the table are in mm

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	24.14	42.93	66.36	81.29	68.11	129.9	252.29	258.58	132.73	32.96	14.62	15.34	1119.25
PET	75.23	86.5	89.32	87.57	84.37	67.82	56.46	60.07	67.07	79.56	76.7	68.01	898.68
P-PET	-51.09	-43.57	-22.96	-6.28	-16.26	62.08	195.83	198.51	65.66	-46.6	-62.08	-52.67	220.57
Acc.pot.WL	-212.4	-256.01	-279	-285.3	-301.5	0	0	0	0	-46.6	-108.7	-161.35	
Sm	198.6	198.28	198.08	198	197.8	200	200	200	200	199.7	199.28	198.93	
∆S	-0.34	-0.31	-0.2	-0.12	-0.18	2.3	0	0	0	-0.32	-0.4	-0.35	
AET	75.23	86.5	89.32	87.57	84.37	67.82	56.46	60.07	67.07	79.56	76.7	68.01	898.68
D	0	0	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	59.78	195.83	198.51	65.66	0	0	0	519.78

Table 4.16 Long term monthly actual evapotranspiration of Berga river catchment summarized from tables 4.12, 4.13, 4.14 and 4.15

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
AET	35.31	52.57	70.97	83.64	71.93	67.82	56.46	60.07	67.07	43.27	28.22	26.92	664.25
S	0	0	0	0	0	53.98	195.82	198.51	65.67	0	0	0	513.98
D	40.12	33.93	18.35	3.92	12.45	0	0	0	0	36.3	48.48	41.09	234.64

Where P is precipitation

PET: - is potential evapotranspiration

Acc.pot.WL:- is accumulated potential water loss, it is calculated by cumulating the negative values of (P-PET) for the dry Seasons starting from the end of wet season, which is October for this work.

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

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

AET: - is actual evapotranspiration, given as

AET=PET, if P>PET

AET=P+ ΔSm, if P<PET

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

D=PET-AET

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

For dry months, S=0

For wet months, S= (P-PET) – ΔSm

4.3. Runoff

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

The pattern of runoff volume of any basin is a function of duration of intensity and aerial distribution of rainfall, evapotranspiration, size of catchment, vegetation cover condition, topography and geology of the catchment. Topography determines the slope and location of drainage channels and the storage capacity of the basin. Channel slope and configuration are directly related to the rate of flow in a basin and the magnitude of the peak flow. Steep water shed will generally indicate a rapid rate of runoff with little storage, where as a relatively flat area is subjected to considerable storage and lower rate of flow (Clark J.W et al, 1977; Tenalem.A and Tamiru.A, 2001).

In the study area both perennial and intermittent streams exist. Berga River, which discharges all runoff from the catchment gauged near Kimoye village. The 26 year river discharge data collected from this station by the minister of water resource shows that 92.73 million cubic meters (mcm) of water leaves annually from the catchment in the form of runoff. Moreover, the amount of discharge is fluctuated from year to year (Fig 4.4), which is the reflection of drought and rainy years. For instance, river discharge in 1984 and 2000 is very low corresponding to high drought years in Ethiopia (1977& 1992 EC). The source of river discharge is both from effective rain fall and base flow component.

The data in table 4.17 indicates that higher mean discharge occurs in the months of July, August and September, which corresponds to higher rainfall amount in that period (Fig 4.2) showing direct correlation between runoff and rainfall.

Table 4.17 Long term (26 year) averaged monthly discharge of Berga River near Kimoye village

unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
mcm	0.67	0.56	0.696	0.923	1.333	3.824	21.576	35.801	20.952	4.162	1.468	0.763	92.728
m3/s	0.26	0.22	0.27	0.36	0.51	1.48	8.324	13.81	8.08	1.61	0.57	0.29	35.784

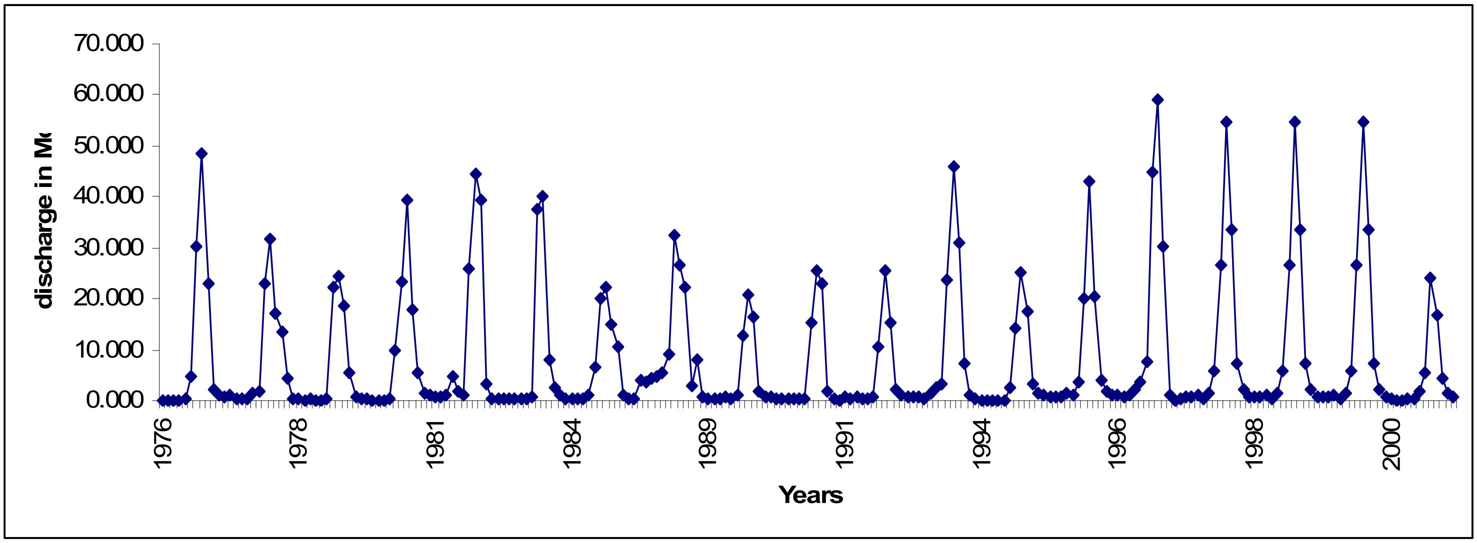

Fig 4.4 19 years (1976—1978, 1980—1982, 1984, 1986, 1989—1991 and 1993—2000) Berga river discharge in million cubic meter (mcm)

4.3.1. Base flow separation method

From river discharge, surface runoff and base flow should be separated using the conventional graphic separation method. The method shows that about 39.33% of flow is contributed from base flow, covering 142.7mm from total runoff 372.3mm annually. Direct runoff contributes 229.6mm annually (table 4.18).

Table 4.18 base flow separation of Berga River

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Total Q(mm)	2.71	2.3	2.81	3.75	5.31	15.41	86.65	143.76	84.11	16.76	5.91	2.82	372.3
BF(mm)	2.1	2	2.1	2.5	3.2	5.6	19.5	45.5	37.2	15.5	5	2.5	142.7
SRO(mm)	0.61	0.3	0.71	1.25	2.11	9.81	67.15	98.26	46.91	1.26	0.91	0.32	229.6

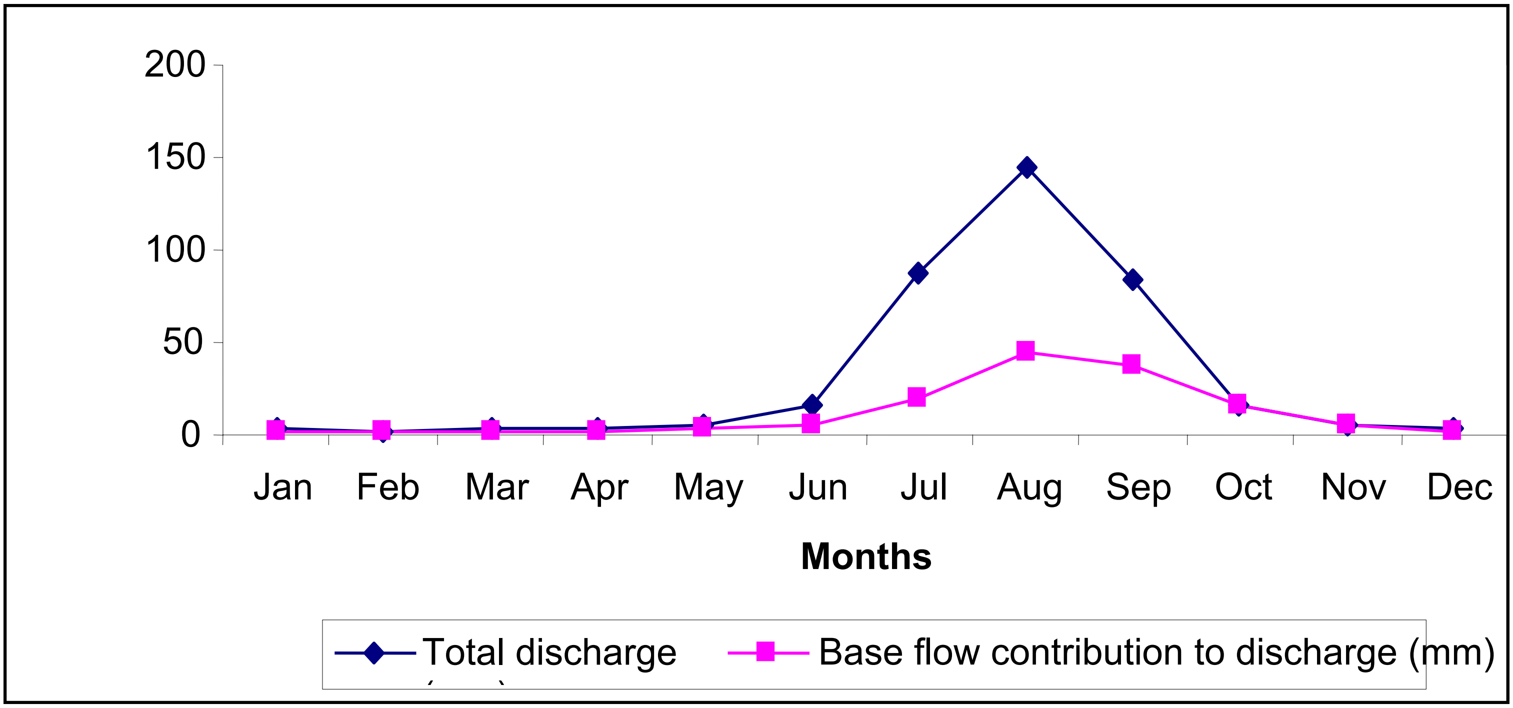

Fig .4.5. Base flow separation of Berga River

4.3.2. River discharge—Rainfall relationship

The nature of river discharge to rainfall relationship over long period depends primarily on the structure and composition of the catchment area, but it can also be affected by the climate of the area (Shaw, 1985).

As it is shown in bar graph (Fig 4.6), high rainfall occurs in the months June, July, August and September, but the maximum river discharge records in the months of July, August and September. From this relationship, even though there is high rainfall in June its river discharge is low, showing most part of the rainfall infiltrates to subsurface to saturate or up to the infiltration capacity of soils.

The catchment is characterized by high rainfall, having sloppy and elongated shape. Higher rainfall and sloppy behavior causes higher discharge whereas elongated shape and fractured rock causes lesser discharge. For this catchment higher rainfall and sloppy behavior dominates to cause high river discharge.

From the hydrogeological point of view, the catchment do not show fast response to rainfall at the beginning of wet seasons, but as rainfall increases the response becomes faster. This means, there is a time lag between high rainfall and run off. September has nearly equal rainfall and river discharge to June and July, having higher river discharge and lower rainfall than June and July respectively. This explains that there is a relatively higher residence time and storage of groundwater.

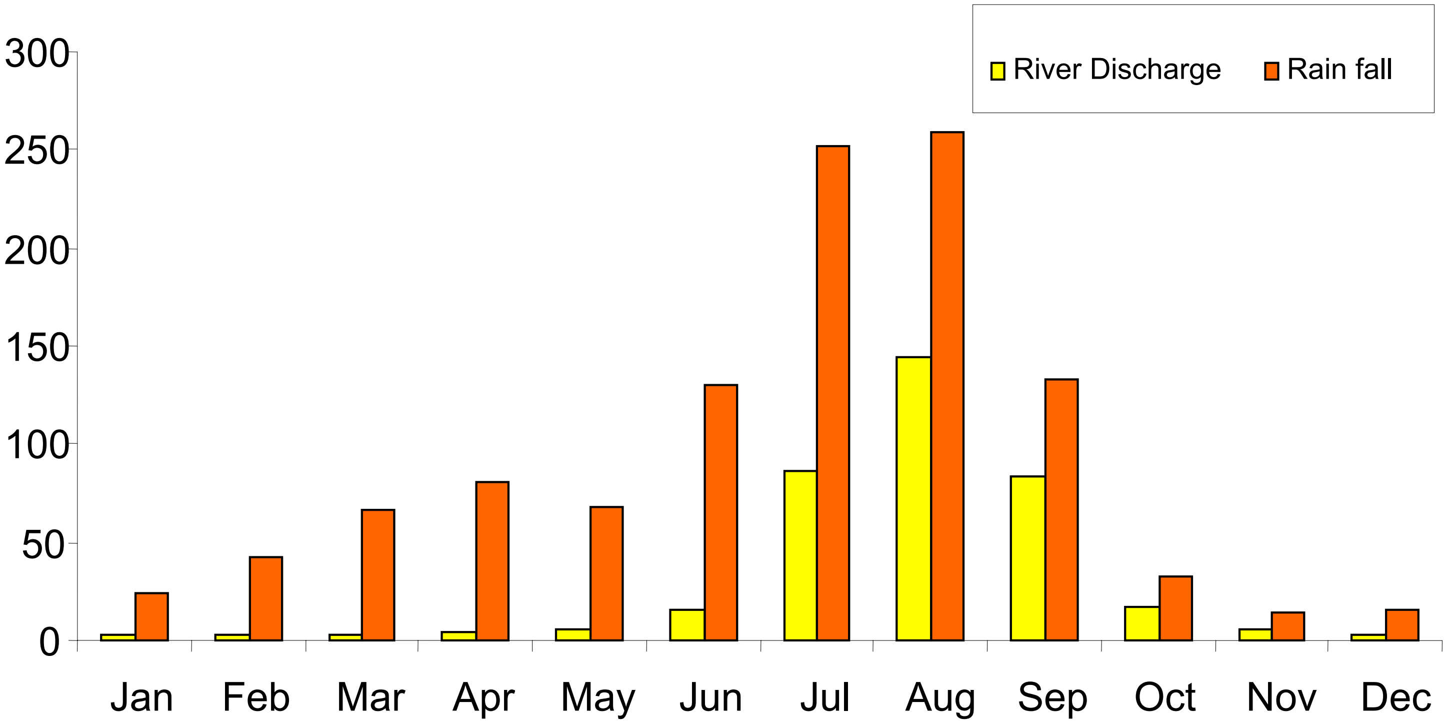

Fig 4.6   Bar graph showing river discharge—rainfall relation ship

CHAPTER FIVE: Hydrogeology

5.1. General

Hydrogeology deals with occurrence, distribution, and movement of groundwater in addition to physical and chemical relation ship with the surrounding environment .It encompasses the interrelation ship of geologic materials and processes with water(Fetter,1994).The occurrence , movement and distribution of groundwater is a function of many variables such as, meteorological, physiographical and geological formations. The behavior of geological materials towards interaction, storage and transmission of subsurface water constitutes the basic part of hydrogeology, i.e., hydrogeology is strongly associated with geological evaluation of the catchment. Based on their transmissivity and hydraulic properties, geological materials can be categorized in to aquifer, aquitard, aquiclud and aquifuge.

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

5.2. Aquifer characterization

An aquifer is a saturated geologic unit that is permeable enough to yield economic quantity of water to well (Kruseman and Ridder, 1990). An aquifer in a given geologic media is largely a function of the degree of weathering, fracturing and faulting; the nature of geologic material, sediment grain size, degree of sorting and packing. Considering all this facts together with topography, spring location, vegetation cover and settlement patterns were used to classify different lithostratigraphic units in to similar groups of hydrostratigraphic units.

The nature and distribution of an aquifer in a geological system is controlled by lithology, stratigraphy and structural features. Accordingly, the lithology of Berga river catchment is dominated by Tertiary volcanic rocks.

To characterize an aquifer quantitatively borehole density and their spatial distribution are the main important conditions. Where these conditions are not sufficiently found, hydro-geological description or interpretation is made by qualitative analysis of an area based on surface information and limited other data's.

In this work, due to lack of evenly distributed borehole data, undulated and steep nature of the topography, the description and interpretation of the lithostratigraphic units are given qualitatively with their similarity in hydrostratigraphic units and having homogeneity in hydrogeological characteristics such as degree of weathering and fracturing, topographic features, spring discharge and location.

In the study area, there are some boreholes drilled for town water supply and irrigation purpose. Their location is limited nearly along one line (south part of the catchment) longitudinally. Handdug wells, with 5—19m depth range having no Lithologic log, are found in the catchment. The area has plenty of springs, almost all of them are unprotected. From pumping test data and borehole logging, aquifers at Kimoye and deeper aquifers at Dobbi (>160m) are confined where as aquifers less than 160m at Dobbi site are unconfined type (table 5.1 and Fig 5.2).

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

5.2.1 High permeability and high groundwater potential zone

This hydrostratigraphic unit covers low lands in the study area. It includes areas near Kimoye village and areas between Bidubente and Iteya above Hinne village (Berga plain). Because of medium to high permeability of recharge area, relatively low topography and flat to gentle slope of the area, the rain water percolated at higher elevation of the catchment flows to this area through different mechanisms. The area is covered by alluvial clay deposits and slight to highly fractured and weathered basalts. From seven boreholes drilled in this zone, only two boreholes have complete pumping test data.

Wells drilled in this hydrostratigraphic unit gives 10—25 L/s yield, 15—22m^2/d transmissivity and 0.6—0.8m/d hydraulic conductivity (table 5.1). Hand dug wells with estimated yield of 4.6—4.8L/min are found in this lithostratigraphic unit. From pumping test data aquifers at Kimoye well field is confined type, showing a relatively lower draw down as pumped at higher discharge rate for longer time, borehole Kimoye-1&2 (table 5.1).

5.2.2 High permeability and medium groundwater potential zone

This hydrostratigraphic unit covers most parts of the study area. It is characterized by highly weathered, fractured and jointed Ignimbrite, Rhyolite /trachyte. This unit is found on a relatively steep slope area. In most places the lateral extent of aquifers are limited in some directions because of undulated land nature. It has a higher elevation than the previous hydrostratigraphic unit. All boreholes drilled in this hydro-stratigraphic unit (four boreholes) have complete pumping test data. The data shows that as depth increases aquifer type changes from unconfined to confined depending on the degree of weathering and fracturing of basaltic rock (table 5.1 Dobbi 1, 2, 3&4;5.2 and Fig 5.3-b).

Wells drilled in this unit gives 1.5—5.6L/s, 0.2—4.2m^2/d and 0.004—0.13m/d yield, transmissivity, and hydraulic conductivity respectively. Springs in this zone has an estimated yield of 0.125—0.250L/s. Most handdug wells are found in this lithostratigraphic unit. This unit bounds Berga River and its tributaries in both eastern and western directions, trending nearly in the NE—SW, parallel to Berga River flow direction.

5.2.3 Moderate permeability and low groundwater potential zone

This hydrostratigraphic unit is lithologically similar to that of section 5.2.2, but found at higher elevation and more dissected area. It is characterized by highly weathered, fractured and jointed Ignimbrite, Rhyolite/Trachyte and at some places upper basalt. It forms the water divide of the catchment in most area and ridges and hills.

Due to the presence of joints, faults and high weathering, this lithostratigraphic unit has moderate permeability. Because of undulated topography , rugged valleys and ridges(looks like mountain chain), most of the precipitation goes as surface runoff and the infiltrated water immediately drained and leaves the area to discharge area. In this unit, there are some springs having very low discharge which serves as a starting point of streams and for drinking by local community. No borehole and handdug wells drilled.

5.2.4 Low permeability and very low groundwater potential zone

This hydrostratigraphic unit is moderately weathered, fractured and jointed rocks. Extreme surface runoff is favored on this formation due to its high topography and ridge forming. It is found as small portion with in different areas in the catchment.

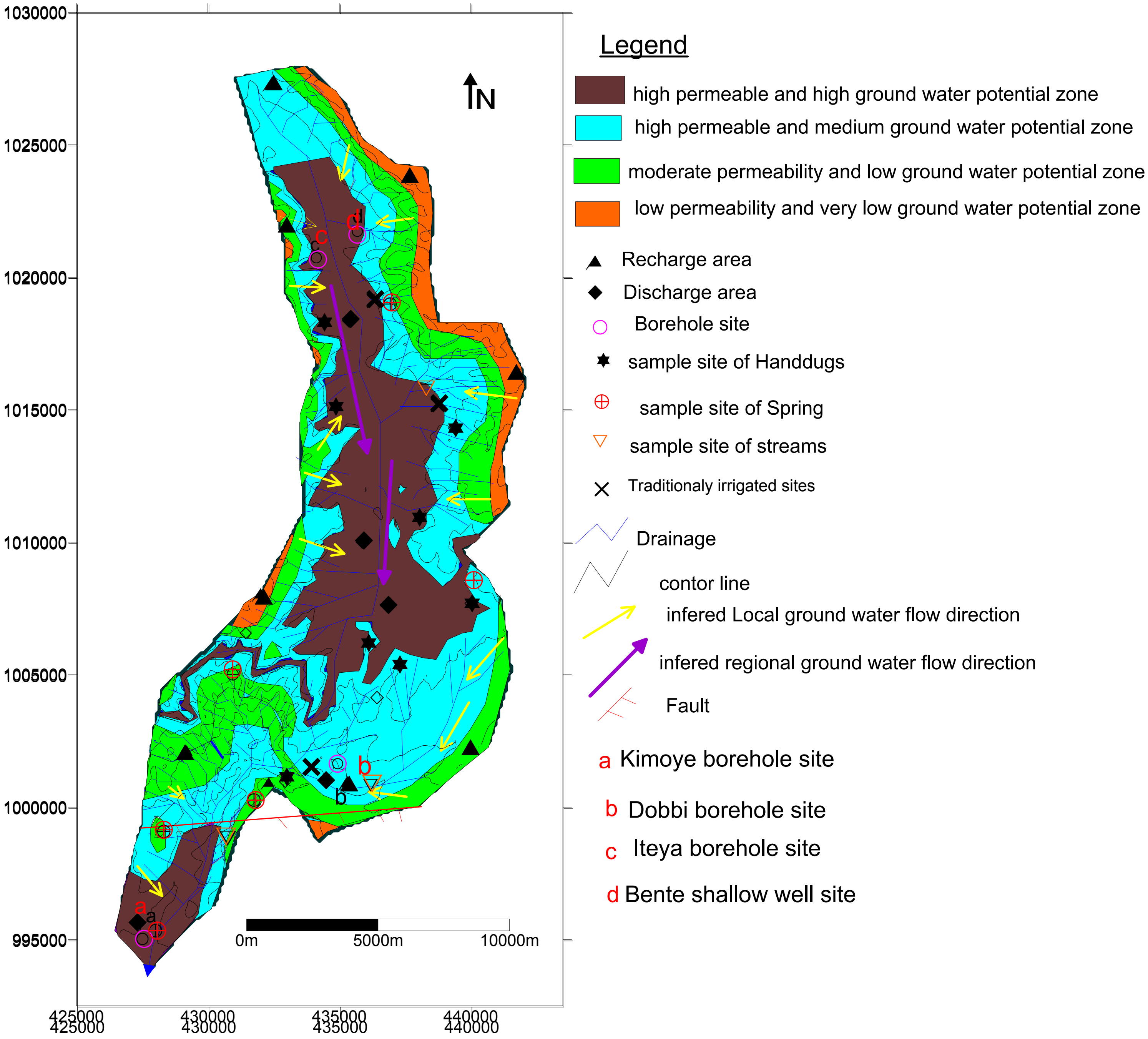

Fig 5.1 hydrogeological map of Berga river catchment

5.3 Recharge and discharge area

A recharge area is a portion of drainage basin in which the net saturated flow of groundwater is directed away from water table and there is a component to the direction of groundwater flow near surface that is downward, where as a discharge area is a portion of drainage basin in which the net saturated flow of groundwater is directed toward water table and there is a component to the direction of groundwater flow near the surface that is upward. In recharge area the water table usually lies at some depth where as in discharge area it is usually at or very near the surface (Freez and Cherry, 1979; Tenalem Ayenew and Tamiru Alemayehu, 2004).

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

As indicated in Fig 5.1, the main recharge areas of the catchment are elevated parts that found at the peripheries of the catchment, mainly in western and eastern parts of the water shed and some domes and cones inside the catchment. When compared to discharge area, recharge area is relatively covers larger part of the catchment. Different streams start from recharge areas and flow down to join the main river in the central part of the catchment 0r disappear in thick clay soil area. Springs are manifestations of ground water in this area.

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

The lower elevated land in the study area gets recharge mainly from direct precipitation and to a lesser amount groundwater flow from upstream sides of the catchment is expected to feed them through streams and springs along limited fracture lines. The later condition is clearly observed during dry period with the fluctuation of their discharge indicating the variation of water table from rainy to dry seasons.

In the study area, different streams locally have their own recharge and discharge area forming their subcatchment. This is because of the undulation nature of topography which may cause local ground water flow, Dobbi well site is an example of this type .Dobbi well site acts as both recharge and discharge area.

5.4 Groundwater flow direction

Groundwater is an important sources of water, always occur in the form of liquid state, it may provide a base flow for rivers, or act as an under ground reservoir from which water can be pumped as a location in to which water can be drained. Usually groundwater movement is continues and slow from recharge to discharge areas (UNESCO, 2004). Groundwater is feed by surface and subsurface waters by means of infiltration and percolation processes. Topography governs the direction of groundwater flow. Groundwater table is coincident with the ground surface in the valleys, and forms a subdued replica of the topography (Tenalem Ayenew and Tamiru Alemayehu, 20001).

In the study area, groundwater flow follows topography. Ground water provides a base flow for streams, manifested by many springs which flow towards streams from sloppy area. The general flow of groundwater, as can be deduced from the spring’s elevation and flow direction, is towards the Berga River from both the eastern and western high land areas. The total increase of electrical conductivity (EC) and total dissolved solid (TDS) down the Berga river indicates that the river is feed by groundwater (table 5.2) and groundwater flow direction in the catchment is nearly parallel to river flow regionally and an increase of chloride concentration in Dobbi well site down the stream in borehole indicates that the flow of groundwater follows topographic condition, parallel to the stream (Annex 7.8).

5.5 water Resource

Boreholes, Handdug wells springs and streams are considered as water resources in Berga river catchment. They have been used for different social and economical purposes of the community with in the catchment. The availability of water resource varies from place to place due to geomorphic set up of the area.

5.5.1 Boreholes

Boreholes are drilled wells with drilling machines (rigs) at different depth for different purposes. They are used for water supply, industries, irrigations, groundwater monitoring and as injection wells for industrial waste disposal purpose. Boreholes in Berga river catchment are drilled mainly for two purposes, water supply and irrigation.

In the study area, there are eleven boreholes. Most of them are drilled in the southern, but one deep and two shallow wells are found at the northern part of the catchment. Boreholes in the northern part of the catchment have no any hydro-geological data except lithological log for two shallow wells. The eight boreholes in the southern part of the catchment are all deep wells (4 at Dobbi and 4 at Kimoye sub-catchments) of which 6 boreholes are drilled for irrigation purpose (flower plantation).

Boreholes drilled on high permeability and high groundwater potential zone have relatively good yield, transmissivity and hydraulic conductivity (10—25L/s, 15—22m^2/d and 0.6—0.8m/d respectively). Those boreholes drilled on high permeability and medium groundwater potential zone (Dobbi well field) has relatively smaller yield, transmissivity and hydraulic conductivity (section 5.2.2). As indicated in borehole logging (Fig 5.2) and interpreted from electrical resistivity survey, the water bearing formation of the boreholes is multiple volcanic aquifers that are all basalt with varying in degree of weathering and fracturing.

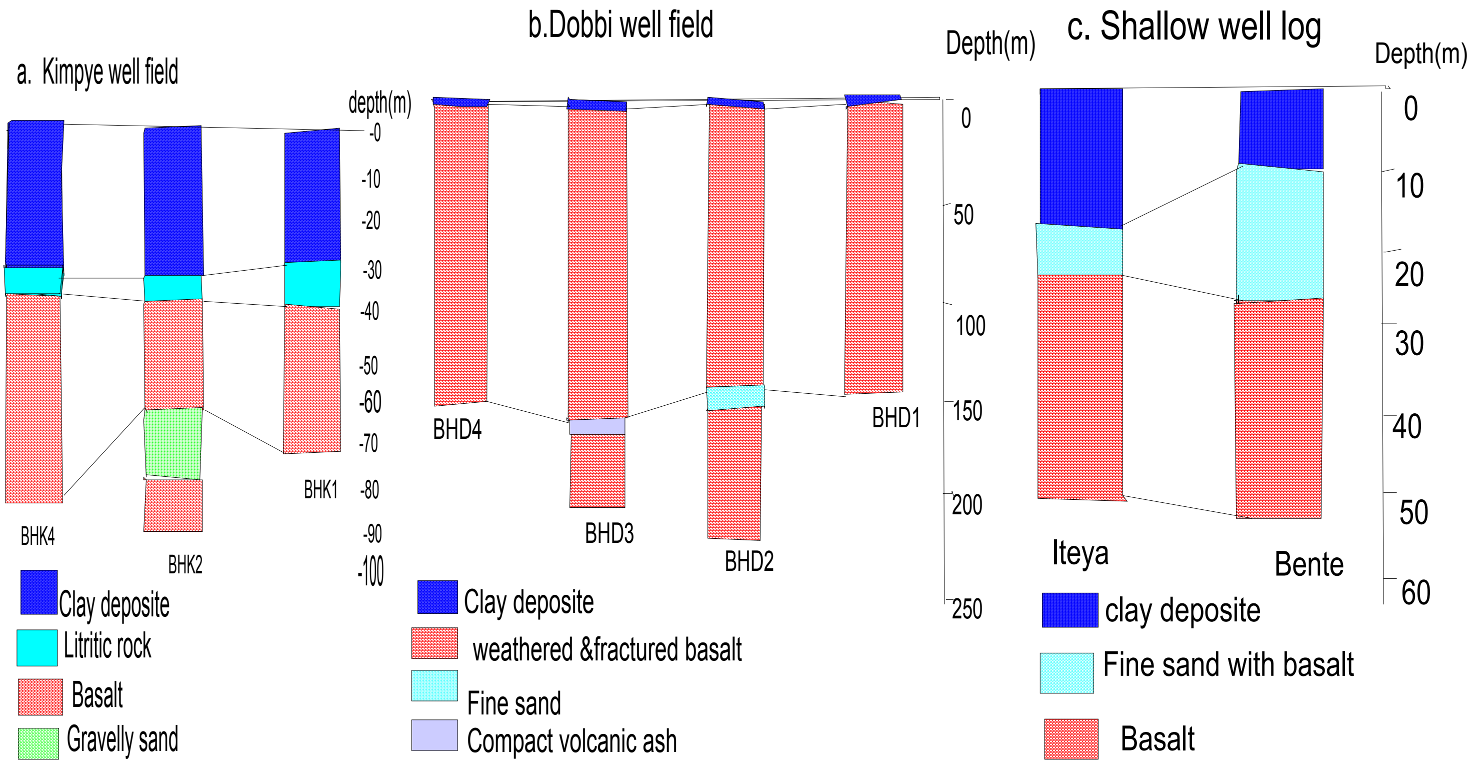

Fig 5.2 Borehole logging, geological section of Berga river catchment at borehole sites (not to scale)

Table 5.1 hydraulic characteristics of boreholes in Berga river catchment

Borehole	Location(UTM)		Altitude(m)	Depth(m)	SWL(m)	DWL(m)	hour/Q(L/s	thickness(m)	Tm2/d)	K(m/d)	aquifer type
	Latitude	Longitude									
Dobbi1	434019	1000122	2349	147	4.8	74.5	0.8/1.5	45	0.34	0.008	basalt
Dobbi2	434162	1000155	2348	221.5	12	89.16	0.42/4.5	99	0.922	0.009	basalt
Dobbi3	435393	1000246	2363	206	9.93	31.16	36/5.6	32	4.17	0.13	basalt
Dobbi4	436130	1000470	2372	153	36.62	136.7	12/1.5	52	0.24	0.005	basalt
Kimoye1	427355	994914	2125	72	14.25	28.85	2/19.6	30.1	21.23	0.705	basalt
Kimoye2	427195	994947	2125	89.75	16.73	38.17	7/24.4	22.88	17.99	0.786	basalt
Kimoye3	427626	994817	2126	108	14.1			40			basalt
Kimoye4	427749	995048	2132	82.8	11			33.3			basalt
Iteya1	432447	1024466	2616	161							basalt
Iteya2	432360	1024158	2612	50							basalt
Bente1	433354	1026420	2634	52							basalt

5.5.2 Handdug wells

These are very shallow groundwater sources. They are excavated in the top alluvial deposits and some parts of the underlying weathered rocks. Handdug wells are good sources of water where local or regional groundwater is very shallow.

In the study area, local peoples use manually dug wells from alluvial silty clay soils and some very less fractured and weathered ignimbrite, rhyolite/trachyte. Most handdugs are found in central part of the study area and are newly constructed and hand pump installed. The maximum drilling handdug well in the study area is 19m on fractured and weathered ignimbrite/trachite near Arusse village and the minimum is 5m on alluvial deposit near Illu-Berga village.

5.5.3. Springs

Natural springs may be defined as points, lines, or limited area of earth's surface through which groundwater rises up according to hydrogeological characteristics of various water bearing formations occurring at shallow or greater depth. Springs occur in many forms and have been classified by means of their origin, rock structure, discharge, temperature and variability (Tenalem Ayenew and Tamiru Alemayehu, 2001). Spring is a way in which a concentrated discharge of groundwater appears at the ground surface as flowing water forming a very small stream. Very small discharge is said to be seepage, but a relatively larger discharge could be defined as spring.

As explained by Foster et al (1982), springs may form in two ways:-

- A spring may formed where a fault has produced groundwater barrier
- A spring may also formed if water accumulates over a localized aquiclud, example clay layer

In the study area, springs are the most common available and relatively evenly distributed water resource. Almost all springs in the catchment are formed due to local faulting and/or fracturing .They are emerging mainly at a foot of the slopes and on steep slope areas. Their discharge varies according to the recharge area coverage, fracturing effect, and seasonal variation. They display seasonal discharge variation. Their availability and discharge rate increases from higher to lower topography. Some protected springs with hand pump have an estimated discharge rate of 0.125—0.250L/s. most springs which may have more than this discharge rate are unprotected and have no hand pumps.

5.5.4 Streams

Water from rainfall, after reaching the ground surface, flows down to the nearest stream channel, spreading first as more or less thick water sheet or wild water film(the major factor for catchment erosion) which overly the surface of the land. Then, with the hydrographic net, streams(frequently die in alluvial and fluvial materials occurring in river beds and banks) flow and gather in to torrents(perennial or temporary water courses) and rivers(perennial) that finally finds their way down to the sea. Rivers or streams can be classified as gaining or loosing type. A stream or river which receives groundwater discharge is termed as gaining or effluent stream/river, its base flow increases down stream. Where as if streams feed groundwater reservoir, they are termed as loosing or influent stream. The bottom of loosing stream channel is higher than local water table (Tenalem Ayenew and Tamiru Alemayehu, 2001).

In the study area, many streams are found mainly on the eastern side of Berga river. This water resource is mainly used as water supplies where springs and handdug wells absent and for traditional based irrigations on relatively flat areas (Duffa, Hida-billo, Jello and Dobbi streams from wider to smaller irrigation area coverage respectively). Most streams are intermittent and do not directly join the main river in the form of surface runoff during dry seasons, disappearing at silty clay flat area, where as some are perennial. Most streams in the study area are gaining type.

Streams like Adama, Gerado, and Hida-billo have higher EC than Berga river. Moreover, EC and TDS of Berga river generally increases down stream showing that the river is feed by ground water (table 5.2).

As shown in the table 5.2, steams in the catchment has 0.202—0.364ms/cm EC, varying from stream to stream. The spatial variability in EC value is not uniform, indicating local variability in degree of weathering and fracturing in each subcatchment. The higher the degree of weathering and fracturing the higher its EC value, this is evidenced by Addama stream that flows starting near the main fault in the catchment (table 5.2 and Fig 5.1)

Table 5.2 some streams and their corresponding Ec and TDS in Berga river catchment

No	stream name	Location(UTM)		Altitude(m)	EC(ms/cm)	TDS(mg/L)	area name
		Latitude	Longitude				
1	Chacho				0.231	137.8	Bidubente
2	Gerado				0.323	193.8	Bidubente
3	Jello				0.288	170.4	Bidubente
4	Hida-billo				0.297	178	Duffa village
5	Dillo				0.282	164.6	Dillo village
6	Dobbi				0.202	125.6	Near Addis-Alem
7	Adama				0.364	184	above Korma cone
8	Berga	434523	1020845	2643	0.274	163.7	below Jello
9	Berga	435576	1017023	2569	0.301	182.4	near Bekete village
10	Berga	433578	1015024	2468	0.295	175.2	above Hinne village
11	Berga	427895	995227	2353	0.308	185.2	near kimoye village

CHAPTER SIX: Water Resource Evaluations

6.1 General

Water resource supply is dependent up on topography and meteorological conditions, as they influence precipitation and evapotranspiration. But the quantities of water stored are dependent largely on physical features of the earth and geological structures (Clark et al, 1977).

The techniques of water resource evaluation require an understanding of the concept of hydrologic parameters. Water resource evaluation of a catchment is mainly used to answer the following questions:-

- Long term yielding capacity of the aquifer
- Influence of proposed development of water resource on the component of hydrologic cycle
- Distribution of groundwater and surface water and their interaction
- Volume of water in storage and that leaving the catchment
- Potential pollution sources and extent with future forecast
- Potential for small scale irrigation

6.2 Surface water

Evaluation of surface water resource of an area requires determination of the general characteristics of the region and all available data on the climate, hydrology, geology and topography of the area should be accounted (Clark et al, 1977).

In previous chapters, the available data, meteorological and hydrogeological parameters are analyzed to evaluate water resource of Berga river catchment. Accordingly, the total mean annual surface water resource of the catchment is 92.73million cubic meter (372.3mm). This amount of water cannot be used for irrigation and it leaves the catchment in the form of runoff. Due to regionally restricted vertical permeability of the layered volcanics of the area, numerous springs flows and contributes to surface water system.

6.3 Groundwater

The source component of groundwater is completely dependent on hydrological cycle that provides water through a catchment and subsequent infiltration process. So investigation of the source requires only hydrological knowledge. Since the reservoir is under ground, the subsurface geology becomes an important media for groundwater existence (Sen. Zekin, 1995)

Groundwater is known to be a renewable resource (Tesfaye Chernet, 1985). Therefore, it is necessary to consider the amount of replenishment in evaluation of groundwater resource with in a given catchment/basin for efficient utilization and management of available water resources. Groundwater replenishment is take place through the process of infiltration and percolation. Water resource evaluation requires understanding and analyzing of both hydrometeorological and hydrogeological parameters.

Meteorological and hydrogeological parameters are analyzed in previous chapters (4 and 6), to evaluate water resource of the study area. As explained in section 1.2, one of the main objectives of this work is to evaluate water resource of the catchment using water balance approach. 82.71mm of water is used to recharge groundwater annually in the catchment, which 7.4% is of annul precipitation (table 6.1).

6.3.1 Groundwater Recharge

Groundwater recharge is the down ward flow of water reaching the water table, forming an addition to the groundwater reservoir.

As explained by Tenalem Ayenew and Tamiru Alemayehu (2001) many factors that influence infiltration also affects the recharge process. These includes:-

- Topography and geology
- Magnitude, intensity and duration of precipitation

- Nature and depth of the soil type
- Ability of aquifers to accept water
- Condition of rivers
- Runoff and pounding of water

In the study area the main source of recharge is from direct precipitation. The annual recharge in the catchment is 82.71mm (25.1mcm), which is 7.4% of annual precipitation.

6.4 Groundwater and Surface water interaction

Surface water is hydraulically connected to groundwater, but their interactions are difficult to observe and measure. Groundwater and surface water interactions can be affected by natural processes and human activities. Due to their interaction the contamination of one system can result in long term contamination of the other. The upward discharge of ground water in valleys caused by the change in slope of water table from being steep on the valley side to being relatively flat in the alluvial valley results in the presence of wet land. Channel irregularity is an important control on the location of groundwater in flow to streams, because change in slope determines the length and depth of groundwater and surface water interaction zone. Interaction of groundwater and surface water in a river valley is affected by the interchange of local and regional groundwater flow system with the river and by flooding and evapotranspiration. Near the bases of mountains water table interacts steep valley wall at some distance from the base of the slope, resulting in perennial discharge of groundwater (Winter et al, 1999).

In any catchment, surface water (stream, river, lake, or wet land) is either gaining or losing. Streams that receives groundwater discharge is gaining whereas that allows water to seep in to groundwater is losing. For water to discharge in to stream channel, the altitude of water table in the vicinity of the stream must be higher than the altitude of the stream water. For surface water to seep in to groundwater, the altitude of water table in the vicinity of the stream must be lower than the altitude of stream water.

In high land areas, precipitation moves down through hill sides to streams, stream flow is strengthened by discharge from groundwater, as springs. In areas of steep land slopes and lower parts of the hill slope water table intersects the land surface resulting groundwater discharge directly to the land surface, resulting overland flow. These are small streams that receive groundwater inflow from local flow systems which usually have limited extent and have highly variable seasonal discharge.

Most streams flowing from ridges and hills across the alluvial valley loss water to subsurface as they traverse the higher permeable area. Berga is the largest stream in the study area that flow in alluvial valley. During dry period, groundwater from regional flow system discharges to the river as well as at varies places across flood plain. During high flood period water moves in to groundwater system as bank storage, as lateral flow through river banks and/or as vertical seepage over flood plain.

During dry period the discharge of many streams is very small, groundwater is lost from the aquifer to the streams along stream profiles. The water table rises and falls depending on the amount of rainfall in different seasons, affecting the amount of stream discharge at that period.

6.5 Water balance of the catchment

In water balance evaluation both natural and artificial gains and losses in water supply must be considered. The primary natural gains to surface bodies are those which result from runoff caused by precipitation and effluent seepage of groundwater. Evapotranspiration and unrecovered infiltration are the major natural losses. Water balance describes the hydrologic regime in a catchment.

Generally, water balance is given as:-

$$\text{Inflow}=\text{Outflow}+\text{ Change in storage} \qquad (6.1)$$

Where in flow includes precipitation and groundwater in flow

Out flow includes evapotranspiration, runoff, groundwater out flow and infiltration

Therefore, the relation of these water balance component is shown as follows:-

$$P+Gi=AET+Ro+Go+I\pm\Delta S \qquad (6.2)$$

Where P is precipitation

Gi and Go are groundwater in flow and out flow respectively

AET is actual evapotranspiration

Ro is runoff

I is infiltrated water to soil, affected by AET & it affects Ro and groundwater recharge(R)

±ΔS change in storage (Recharge)

Assuming the catchment is water tight and no subsurface movement of water across the defined water shed, to conduct the water balance on long term averaged data equation (6.2) can be reduced in to:-

$$P = AET + Ro \pm \Delta S \qquad (6.3)$$

Using this formula, the recharge of the catchment is 82.71mm (7.4% of annual precipitation) (table 6.1). Groundwater recharge in the catchment occurs in three months (June to August). Whereas in the other months groundwater contributes to AET and total runoff, this condition is shown by negative value of recharge in table below.

As shown in Fig 6.1 and table 6.1 the annual surplus and deficit in the catchment is 513.98mm and 234.64mm respectively.

Table 6.1 water balance of Berga river catchment (all in mm)

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	24.14	42.93	66.36	81.29	68.11	129.91	252.29	258.58	132.7	32.96	14.62	15.34	1119.26
PET	75.23	86.5	89.32	87.57	84.37	67.82	56.46	60.07	67.07	79.56	76.7	68.01	898.68
AET	35.31	52.57	70.97	83.64	71.93	67.82	56.46	60.07	67.07	43.27	28.22	26.92	664.25
S	0	0	0	0	0	53.98	195.82	198.51	65.67	0	0	0	513.98
D	40.12	33.93	18.35	3.92	12.45	0	0	0	0	36.3	48.48	41.09	234.64
Total Q(mm)	2.71	2.3	2.81	3.75	5.31	15.41	86.65	143.76	84.11	16.76	5.91	2.82	372.3
BF(mm)	2.1	2	2.1	2.5	3.2	5.6	19.5	45.5	37.2	15.5	5	2.5	142.7
SRO(mm)	0.61	0.3	0.71	1.25	2.11	9.81	67.15	98.26	46.91	1.26	0.91	0.32	229.6
Recharge	-13.88	-11.94	-7.42	-6.1	-9.13	46.68	109.18	54.75	-18.45	-27.07	-19.51	-14.4	82.71

Where P= precipitation PET = potential evapotranspiration AET = Actual evapotranspiration
S= soil moisture surplus D = soil moisture deficit Total Q = total river discharge
BF = base flow SRO= surface runoff mm= millimeter

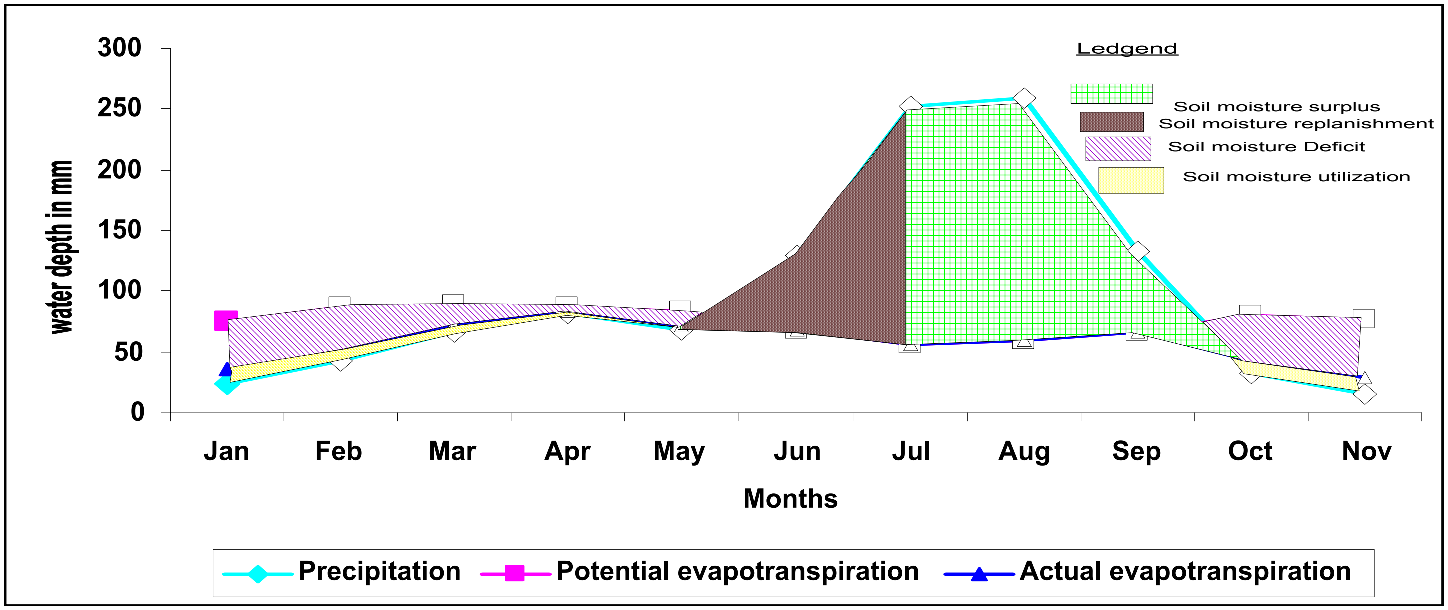

Fig 6.1 Water balance of Berga river catchment

CHAPTERSEVEN: Hydrochemistry

7.1 General

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

Organic matter in the soil is degraded by microbes, producing high concentration of dissolved carbon dioxide (CO_2). This process lowers the P_H by increasing carbonic acid (H_2CO_3) concentration in soil water. The production of carbonic acid starts a number of mineral weathering reactions, which result in bicarbonate (HCO^-_3) commonly being the most abundant anion in the water (Winter et al, 1999)

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

7.2 Water sampling and analysis

Samples are collected from different water sources, i.e. boreholes, streams, unprotected springs and handdug wells to compare parameters among these sources. To analyze geochemical properties of water with in the catchment, water samples are taken from appropriate and representative sites. Totally 15 water samples are collected from 2- boreholes, 5- handdug wells, 5-springs and 3-streams. But due to limitation of budget, only 3-samples chemical laboratory analysis was done in water works design and supervision enterprise. Additionally 6-boreholes, 6-handdug wells, 1-spring and 1-stream water chemistry data analyzed by different laboratories (water works design and supervision enterprise, Oromiya water resource bureau water laboratory, Addis Abeba water and sewerage authority laboratory, and Saba engineering PLC laboratory),done from 2003—2006 , were collected from different governmental and non-governmental organizations.

To understand the hydrochemical property of the study area a total of 6-boreholes (3- at Dobbi and3-at Kimoye well site), 7-handdugs (2, 1, 2 and 2 at the northeastern, western, eastern and south eastern of the catchment respectively), 2-springs (1 at northern and 1 at western part of the catchment) and 2-stream (1 at southern and one at northeast of the catchment) samples chemically analyzed data were used.

7.3 Water type classification

Classification, interpretation and presentation of chemically analyzed water sample results depend on the specific objective of the analysis. For instance, water used for drinking has different quality and analysis from that of for agriculture and industries.

In order to utilize water for different purposes, it is essential to classify water on the basis of:-

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

7.3.1 Classification based on total hardness (TH)

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

Total hardness (TH) is given by:-

$$TH=2.5Ca+4.1Mg \qquad (7.1)$$

Where Ca and Mg are given in mg/L

Based on table 7.2, the water type in the study area is grouped as hard and very hard, except 1-handdug well and 1- stream which are moderately hard and soft respectively. Water samples from boreholes are harder than near surface sources. This indicates that the aquifer in the study area is Ca and Mg-bearing volcanic rocks, rocks reach in olivine, pyroxene, amphibole and feldspars. This is due to a relatively longer residence and flow time of water in deeper aquifers.

Table 7.1 Hardness classification of water (Durfer and Becker, 1964; cited in Tenalem Ayenew and Tamiru Alemayehu, 2001)

Hardness in mg/Las CaCo3	water classes
0—60	soft
61—120	moderately hard
121—180	hard
>180	very hard

Table 7.2 water classification based on hardness of Berga river catchment

water source	no of samples considered	minimum value(mg/L)	maximum value(mg/L)	average value	water class
Borehole	3	230	424	327	very hard

	3	123	175	149	hard
Handdug well	1			83.6	moderately hard
	1			320	very hard
Spring	1			162.8	hard
	1			308	very hard
Stream	1			40	soft
	1			143	hard

7.3.2 Classification based on Total Dissolved Solids (TDS)

Total dissolved solids include all solid materials in solution, whether ionized or not. As it is related to the sum of concentrations of all ions, it is directly related to electrical conductivity. Total dissolved solid of natural water range from less than 10 ppm of dissolved solids for rain and snow to more than 300,000ppm for some brine. Thus the total concentration of dissolved solids can be used for simple classification of water (Tenalem Ayenew and Tamiru Alemayehu).

As shown in table 7.4 the water type of Berga river catchment is fresh. This is due to the short resident time of water in the catchment.

Table 7.3 water classification based on TDS values (Tenalem Ayenew and Tamiru Alemayehu, 2001)

water type	TDS(ppm)
Fresh water	0—1,000
Brackish water	1,000—10,000
salty water	10,000—100,000
brine water	>100,000

Table 7.4 water classification of Berga river catchment based on TDS value

water source	no of samples considered	minimum(mg/L)	maximum(mg/L)	average	water type
Borehole	9	138	479	308.5	Fresh

handdug well	11	64	367	215.5	Fresh
spring	9	148.2	395	271.6	Fresh
stream	8	125.6	193.8	159.7	Fresh

NB For this analysis, in addition to laboratory results, in-situ measurements are also used

7.3.3 Classification based on major cations and anions

Of all chemical data analyzed in different laboratories only 12- samples have complete major ions analysis:- 6-boreholes, 2-handdug wells, 2-springs and 2-streams. So classification based on major ion is done depending on this available data. Naturally, the total ionic concentration of cations is equal to the total ionic concentration of anions. This character, which is termed as electrical neutrality, is used as a check on the accuracy of chemical analysis (Tenalem Ayenew and Tamiru Alemayehu, 2001). The major ionic species in most natural water are Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO^{-}_3, CO_3^{2-}, Cl^{-}, and SO_4^{2}.

Reaction errors are used as a method to assess the quality of data. Using the error range recommended by Maser, 1977(cited in Debebe Muleta, 2005), i.e. a reaction error (RE) up to 5% is acceptable, except one stream data all the data's analyzed are acceptable (annex 7.4).

$$RE=[(|TSC—TSA|)/(TSC+TSA)]100 \qquad (7.2)$$

Where RE is reaction error given as percentage

TSC Total Soluble Cations

TSA Total Soluble Anions

Before calculating RE all data's in mg/L must be changed to meq/L (UNESCO, 2004). This is done as follows:-

$$Meq/L=mg/LxCF \qquad (7.3)$$

Where meq/L is mill equivalent per litter

mg/L is mill gram per litter

CF is Conversion Factor (annex 7.1, 7.2 and 7.3)

In order to classify water on the basis of their respective percentage composition of cations and anions, they are recalculated (from their meq/L) from 100% each cations and anions separately (annex 7.3).

7.3.3.1 Chemical behavior of water samples

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

As already discussed in chapters 2,3,4 and 5, the study area is dominated by high land topography and tertiary volcanic rocks affected by high rain fall. Weathering and dissolution of these volcanic rocks (basalt, ignimbrite, and rhyolite/trachyte) releases elements in to water. These types of rocks are dominated by silicate minerals such as olivine, pyroxene, amphibole and feldspars. Calcium and magnesium are the major cations in this type of minerals. Like wise, the hydrochemical laboratory results of the study area show dominantly Ca followed by Mg and Na cations and bicarbonate anions (annex 7.1). The sum of Ca and Mg ions range from 56.57—93.3% where as that of Na and K is 6.7—43.4 %(annex 7.3). All water samples from hand dug wells, springs and streams are Ca-Mg-HCo_3 type. Samples from boreholes show special variability in water type in a shorter distance. This is more observable at Dobbi well site where the water type changes from Ca-Na-Mg-HCO to Ca-Mg-HCO to Ca-Mg-HCO-Cl type down the stream subcatchment. The case for this change is that an increases in Cl concentration down the stream catchment (Annex 7.8). Water type from Kimoye well site is generally Ca-Na-HCO_3 type (Fig 7.1 and Annex 7.3). The case for the difference in water type in the two well fields is that Kimoye well field is covered with thick alluvial deposit, which may be the source for Na, and found on a relatively flat area.

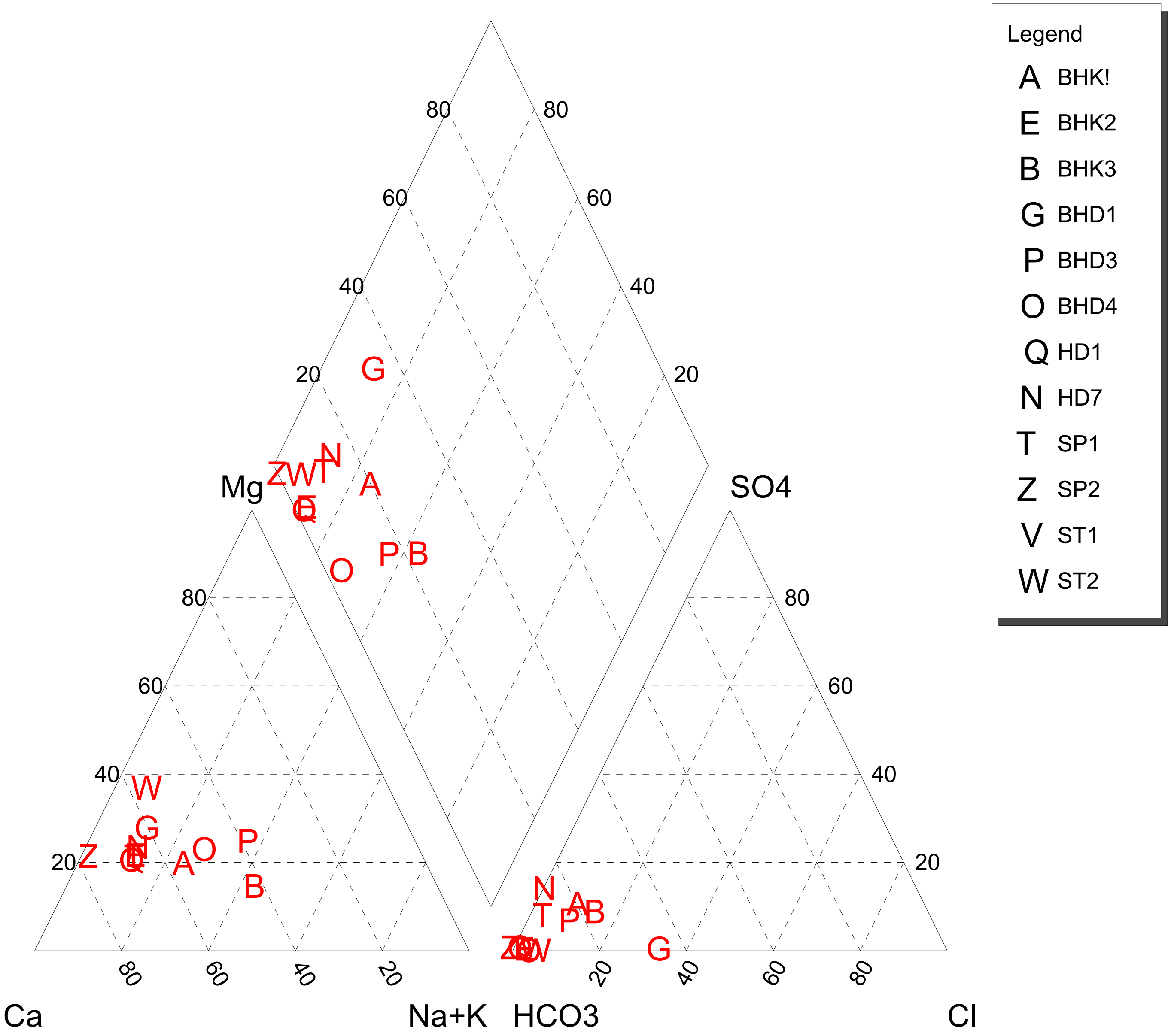

Fig 7.1 piper tri-linear plot of water samples of Berga river catchment

Where BHK1, 2 and 3 boreholes 1, 2 and 3 at Kimoye

BHD$_i$ = borehole i at Dobbi site

HD$_i$ = i Handdug wells

SP$_i$= i Spring

ST$_i$=i stream

The chemical behavior of water in the catchment is totally fresh (table 7.4) and mainly hard to very hard (table 7.2). The analysis shows that there is no recognized hydrochemical behavior difference from upper to lower catchment and among different water sources. This is because the infiltrated water leaves the recharge area with short time to discharge area due to undulated nature of the land and relatively higher permeability of the geologic formation.

7.4 Water quality

The primary purpose of water analysis is to determine the suitability of water for a proposed use. The three main classes of use are domestic, agricultural and industrial (Tenalem Ayenew and Tamiru Alemayehu, 2001). Therefore, in the assessment of water quality, it needs to identify the purpose for which the quality is referred to. Accordingly the quality for drinking is different from irrigation and industry.

Water quality standards are regulations that have specific limitations in the chemical constituents present in Water utilization and consumption for different purposes are examined in view of rejecting and accepting it depending on its intended use and given standards.

7.4.1 Water quality for domestic use

The exact optimum limits of all ions are actually controlled by the health, size, age and length of consumption of the individual (Freeze and Cherry, 1979).

In this work, two water quality standards or guide lines, WHO and Ethiopia has been used for comparison purpose with water quality of the study area (table 7.5)

Table 7.5 drinking water quality standard (source WHO and Ethiopia water quality standard/guide lines, 1993&2002 respectively, cited in UNESCO, 2004; Debebe Muleta, 2005)

			water source and range in study area (mg/L)			
parameter	WHO(mg/L)	Ethiopia(mg/L)	Borehole	Hand dug well	spring	stream
color	15	22	Nil—10			
turbidity	5	7	Nil—1			
PH	<8	7------------8.5	7.71—8.54	6.38—7.47	7.1—7.15	7.02—7.78
TDS	1,000	1,176	138—479	64—367	148.2—395	125.6—193.8
Hardness	300	392	123—424	83.6—320	162.8—308	40—143

Ammonia	1.5	0.4	Nil——0.25	0.17	0.154	
Sodium	200	358	11.69—53.0	4.2—16.49	2.53—10.6	7.5
manganese	0.1	0.13	Nil—0.20	0.003	0.003	
Total iron	0.3	0.4	Nil—0.04	Nil—0.2	0.45	0.04
cupper	1	2.0	0.0014—0.13	0.01	0.01	
Chromium	0.05	0.05	0.006—0.08	0.01	0.01	
Nitrate	50	50	Nil—16.72	Nil—28.2	10.45—10.56	4.3—5.1
Nitrite	3	6	Nil—0.03	0.0033	0.036	
sulphate	250	483	Nil—35.2	Nil—16	2—13.3	Nil—14.6
Fluoride	1.5	3	0.15—1.3	0.03—0.6	Nil—0.19	0.04—0.14
Chloride	250	533	4.0—64.0		Nil—4.7	1.2—3.8

As shown in the above table (table 7.5), almost all chemical constituents are with in the permissible limits 0f drinking water quality of WHO and Ethiopian standard/guide line, except those shows a slight change in parameters PH, Mn, total Iron and Cr at water sources of BHD3, BHD1, SP2&BHD1 having 8.54PH, 0.2mg/l, 0.45mg/l and 0.08mg/l respectively. This indicates that the area has fresh groundwater resource that is favorable for drinking purpose that could be used directly with out the need for chemical purification.

7.4.2 Agricultural water quality

Water quality, soil type and cropping practice play a role in successful irrigation. Goodwater quality permits maximum yield consistent with proper soil and water management. Water quality problems in irrigation include salinity and toxicity. Excessive salinity occurs when there is an accumulation of salts in top soils. Sodium has a far reaching effect on soils (Tenalem Ayenew and Tamiru Alemayehu, 2001). The type and concentration of salts depend on the geologic environment, the source and movement of groundwater. Weathering of primary minerals is the direct source of all soluble salts in groundwater. Sodium in the water originates from weathering of feldspars (albite), clay minerals and solution of evaporates (halite &mirabilite) (Boonstra, 1997). Groundwater salinity varies with the type and texture of sediments, solubility of minerals and contact time.

Water used for irrigation always contains dissolved salts. The salinity of the water governs its suitability for crop irrigation. Since it adds salt to soil and dissolves salt in root zone, irrigation also acts as a source of salts in groundwater. Evapotranspiration tends to concentrate salinity of groundwater. Thus highly saline groundwater may found in arid basins. The development and maintenance of successful irrigation projects involve not only the supply of water to the land but also the control of salt in the soil. When sodium rich water is applied to the soil, some of the sodium is taken up by clay causing Base Exchange and leading to plant growth retardation. Salinity is mostly measured by using electrical conductivity (EC) and sodium hazard.

The quality of water for irrigation can be measured using the following 3- methods with relation to EC.

- Sodium Adsorption Ratio(SAR)
- Sodium percentage among the principal cations(%Na)
- Residual Sodium Carbonate(RSC)

a) Sodium Adsorption Ratio

This method considers the concentration of sodium ion to the ratio of the concentration of calcium and magnesium ions. It is given as follows:-

$$SAR=Na/\{\sqrt{[(Ca+Mg)/2]}\} \qquad (7.4)$$

As indicated in table 7.7 and annex 7.5 water quality of Berga river catchment is excellent with respect to the calculated SAR values of analyzed samples.

Table 7.6 water classification based on SAR and EC (Tenalem Ayenew and Tamiru Alemayehu, 2001)

water class	EC in Ns/cm	Alkali hazard(SAR)
Excellent	<250	up to 10
Good	250—-750	10—18
Medium	750—-2250	18—26

Bad	2250—4000	>26
Very bad	>4000	

Where SAR is used as an index for sodium hazard and EC as an index of salinity hazard

Table 7.7 water classification of Berga river catchment based on SAR, all ions expressed in meq/L

water source	no of samples	SAR(meq/L)			water class
		minimum value	maximum value	average value	
Borehole	6	0.3222	1.79827	1.060235	Excellent
Handdug well	2	0.199834	0.4018997	0.30086685	Excellent
Spring	2	0.3611815	0.5098904	0.43553595	Excellent
stream	1			0.272644	Excellent

b) Sodium percentage among the principal cations (%Na)

The relative proportion of sodium to other cations in irrigation water usually has been expressed simply as the percentage of sodium among the principal cations.

It is given as follows:-

$$\%Na=[(Na+k)/(Ca+Mg+Na+K)]x100 \tag{7.5}$$

From %Na point of view, the quality of water in Berga river catchment is good, except BHK3 which is permissible, as shown in table 7.9 and annex 7.6. From EC point of view, the water is generally good except BHK2, HD1 and SP2, which are permissible (table 7.10).

Table 7.8 water classification based on %Na (source:- Tenalem Ayenew and Tamiru Alemayehu, 2001)

water class	EC in Ns/cm	%Na
Excellent	<250	<20
Good	250—750	20—-40
Permissible	750—-2250	40—-60
Doubtful	2250—-4000	60—80

Unsuitable	>4000	>80

Where %Na used as an index for sodium hazard and EC as an index for salinity, all ions given in meq/L

Table 7.9 classification of water in Berga river catchment based on %Na

water source	no of samples	%Na			water quality
		minimum	maximum	average	
Borehole	2	11.48	12.57	12.025	Excellent
	3	24.57	35.93	30.25	Good
	1			43.47	Permissible
Handdug well	2	10.7	11.8	11.25	Excellent
spring	2	13.23	13.3	13.265	Excellent
stream	1			11.85	Excellent

Table 7.10 water classification of Berga river catchment based on EC

water source	no of samples	EC(Ns/cm)			water quality
		minimum	maximum	average	
Borehole	8	276	596	436	Good
	1			789	Permissible
Handdug well	5	128	186.8	157.4	Excellent
	7	252	372	312	Good
	1			798	Permissible
Spring	2	143.7	224	133.85	Excellent
	6	311	661	486	Good
	1			770	Permissible
Stream	2	202	230	216	Excellent
	7	274	364	319	Good

NB .For this classification, in situ measurements are considered in addition to laboratory results.

c) Residual Sodium Carbonate (RSC)

In waters having high concentration of bicarbonate, there is a tendency for Calcium and Magnesium to precipitate as the water in the soil becomes more concentrated as a result of evaporation and plant transpiration. This reaction ordinarily does not go to completion, but when it does, there is a reduction in the concentration of Ca and Mg, and therefore, a relative increase in sodium. Ca and Mg are precipitated as carbonates, and any residual carbonate or bicarbonate is left in solution as sodium carbonate (Debebe Muleta, 2005).

Residual Sodium Carbonate is given as:-

$$RSC=(CO^{=}_{3}+HCO^{-}_{3})-(Ca^{2+}+Mg^{2+}) \qquad (7.6)$$

As displayed in table 7.12 and annex 7.7, all water in Berga river catchment is good with respect to RSC.

Table 7.11 water classification based on RSC

water class	RSC
Good	<1.25
Medium	1.25----2.5
Not suitable	>2.5

Table 7.12 water classification of Berga river catchment based on RSC

water source	no of samples	RSC(meq/L)			water quality
		minimum	maximum	average	
Borehole	6	-1.33357	1.205111	-0.128459	Good
handdug well	2	-0.23598	0.027556	-0.208424	Good
Spring	2	-0.235682	0.2248	-0.010882	Good
Stream	1			-0.180739	Good

7.5 Water Pollution

Pollution can be defined as, the addition of chemical, physical or biological substances which causes deterioration in the natural quality, generally through the action of man, animal or natural activities. Water is said to be polluted if it is not used for a specific purpose.

All solutes introduced in to a hydrologic environment are referred to as contaminants, regardless of whether or not the contaminations reach levels that cause significant degradation of water quality. A wide variety of materials have been identified as contaminants found in groundwater. These include synthetic organic chemicals, hydro-carbons, inorganic cations and anions, pathogens, and radionuclide (Fetter, 1999).

In the study area, the possible sources of pollution are agricultural activities and municipal wastes. Industrial sources of pollution are totally absent in the basin except those areas now started for flower farm. Agricultural sources include animal wastes, fertilizers, and pesticides. In general, the main pollutant sources are related to the intense fertilizer usage and animal waste distributed in the catchment. Due to fractured and jointed nature of the area, pollutants might leach and infiltrate to subsurface and contaminate groundwater.

7.5.1 Nitrate pollution

Nitrate is said to be pollutant when its concentration in the water is beyond certain limits that causes health risk. The main source of nitrate can be microbial break down of soil organic mater, organic manure, plant residues and agricultural sources (like fertilizers). Excessive concentrations of nitrate have a potential to harm infant human beings and livestock if it is consumed on a regular basis. Adults can tolerate much higher concentrations. Therefore, the extent to which nitrate in water viewed as a serious pollutant is depend on water use (Freeze and Cherry, 1979).

From 17-water sample chemical analysis, all of them have very low nitrate ion concentration (table 7.13). As indicated in table 7.5 the maximum permissible limit of WHO and Ethiopian water quality standard/guide lines is 50mg/L. Therefore, the water quality of the study area is good for a time being from nitrate point of view. Even though, this pollutant is not passing the maximum water quality standard/guide lines, their concentration is high in shallow ground water than deep boreholes (table 7.13). This shows that shallow groundwater is more susceptible to pollution from human source and activities because of its close proximity to land surface.

Table 7.13 Nitrate ion concentration in Berga river catchment water samples (in mg/L)

water source	no of samples	Nitrate ion in mg/l		
		minimum	maximum	average
Borehole	6	Nil	16.72	8.36
Handdug well	7	Nil	28.2	14.1
Spring	2	10.45	10.56	10.51
Stream	2	4.3	5.1	4.7

7.5.2 Chloride

Chloride ion occurrence in natural water is fairly low concentrations, usually less than 100mg/L, unless the water is brackish or saline. Chloride is used by human in many applications and can be added to subsurface through industrial discharges, sewage, animal wastes, and road salting. Commercial fertilizers can contain chloride as KCl. Chloride is a non-reactive substance and some times used as a tracer in groundwater studies (Fetter, 1999).

As shown in table 7.5 and 7.14, water samples of the study area have a very low concentration of chloride ion as compared to that of WHO and Ethiopian water quality standard/guide lines which are 250mg/L and 533mg/L respectively. So there is no health risk due to chloride ion in Berga river catchment.

Table 7.14 chloride ion concentration in Berga river catchment (mg/L)

water source	no of samples	chloride ion in mg/L		
		minimum	maximum	average
Borehole	6	4	64	34
Handdug well	2	Nil	Nil	Nil
Spring	2	Nil	4.7	2.35
Stream	2	1.2	3.8	2.5

7.5.3 Fluoride

Fluoride is present in minerals such as Fluorite (CaF_2) and apatite [Ca_5 (Cl, F, OH) $(PO_4)_3$]. Weathering of these minerals may release fluoride. Fluoride may also released as a contaminant from industrial processes utilizing hydrofluoric acid and manufacture of phosphate fertilizer from phosphate rich rock may release fluoride(Fetter,1999).

Fluoride is mobile under most geochemical conditions. In water, stability of fluoride is limited by the formation of CaF_2, high fluoride concentration will thus occur in low Ca-water.

The source of fluoride in the study area might be volcanic rocks that contain apatite deep in the earth's crust. This condition is obviously seen in that the fluoride concentration is relatively higher in boreholes than in handdug wells and springs (table 7.15).

Fluoride concentration in drinking water can have toxic effects in both excess and deficiency. Excess fluoride may lead to dental or skeletal fluorosis. A lack of fluoride may cause dental caries, a weakening of the teeth. As shown in table 7.15, all water samples in Berga river catchment have nil —1.3mg/l fluoride concentration range. These values are very less than WHO and Ethiopian water quality standard/guide lines. Thus, there is no health risk due to fluoride ion concentration in the study area.

Table 7.15 Fluoride ion concentration in Berga river catchment (in mg/L)

water source	no of samples	Fluoride ion in mg/L		
		minimum	maximum	average
Borehole	6	0.15	1.3	0.725
Handdug well	7	0.01	0.6	0.305
Spring	2	Nil	0.19	0.095
Stream	2	0.04	0.14	0.09

7.5.4. Micro-biological water pollution

In assessing water quality for domestic supplies, the content of micro-organisms in the water has much greater importance. Many harmful diseases are transmitted by water born organisms either with in parasitic carrier, like Schistosoma causing bilharzias, or as free-swimming pathogenic bacteria and viruses. The common organism Escherichia coli (E.coli) found in all human excreta is taken as an indicator of sewage position. Study of these organisms is advantageous because they are non-pathogenic, do not multiply out side the human body, and are easily identified and counted (Shaw, 1985; Tenalem Ayenew and Tamiru Alemayehu, 2001).

The most likely polluted water by micro-organisms are surface water and very shallow groundwater, i.e. handdug wells and springs emanate from shallow water bearing formation. Mostly, springs emerging from deep sources have low chance to be contaminated by micro-organisms which causes diseases.

In this work some handdug wells and spring samples were tested for their content of micro-organisms using membrane filtration methods. The coli form bacteria groups are organisms originating in the intestinal tract of warm blooded animals (Faecal-coli or E.coli) and organisms from soil or vegetation.

As indicated in table 7.16 two handdug wells are contaminated with coli form bacteria. The causes of contamination in these water samples is poor sanitary protection of the handdug wells due to shallow water table and related to human and cattle population in the area.

Table 7.16 Bacteriological laboratory results for Berga river catchment

no	site name	source	no of F.coli/100ml	no of E.coli/100ml
1	Arb-Gebeya	Hand dug	free	free
2	Illu-Berga	Hand dug	90	
3	Illu-Berga	Hand dug	6	
4	Rob-Gebeya	Hand dug	free	free
5	Dhamotu	Hand dug	free	free
6	Dhamotu	Hand dug	free	free
7	Arb-Gebeya	spring	free	free

CHAPTER EIGHT: CONCLUSIONS AND RECOMMANDATION

8.1 Conclusion

Berga river catchment is part of the upper Awash basin found at the starting point of the basin covering 303km^2 and bounded with in 8^{0}57'58" N—9^{0}18'35" N latitude and 38^{0}20'49" E—38^{0}29'33" E longitude. It has an average elevation ranges from 2080m—2920m above mean sea level. The area has 15.39^{O}c and 1119.26mm average monthly temperature and annual precipitation. The climate of Berga river catchment ranges from temperate to cool temperate (weina-Dega to Dega). The catchment is characterized by highly rugged topography in western and eastern parts and small flat plain areas at the central part.

The geology of the study area is mainly belongs to Trap series characterized by weathered and fractured basalt, ignimbrite, rhyolite/ trachyte and alluvial clay deposits. Ignimbrite, rhyolite/trachyte are mostly found in eastern and western parts forming ridges and hills and the water divide of the catchment where as alluvial clay deposits found on lower topographic areas along the river sides mainly at Berga plain and Kimoye areas. Basalts are found at some areas in the catchment in the form of dykes and cones forming higher topography.

Four meteorological stations with in and around the catchment had recorded 980.11mm—1204mm annual rainfall. Wellenkumy and Enchiny stations record minimum (980.11mm) and maximum (1204mm) annual rainfall values respectively, showing that rainfall values vary with altitude. The area has two rainfall regimes, small rain (bulge season, March to May) and big rain (Kiremt season, June to September), dominated by uni-modal type of distribution. The annual aerial rainfall computed by Theissen polygon method is 1119.26mm. The estimated mean annual relative humidity of the study area is64.37% with its minimum in January (54.24%) and maximum in August (83%). Wind speed at 2m height above the ground is minimum in August (0.8m/s) and maximum in February (1.64m/s) having an annual mean of 1.16m/s. the annual mean sunshine hour is estimated as 6.5hr/d with its minimum in July (2.93hr/d) and maximum in November (9.44hr/d).

As estimated by penman combined method, from the available meteorological data, the annual open water evaporation is 1210.84mm with its minimum in July to September and maximum in February to April. The potential evapotranspiration of the catchment is estimated using both penman combined method and Thornthwaite method. The mean annual potential evapotranspiration is 898.68mm with its minimum in July and August and maximum values from February to May. This minimum and maximum values of open water evaporation and potential evapotranspiration are corresponds to their relative minimum values of wind speed & sunshine and maximum relative humidity in the months of July to September; and maximum values of wind speed & sunshine and minimum relative humidity in the months of February to may. Based on soil type, land use categories and meteorological data, the actual evapotranspiration of the catchment is calculated using Thornthwaite and Mather soil water balance model. The annual actual evapotranspiration of the catchment is 664.25mm, 59.35% of the annual rainfall, leaves the catchment in the form of evapotranspiration. 92.73 million Cubic meter (or 372.3mm) of water, 33.25% of annual precipitation, leaves annually from the catchment in the form of runoff.

Streams in the catchment are mainly characterized as gaining type and have high variation of discharge from dry to wet seasons, during dry seasons many tributaries of Berga River could not directly join to it in the form of surface runoff; they disappear at flat area (alluvial clay deposits). At higher topography, there is higher infiltration and groundwater out flow following local fractures. Water that recharged at higher elevation discharged at low topographic area. 7.4% of annual precipitation (82.71mm/year) is used to recharge groundwater annually in Berga river catchment. Due to undulated topographic nature of the area and high permeability of geologic formation, the infiltrated rain water has shorter residence time at recharge area.

The main aquifer type in the study area is weathered and fractured basalt. The aquifer is multiple and mainly behaves confined type at Kimoye well field and at higher depth of Dobbi well field (>160m). It is unconfined type at a relatively shallow depth of Dobbi well field (up to an average of 160m depth). The confined wells have smaller drawdown when pumped at a relatively higher discharge rate for longer time. Where as unconfined wells have higher drawdown when pumped at a relatively smaller discharge rate for shorter time. The drawdown condition at two well sites is also an indicator of hydrostratigraphy, medium groundwater potential for Dobbi site. Groundwater potential of the catchment is more localized along weathered and fractured parts of the rock.

Because of high to medium permeability of recharge area, relatively low topography and flat to gentle slope of the area, rain water infiltrated at recharge area in the catchment flows to low land area along fractured and jointed zones. A nearly N—S elongated ridge at Hinne village dams the groundwater above it forming Berga plain (wet land) and increases groundwater circulation and storage of that area. Wells drilled at low land area gives 10—25 l/s yield having 15—22m^2/d transmissivity and 0.6—0.8m/d hydraulic conductivity. This area is covered with thick alluvial clay deposits (having up to 33m thickness at some locations, like Kimoye area). It is identified as high permeability and high groundwater potential zone and found along the Berga river line. High to moderate permeability with medium to low groundwater potential aquifers are found at a relatively higher topography along sloppy areas, covered with thin alluvial clay deposit having maximum thickness of 2m. Wells drilled on this hydrostratigraphic unit gives 1.5—5.6l/s yield and has 0.2—4.2m^2/d transmissivity and 0.004—0.13m/d hydraulic-conductivity.

Springs and streams are the common available water resources that are used by local people for domestic and small scale irrigation purposes. Springs emerge both at the foot and top of ridges and hill and used as the starting point of streams. The discharge of springs is variable depending on the amount of precipitation and recharge area coverage.

From 31-water samples field physical parameter measurement and 17-water samples chemical laboratory analysis, all water samples are fresh water with TDS range 64—479mg/l. The water quality of the catchment is mainly hard to very hard, indicating high concentration of $Ca\text{-}HCO_3$ in the water.

Based on chemical laboratory analysis, except boreholeDobbi-1(BHD1), which shows $Ca\text{-}Mg\text{-}HCO_3\text{-}Cl$ type, the water type of the study area is mainly Ca- Mg-HCO3 and Ca-Na- HCO3 type. In all water samples the concentration of Ca^{2+} + Mg^{2+} is greater than the concentration of Na^+ + K^+. There is no significant hydro-chemical spatial variation with in the catchment.

The drinking water quality of the catchment is almost with in the limits of WHO and Ethiopian water quality standard/guide lines, except two handdug wells found at Illu-Berga which have higher bacterial content due to poor sanitary protection. Based on SAR, %Na and RSC parameters, the water quality of the catchment is generally good for irrigation purpose. There are no water pollution indicators in the catchment, except bacterial pollution of some handdug wells at Illu-Berga Village.

8.2 Recommendation

Based on the available meteorological, hydrogeological and hydro-chemical data's and their analysis and out come of the study, the following recommendations are given:-

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

- The present water resource development activities like spring development, handdug well construction and shallow well machine drilling, particularly in rural areas, are very low. In order to solve drinking water supply and food deficiencies problems, water resource development activities should be practiced in the catchment.
- Conservation of over land flow and channel flow for possible aquifer recharge through land terracing, afforestation and proper land use, protection, management and safe use of natural resources are some of the basic strategies to mitigate drought hazard and enhance food security in the catchment.
- In order to understand and evaluate the aquifer behavior and groundwater potential zone precisely, additional boreholes, with evenly distribution and fully penetration, could be drilled in the catchment.
- Since wet land area in the catchment has small area connection to Abbay basin and Holleta catchment in the north and east boundaries of the catchment respectively, proper studies at these locations should be needed to understand the nature of boundary layer(permeable or not) and ground water flow conditions at these boundaries.
- Due to poor sanitary protection handdug wells and springs are micro-biologically polluted. These water sources need continuous follow up, sanitary protection and disinfection to keep healthy and productive community.

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ANNEX

Annex 4.1 Monthly total rain falls at Addis-Alem station (in mm)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1962	x	x	x	x	55	114.5	157.4	241.3	226.3	36.1	31.2	6.8
1963	8.4	39.1	32.2	160.2	141.2	.204.0	217.1	273.3	112.7	11.3	6.9	72.1
1964	0	3.5	80.1	76.1	88.9	156.7	222.3	145.9	124.4	38.5	0.6	15.3
1965	20.8	1.5	33.3	73.1	16.2	85.5	216.2	232.9	101.8	53.2	23.5	0
1966	3	87.3	72.6	180	49	148.7	293.3	397.7	160.5	30.5	8	0

1967	0	2	53	86	118	100.5	266.8	266.5	181	x	x	0
1968	0	131	18	180.5	39	179.5	257	377	184.5	13	0	0
1969	106	63	175	185	57	200	429	353	156	21	15	0
1970	41.5	89	124	44	74.5	149.5	397.5	307	198	51	0	1.5
1971	3	0	57	79	173	226.5	233	303.5	183.5	27.5	16.5	23
1972	28	71.5	60.8	152.5	70.8	116.2	215.5	260.5	156.5	1.5	17.5	0
1973	x	x	x	x	x	x	x	x	x	x	x	x
1974	0	25	132.8	11.1	110.5	97	241.2	281.6	150.6	2	0	0
1975	0	8.2	25.5	121	52	150.9	274.9	288.6	182.9	35.1	0	0
1976	20.5	4.1	50.8	54.5	89.5	96.8	266.1	295.9	104.2	17.8	19.3	2.5
1977	61.3	28.5	98	22	115.6	134	241.5	223.5	176.2	206	186.1	9
1978	7	56	49.5	39.5	41	163.5	315.1	231.2	232.1	75.5	2	25.5
1979	71.4	100	94.5	69	61	137	277	296	184.5	22	0	38
1980	33	45	62	69	69	168	215	236	138.4	1.7	8.1	0
1981	0	87.5	141	98.2	75.6	88	245.6	267	267	12	9	47
1982	52	49	42.5	65.5	70.9	65.5	228	256	59	64	112	40
1983	18	65	29	102	x	x	x	4	136.6	29.6	14.5	42.5
1984	2.5	0	32	12	138	157.6	157.4	150.5	109.5	3	8.1	8
1985	10	0	8	59.2	50	98.5	170	168.5	86.9	61.1	12	0
1986	2.5	64.3	105	89	148	138	193	179	121	16	3	4.5
1987	78	44.4	106	52	127	89	129	122	88	13	0	5.5
1988	11	35.5	9	55	13.9	117	182	242	127	21	0	0
1989	32	61	28	104	38.9	126.2	250.2	256	210	10.5	0	24
1990	9.6	131.6	55	55.8	105.1	111.5	187.6	342.8	196	13	0	7
1991	0	79.8	102.6	43.9	16.8	144.6	370.4	350.8	193.6	0	0	24.1
1992	41	50.7	72.4	85.5	33.7	75.1	323.1	385.4	234.3	36.3	5.4	8.2
1993	10.2	12.5	14.4	116.8	88.9	168.6	359.7	367.3	168.1	44.3	0	0
1994	0	0	34.5	44.8	37	218	x	x	x	0	17.5	x
1995	0	39.5	47.1	144.9	94.5	245.1	393.5	352.3	136.8	6.4	0	15.6
1996	0	7.9	129.5	70.1	160.4	163.2	371.9	326.6	123	6.2	0	2.2
1997	23.5	0	17.6	65.9	23.7	88.1	243.1	164.1	86.1	58.8	82.2	0.5
1998	53.2	86.5	107.4	67.3	101.1	198.1	289.5	251	154	53.9	13.9	0
1999	29.5	3.3	28.6	13.5	72.6	197.5	255	299.8	46.8	125.6	0	0
2000	0	0	12.5	103.1	135.4	168.1	266.6	238.1	186.8	28.4	17.4	29.2
2001	0	0	169.4	28.2	124.3	233.9	309.7	265	43.3	21.4	0	0
2002	48.6	83.8	77.8	26.4	35	174.5	333.1	275.3	38.8	0	0	34.9
2003	24.8	19.8	173.2	96	2.1	49.5	156	224.4	87.7	0	8.8	22.2
2004	17.5	27.6	70.5	144.6	69.9	143.2	190.4	212.5	172.5	57.9	11.3	x

X = missed data

Annex 4.2 long term mean monthly rain fall at Enchiny station

year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
1975	x	x	x	x	x	228.3	360.8	519.8	302	10.7	0.7	48	1470.3
1976	28.1	95.2	0	135.6	102.7	253.6	469.3	493.1	174.8	46.5	57.7	35.3	1891.9
1977	141.9	14.6	x	x	23.6	185	381.2	250.9	44.7	123.9	21.9	27.2	1214.9

1978	0	19.3	45.6	32.9	58	167.3	257	204.5	177.7	13.2	5.7	102.1	1083.3
1979	39.3	54.2	62.5	33.1	0	x	x	x	x	3.5	4.1	76.5	273.2
1980	28	15.8	0	84.1	54.4	173.4	330.8	269.7	115.9	41	9.5	0	1122.6
1981	10.4	2.4	155.8	190.5	35.4	72.1	366	221.2	52.4	x	x	x	1106.2
1982	0	14.6	75.8	45.2	108.2	93.1	248	294.4	104.7	105.9	105.6	10.5	1206
1983	8.5	52	71	97.8	253.6	119.1	312.7	338.9	140.6	27.6	45.7	4.3	1471.8
1984	x	0	0	0	0	35.4	188.2	110.8	262.7	0.2	0	0	597.3
1985	0	19.4	0	0	0	159.3	171.5	68.3	59.5	38.4	12.2	17.7	546.3
1986	0	11.1	x	x	x	x	x	x	x	x	39.8	11.6	62.5
1987	3.6	24.3	234	95.2	164.4	124	161	207.7	68.5	17.6	0	x	1100.3
1988	x	x	x	x	x	x	x	x	x	x	x	x	x
1989	38.9	105	14.4	81.3	19.2	163.4	254.4	358	121.1	54.9	1.8	x	1212.4
1990	12.5	58.7	0.5	4.2	39.8	157.9	396.6	x	x	x	12	11.1	693.3
1991	48.4	46	103	24.9	26.1	116.2	316.8	265.1	108.9	43.5	8.4	29.8	1137.1
1992	57.3	48.2	64.7	143.5	75.5	150.8	207.6	267.1	142.6	69.2	50.4	7	1283.9
1993	1.9	53	31.6	200.6	79.3	146.3	270.4	235.7	269.6	70	1.5	5.7	1365.6
1994	6.8	8.1	100.9	34.2	70.4	231.2	330.3	222.7	148.7	12.7	11.6	0	1177.6
1995	0	12.2	73.7	134.4	x	91.5	338.8	233.3	117.2	10	12.7	58.1	1081.9
1996	82.9	21.8	168.6	93.8	99	191.7	310.5	341.3	122.2	21.9	37.1	3.8	1494.6
1997	49.3	0	25.6	100	89	123.3	306.1	218.1	98.7	151.2	101.4	16.1	1278.8
1998	46	19.4	66.2	18.4	119.5	195	348.2	304.4	170	113	13	0	1413.1
1999	16.7	9.3	22.6	22.5	41	90.4	274.7	319.1	88.8	136.5	1.3	1.8	1024.7
2000	0	0	26.1	182.2	77.7	122.8	346.3	263.1	111.9	55.8	62.5	4.5	1252.9
2001	9.9	38.5	195	48.4	126.1	171.1	308.9	207	121.2	38.5	3.4	8.6	1276.6
2002	62.8	5.5	121.1	32	20.6	163.1	222.6	305.1	154.2	0	0	53.2	1140.2
2003	61.1	95.1	140.1	235.2	9.1	174.3	308.2	320.9	158.2	10.1	14.5	29.6	1556.4
2004	41.1	25.3	29.9	71.2	0	136.5	253.5	296	196.4	37.7	1.7	63.9	1153.2
Aver	29.46	31.04	70.33	82.35	65.1	139.2	277.3	274.5	139.7	48.21	22.72	24.09	1203.9

X= missed data

Annex 4.3 long term mean monthly rain fall at Holleta station

Year	Jan	Feb	March	April	May	Jun	July	Aug	Sept	Oct	Nov.	Dec.	Total
1980	45.30	21.20	81.00	88.00	62.10	163.70	241.00	232.30	110.90	25.80	1.20	0.00	1073
1981	0.00	22.50	117.70	111.70	34.90	56.10	366.50	258.10	188.80	3.60	0.50	15.40	1176
1982	43.40	58.70	84.70	120.30	53.70	84.90	250.90	284.50	124.60	42.20	46.70	30.30	1225
1983	19.90	49.40	120.40	126.30	219.10	87.50	241.20	284.10	101.90	23.80	3.90	22.70	1300
1984	0.00	0.00	41.80	8.50	141.60	178.50	260.50	221.80	106.10	0.00	0.60	13.10	973
1985	15.20	0.00	47.70	62.10	48.50	45.60	257.30	281.90	105.10	21.10	4.10	0.00	889
1986	0.00	51.20	88.00	139.10	89.00	157.90	243.90	279.40	144.00	11.90	0.00	0.00	1204
1987	2.40	77.30	112.10	82.40	137.00	86.50	182.10	261.80	112.90	19.00	1.40	27.40	1102

1988	10.30	78.70	7.80	90.10	21.10	107.40	291.60	283.90	239.90	31.90	0.00	0.20	1163
1989	7.10	86.90	78.00	69.80	8.30	74.90	240.70	279.30	117.50	3.00	0.30	21.60	987
1990	0.50	162.50	34.80	95.40	55.50	131.80	262.40	338.20	155.50	8.00	0.00	0.90	1246
1991	23.90	74.80	118.00	21.30	115.40	89.90	232.10	229.00	112.50	2.60	0.30	5.80	1026
1992	57.40	34.80	58.80	95.00	34.60	115.40	190.90	312.60	112.10	36.30	0.60	7.80	1056
1993	18.20	83.60	3.80	127.00	60.30	103.10	218.10	276.10	214.30	27.40	0.00	0.00	1132
1994	0.00	2.30	86.20	45.90	29.80	107.30	216.40	203.30	149.70	0.00	34.80	0.00	876
1995	0.00	84.60	41.90	123.80	81.30	91.60	197.10	262.70	82.10	15.50	0.00	34.00	1015
1996	62.60	8.50	96.10	58.40	55.40	183.80	249.80	226.60	120.70	5.30	1.40	2.30	1071
1997	15.30	0.00	21.10	95.40	13.50	131.00	233.50	193.20	42.50	53.50	23.60	2.10	825
1998	54.60	42.30	25.70	65.70	80.40	141.50	342.10	238.10	168.30	67.40	0.80	0.00	1227
1999	76.30	4.60	34.00	16.60	50.60	98.90	272.80	306.80	88.90	65.40	0.00	0.00	1015
2000	0.00	0.00	12.50	123.80	52.00	89.90	187.10	260.60	120.70	9.50	38.90	30.40	925
2001	7.9	10.6	130.7	48.6	100.6	175.5	301.6	162.1	103.2	24.2	0	0.1	1065
2002	72.6	25.7	56.8	37.1	48.9	123.2	273.1	194	77.4	0	0	15.7	925
2003	17.5	11.3	33.3	84.2	13.6	117.1	194	237.2	107.4	10	0	8.4	834
2004	12.7	0.8	42.5	155.1	27	121.4	204	226.6	119.7	3.6	0.7	0	914
2005	22	4.5	61.7	49.1	94.4	81.8	253.9	187.5	130.7	31.5	3.8	0	920.9
Average	23	40	63	84	65	115	246	253	125	20	6	10	1050

Annex 4.4 monthly maximum temperatures at Addis-Alem station (in ^{O}c)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997	x	x	x	x	x	x	x	21.0	21.3	23.4	20.7	25.2
1998	24.7	25.2	25.1	27.1	25.3	25.2	22.1	20.6	21.5	22.4	23.6	23.3
1999	23.8	26.2	24.3	24.2	25.2	23.8	21.2	20.8	23.3	22.3	23.0	24.0
2000	23.9	24.1	25.6	24.9	24.2	24.0	23.2	21.2	22.0	24.1	24.1	23.8
2001	24.1	25.5	24.7	23.6	20.0	23.3	21.9	21.7	23.5	24.4	24.3	24.4
2002	24.6	24.8	24.9	26.9	28.2	26.0	23.1	21.8	23.4	24.2	24.9	23.9
2003	24.8	24.6	26.2	26.1	27.8	23.3	20.7	20.8	22.3	25.6	26.1	25.7
2004	27.0	26.4	27.1	25.2	27.1	24.0	21.3	21.5	22.3	23.8	24.7	x

X= missed data

Annex 4.5 monthly minimum temperature at Addis-Alem station(^{O}c)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997	x	x	x	x	x	x	x	10.5	9.9	9.3	4.7	7.0
1998	9.6	11.0	11.2	11.9	11.5	10.9	11.0	11.8	10.3	8.6	4.4	2.7
1999	5.9	6.6	9.2	9.2	10.1	9.9	10.0	9.9	9.6	8.5	4.5	4.3
2000	4.5	5.2	7.3	7.5	7.5	9.4	9.5	9.5	9.7	7.8	5.7	4.7
2001	5.7	6.3	7.0	6.9	4.1	9.3	9.3	10.3	8.6	7.7	5.6	5.5
2002	7.0	7.3	7.3	8.6	9.6	9.2	9.9	9.5	7.6	6.4	6.1	8.7

2003	5.7	7.3	9.3	9.2	9.7	9.5	9.8	10.6	11.1	12.7	15.1	15.5
2004	13.5	12.6	14.1	12.8	14.9	12.0	9.8	10.5	12.8	12.4	13.0	x

X= missed data

Annex 4.6 monthly maximum temperature at Holleta station (^{O}c)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun	July	Aug.	Sept.	Oct.	Nov.	Dec.
1980	23.8	24.1	24.4	24.4	24.4	22.5	19.5	19.5	20.5	21.5	23	23.2
1981	24	24.2	22.5	22.4	24.6	24.5	19.6	19.3	19.6	21.4	22	22.6
1982	22.5	22.7	23.9	22.9	23.3	23.1	19.7	18.6	20.1	20.7	21	21.9
1983	22.7	23.6	24.2	23.1	22.7	22.4	21.2	19	20.1	21.3	22	22.4
1984	23.2	24.6	25.3	26.3	23.6	21.2	19.4	19.9	20.6	22.6	23	22.7
1985	23.6	24.2	24.6	22.7	23.3	23.4	19	19	20.1	21.4	23	22.8
1986	23.7	23.9	23.7	22.2	23.8	20.8	20.2	19.5	20.4	21.8	23	23
1987	22.9	23.6	22.5	22.6	22.6	22	20.9	20	21.5	22.6	23	23.5
1988	22.6	23.7	26	24.4	25.5	22.1	18.7	19.4	19.9	21.2	22	22.3
1989	22.4	22.3	23.2	21.6	24.1	22.6	19.4	19.6	19.9	21.3	23	22.1
1990	23.1	21.9	22.7	23	24.5	22.2	19.8	19.5	20.1	21.9	23	23.2
1991	24.2	23.8	23.3	24.4	25.9	23.8	19.5	19.8	20.9	22.2	23	22.7
1992	22.4	22.6	24.8	24.5	24.2	22.5	19.4	18.6	19.7	20.9	22	22.5
1993	23	22	25.1	22.4	22.8	21.6	19.6	19.4	19.4	21.5	22	23
1994	24.1	25.2	24.4	24.1	25	21.4	18.9	19.3	20.6	22.4	22	23.2
1995	24	24.3	24.5	22.5	23.9	23.6	19.4	19.6	20.6	22.6	23	22.8
1996	21.8	24.9	23.9	23.2	23.5	20.6	19.8	19.4	20.4	22.4	23	22.6
1997	22.9	24.6	25.5	23.8	25.3	23.4	20.2	20.3	22.2	22.4	23	23.5
1998	23.7	24.4	24.8	25.6	24.3	23.2	19.6	19.7	20.6	21.5	22	22.4
1999	23.2	25.2	23.9	25.5	24.5	23.1	19.1	19.4	20.5	20.6	21	22.3
2000	23.3	25.5	25.7	23.8	23.5	21.7	20.2	18.9	20.1	21.5	23	22.8
2001	22.9	24.8	22.4	24.3	23.7	21.2	19.9	19.5	20.6	22.7	23	23.4
2002	23.1	24.8	24.1	25.3	25.6	22.9	20.9	20.3	21.2	23.3	24	23.3
2003	23.4	25.3	23.5	23.3	23.3	21.5	18.1	18.7	19.7	21.9	22	22.2
2004	23.5	23.9	24.5	22.2	24.2	21.2	19.4	19.1	19.8	20.9	22.5	23.0
2005	22.9	25.3	24.5	23.8	22.0	21.1	19.5	19.7	20.1	21.4	22.0	22.9

Annex 4.7monthly minimum temperature at Holleta station (^{O}c)

Year	**Jan.**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
1980	5.1	6.7	7.8	8.6	8.4	8.4	9.5	9.3	8.4	5.2	3.5	1.7
1981	3.4	5.3	9.2	9.4	7.3	6.9	9.7	10	8.8	4.5	3	1.3
1982	5.7	8.3	6.3	9.2	8.9	6.9	9	9.5	8.1	5.5	5.5	4.4
1983	3	7.4	9.3	9.6	10.3	8.4	9.7	10.7	8.8	6.3	4.4	4
1984	4.1	3.8	8.8	9.4	9.2	9.2	8.7	8.3	7.4	2.2	3	1.8
1985	2.4	3.3	7	9	7.7	6.8	8.3	8.9	7.3	4.5	1.4	1.1
1986	0.2	6.3	6.2	9.1	8.2	8.5	8.6	8	7.1	3.4	1.5	2.1

1987	2.5	6	10.1	8.2	8.8	7.8	8.8	9.7	7.8	5.6	2.2	3
1988	4.7	8.5	5.6	8.8	6.9	8.3	10.4	9.9	8.9	5	0,2	0.3
1989	2.1	5.1	6.5	8.8	6.4	7.3	9.2	9.1	8.1	4.4	1.9	5.9
1990	2.6	9.9	7	8.5	7.7	7.3	9.3	9.2	8.5	4.3	3.5	0.7
1991	4.6	7.3	8.5	7.9	7.6	8.5	10.2	10	7.9	3.4	1.5	2.6
1992	5.7	8.6	8.2	8.2	8	6.9	9	10.5	7.5	5.9	3.2	3.7
1993	5.6	7.4	4.4	9.5	8.3	8.3	9.1	8.6	7.7	5.7	1.8	0.9
1994	1.6	3.9	8.3	7.8	7.3	8.1	9.9	9.1	6.6	2.4	2.6	0.5
1995	1.4	5.7	6.9	9.8	7.6	6.5	8.6	8.8	6.3	3.4	1.7	3.3
1996	5.4	3.5	7.7	7.4	7.3	8.2	8.6	8.3	7.1	3.2	2.5	1.6
1997	5.6	1.1	7.3	8.1	6.6	8.4	8.4	8.4	7.2	6.4	5.5	2.9
1998	6.5	7.7	8.7	8.8	9.1	7.8	9.3	9.3	7.8	6.6	0.6	-2
1999	1.7	1.1	6.2	5.7	6.9	6.7	8.4	8.1	6.4	5.8	0.1	0.4
2000	0.3	0.6	3.5	7.3	6.9	6.5	7.7	7.6	6.6	4.6	2.3	1
2001	2.6	2.4	7.3	6.4	5.5	6.7	7.9	8.2	5.1	3.5	1.1	3.2
2002	4.6	4.7	7.8	8.3	8.9	7.8	9.1	8.3	6.8	4.6	2.1	6.5
2003	5	5.8	6.9	9.4	8.3	7.9	9.2	9.1	7.8	3.75	2.2	2.3
2004	5.3	4.5	6.7	9.6	7.0	8.1	8.7	8.7	7.7	4.3	2.5	3.7
2005	3.4	4.5	7.3	8.0	9.4	7.0	8.7	8.8	8.3	4.3	1.9	-0.3

Annex 4.8 Long term mean monthly relative humidity at Holleta station (%)

Year	Jan.	Feb.	March	Apr.	May	Jun	July	Aug.	Sept.	Oct.	Nov.	Dec.
1980	49	46	52	52	51		71	70	65			
1981	35	41	61	59	39	50	81	95	72	42	33	38
1982	48	61	53	67	57	67	81	86	66	70	71	65
1983	56	61	61	68	71	69	80	87	82	66	58	56
1984	49	46	47	47	63	76	81	80	73	52	55	54
1985	53	51	51	66	62	61	80	83	75	57	54	52
1986	47	60	59	66	63	77	79	79	74	57	56	52
1987	49	49	69	64	67	73	79	77	69	58	49	49
1988	50	50	38	53	41	67	81	80	77	56	42	42
1989	51	49	52	61	41	61	77	76	73	52	45	59
1990	43	65	57	56	51	69	76	79	75	50	50	41
1991	45	54	53	42	45	62	84	82	73	48	43	47
1992	57	64	51	56	51	67	79	84	75	61	50	53
1993	57	64	46	69	66	77	82	83	81	62	52	44
1994	39	41	54	56	48	74	82	83	73	49	51	44
1995	43	50	53	66	56	63	79	81	73	52	46	48
1996	58	39	54	56	56	74	78	79	74	48	46	42
1997	54	34	43	55	42	59	77	75	64	59	59	51
1998	58	55	42	51	55	66	81	82	75	65	46	38
1999	45	33	53	39	49	62	77	78	72	68	43	48
2000	44	34	36	53	59	73	77	83	79	64	58	51
2001	55	46	61	52	65	75	80	83	74	59	49	48
2002	58	44	59	51	49	67.2	78	83	71	49	43.2	59
2003	50.2	43	46	61	46	62	81	83	81	56	51	52
2004	57	47	44	66	49	66	81	83	77	59	51	55

2005	57	45	56	47	65	68	83	80	76	62	72	47

Annex 4.9 Long term mean monthly wind speed at Holleta station (Km/hr)

Year	Jan	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov	Dec.
1981	5.75	5.87	4.95	5.15	5.69	4.68	3.96	4.2	4.03	5.46	5.62	4.99
1982	5.25	4.93	6.26	5.44	6.08	4.12	3.83	3.55	4.25	4.62	3.98	4.48
1983	4.37	4.84	4.81	4.76	4.72	4.22	3.61	3.29	3.48	4.36	4.56	4.46
1984	4.66	5.58	6.17	6.5	5.55	4.02	3.65	3.76	4.39	5.44	4.83	4.67
1985	4.65	5	6.59	5.13	5.14	4.05	3.57	3.62	4.03	4.88	4.48	4.54
1986	3.91	4.89	5.43	4.49	4.84	3.65	3.94	3.61	3.78	4.71	4.79	4.88
1987	4.66	4.65	4.53	4.98	4.6	3.77	3.48	3.44	3.98	4.18	4.2	4.57
1988	4.9	5.48	5.54	5.36	5.5	3.91	2.88	3.22	3.34	4.29	4.35	4.7
1989	4.17	5.06	4.34	4.58	5.52	3.81	3.46	3.53	3.66	4.25	5.03	4.36
1990	5.21	3.88	5.08	4.49	4.79	3.71	3.46	3.45	3.54	4.54	4.37	4.63
1991	5.02	4.48	4.93	7.04	7.07	4.14	2.93	2.94	3.43	4.23	4.35	4.56
1992	4.48	4.18	5.42	4.77	5.41	3.32	2.93	2.67	3.23	3.72	4.36	4.69
1993	4.53	4.75	5.89	5.13	4.46	3.03	3.29	3.06	2.85	3.94	4.31	4.13
1994	4.21	4.76	4.99	5.14	5.38	3.29	2.97	2.17	3.03	4.21	4.18	4.51
1995	4.41	4.45	5.26	4.43	5.75	3.83	2.79	2.3	2.46	4.11	3.88	3.82
1996	3.31	3.93	4.22	4.78	4.75	3.25	3.24	3.06	2.98	3.89	3.24	4.13
1997	4.12	5.74	5.18	5.07	5.79	4.56	2.98	2.68	3.27	3.93	3.86	3.96
1998	4.08	33.83	5.04	4.99	3.93	3.25	2.28	1.85	1.88	2.65	3.77	4.02
1999	4.01	4.68	4.42	5.42	4.64	3.43	2.97	2.66	2.12	2.13	4.02	3.92
2000	4.07	4.62	5.29	5.16	3.61	2.54	3.14	2.55	2.58	2.86	2.97	3.24
2001	2.98	4.08	4.11	4.63	3.14	2.35	2.73	2.36	2.92	3.05	3.74	3.85
2002	3.41	3.99	3.63	5.39	3.63	2.89	2.67	2.18	2.65	3.23	3.62	3.19
2003	3.23	4.49	4.84	4.17	5.12	2.83	2.23	2.06	2.35	3.62	3.7	3.6
2004	3.3	4.26	4.98	3.41	3.98	2.69	2.25	2.15	2.34	2.7	2.61	3.57
2005	3.4	4.7	4.8	4.9	4.2	2.8	2.7	2.8	2.6	2.5	2.8	3.0

Annex 4.10 Long term mean monthly sun shine hour at Holleta station (hr/day)

Year	Jan	Feb	March	April	May	Jun	July	Aug.	Sept.	Oct.	Nov.	Dec.
1981			4.3	5.7	7.9	6.5	2.9	3.5	4	8.6	9.9	9.2
1982	7.8	6.6	8.1	6.7	5.8	3.8	3	5	5.2	7.2	7.3	8.6
1983	8.2	8	6.9	6.9	6	7	4.6	2.4	4.1	7	8.9	9.1
1984	9.8	10	8.8	8.7	5.8	5.2	3.4	4	3.5	9.9	9.3	9.5
1985	9	8.4	7.8	5.4	6.3	5.5	2.4	3.3	5.4	8.3	9.4	8.9
1986	9.3	6.3	7.2	5.6	7.7	4.4	4.1	3.6	6	8.5	9.8	9.2
1987	8.9	4.9	5.7	7.5	6	5.9	4.1	3.6	5.8	7.9	9.4	9.4

1988	8.1	7.3	9.2	6.6	8.1	5.3	1.5	3.3	4.3	7.8	10.2	10
1989	8.6	8.2	6.8	5.9	8.5	5.9	2.8	3.6	4.7	7.8	9.5	7
1990	9.5	5.5	7.5	6.9	7.4	5.8	3.3	3.2	4.5	8.7	8.5	9.8
1991	8.8	7.6	7.2	8.1	8	5.4	2.6	3.4	5.3	8.4	9.2	8.4
1992	6.5	6.4	7.6	7.1	7.5	5.6	3.1	1.7	4.5	6.8	7.9	8.4
1993	7.9	6.4	9.2	5.4	6.9	5.3	3.2	3.4	3.2	7.1	9.3	9.4
1994	9.8	9.3	7.2	6.5	7.4	4.3	2.5	2.8	5.5	8.8	8.7	9.8
1995	10.3	8.6	8	4.8	7.6	6.6	2.7	3.1	4.5	8.2	9.6	8.8
1996	7.1	8.9	6.7	6.4	5.9	3.9	3.2	2.8	4.4	8.6	8.5	9.2
1997	6.7	10.3	8.2	6.1	7.8	5.5	3.1	3.1	6.6	6.7	7.4	9.3
1998	8	7.3	6.8	7.1	6.1	5.4	2.4	2.4	4	5.5	9.3	10
1999	8.7	9.9	7.3	8	6.6	6.2	2.5	3.5	4.9	4.7	9.8	9.5
2000	10.2	10.2	9.6	5.9	6.7	4.9	2.8	2.3	3.9	6.4	7.9	8.9
2001	8.2	9.7	5.2	8.2	6.6	4.8	3.3	2.5	5.5	7.2	9.5	9.4
2002	7.9	9.3	7.1	8.8	7	5.8	3.4	2.8	5.8	7.8	20.3	6.9
2003	8.1	8.7	7.2	5.7	7.9	1.22	2	1.8	3.3	8.17	8.9	8.7
2004	7.3	8.2	6.8	5.3	7.4	3.6	2.5	2.7	3.8	6.3	8.7	8.3
2005	8.1	9.1	7.6	6.2	5.9	4.4	1.9	2.8	4.3	5.6	8.8	

Annex 4.11 mean monthly Berga river flow (near Addis-Alem town) in million cubic meters

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1975	x	0.219	0.127	0.240	0.164	1.051	20.105	48.040	39.580	0.602	0.116	0.013
1976	0.022	0.035	0.124	0.121	0.265	4.742	30.159	48.476	22.964	2.300	1.259	0.721
1977	1.159	0.501	0.417	0.278	1.301	1.881	22.915	31.843	17.097	13.428	4.469	0.540
1978	0.219	0.126	0.211	0.098	0.080	0.354	22.254	24.267	18.463	5.574	0.728	0.396
1979	0.616	0.505	0.341	0.309	0.337	3.189	16.978	25.884	8.213	x	x	x
1980	0.207	0.176	0.159	0.173	0.248	9.907	23.212	39.382	17.769	5.436	1.550	1.104
1981	0.824	0.640	1.276	4.770	1.872	1.062	25.814	44.373	39.512	3.228	0.399	0.290
1982	0.464	0.304	0.291	0.517	0.432	0.622	37.495	40.094	7.957	2.443	1.186	0.431
1983	0.064	0.124	0.083	0.377	x	x	x	x	x	3.473	1.562	0.811
1984	0.497	0.304	0.302	1.013	6.407	19.879	22.091	15.026	10.406	1.230	0.422	0.280
1985	0.210	0.122	x	x	x	x	x	x	x	x	x	4.370
1986	3.847	3.721	4.440	4.620	5.410	9.260	32.300	26.770	22.060	2.770	8.060	0.690
1987	x	0.228	1.758	1.270	1.950	2.758	7.425	26.800	15.190	2.681	0.991	0.690
1988	0.608	0.633	0.456	0.448	0.261	0.729	22.781	42.420	x	x	0.708	0.508
1989	0.450	0.484	0.398	0.576	0.285	0.915	12.723	20.660	16.540	1.831	0.609	0.679
1990	0.316	0.519	0.523	0.365	0.365	0.529	15.413	25.703	22.931	1.941	0.251	0.079
1991	0.567	0.517	0.814	0.417	0.371	0.716	10.690	25.610	15.240	2.340	0.939	0.641
1992	0.926	1.271	0.818	0.975	1.060	1.250	x	29.883	17.660	4.690	1.330	0.850
1993	0.668	0.757	0.427	1.420	2.560	3.430	23.520	46.080	30.970	7.220	0.986	0.434
1994	0.161	0.162	0.148	0.180	0.124	2.489	14.330	25.104	17.453	3.310	1.610	1.149
1995	0.813	0.791	0.732	1.307	1.270	3.750	20.107	42.880	20.440	3.863	1.729	1.218

1996	1.134	0.763	0.977	2.055	3.541	7.564	44.683	59.120	30.197	1.231	0.014	0.446
1997	0.727	0.567	1.049	0.527	1.436	5.834	26.533	54.621	33.642	7.461	2.024	0.850
1998	0.727	0.567	1.049	0.527	1.436	5.834	26.533	54.621	33.642	7.461	2.024	0.850
1999	0.635	0.373	0.378	0.295	0.347	2.093	12.700	37.690	7.349	6.835	0.816	0.396
2000	0.227	0.139	0.098	0.196	0.470	1.947	5.492	23.885	16.627	4.381	1.461	0.639
AVER	0.670	0.560	0.696	0.923	1.333	3.824	21.576	35.801	20.952	4.162	1.468	0.763

X= missed data

Annex 7.1 measured value of major ions water samples from different sources (in mg/l)

water source	Ca2+	Mg2+	Na+	K+	HCO3	CO3	Cl	SO4
BHK1	75.6	16.32	35	5.6	336.7	Nil	24.2	35.2
BHK2	128.2	25.4	26	3.5	538	Nil	8.7	1.58
BHK3	48.9	10.3	53	8.7	274.1	Nil	30.7	24.8
BHD1	68.4	18.96	11.69	5.36	222.04	Nil	64	1
BHD3	30	11.5	29.97	2.6	110	35	6.8	7
BHD4	36.7	10.2	21.3	2.54	204	Nil	4	Nil
HD1	98.4	17.76	16.49	1.8	390.4	Nil	Nil	2
HD7	24.6	5.4	4.2	1.6	87.6	Nil		11.3
SP1	49.3	9.72	10.6	1.4	184.5	Nil	4.7	13.3
SP2	96	16.32	2.53	1.86	387.9	Nil	Nil	2
St1	41.4	9.7	7.5	2.3	163.7	Nil	3.8	14.6
St2	9.6	3.8	1.28	0.05	42	Nil	1.2	Nil

Where: - BHK1, 2, &3 =Borehole 1, 2, and 3 at Kimoye well field
BHD 1, 2, 3&4 = Borehole 1, 2, 3, and 4 at Dobbi well field
HD1 =hand dug well at Arb-Gebeya
HD7 = hand dug well at Kerbo village
SP1 = spring at Bidubente village (Burka shinkurty)
SP2 = spring at Arb-Gebeya
St1 = Hida-Billo stream
St2 =Berga river at its mouth

Annex 7.2 conversion factors for hydro-chemical data (source UNESCO, 2004)

Cations			Anion		
Cations	F1	F2	Anion	F1	F2
Ca^{2+}	0.0499	0.02495	HCO_3^-	0.01639	0.01639
Mg^{2+}	0.08226	0.04113	Cl^-	0.02821	0.02821
Na^+	0.0435	0.0435	CO_3^{2-}	0.03333	0.01666
K^+	0.02557	0.02557	SO_4^{2-}	0.02082	0.01041

Al^{3+}	0.11119	0.03715	F^-	0.05264	0.05264
NH_4^+	0.05544	0.05544	Br^-	0.01251	0.01251
Ba^{2+}	0.01456	0.00728	OH^-	0.0588	0.0588
Be^{2+}	0.22192	0.11096	I^-	0.00788	0.00788
Cu^{2+}	0.03148	0.01574	NO_3^-	0.01613	0.01613
Co^{2+}	0.03394	0.01697	NO_2^-	0.02174	0.02174
Cd^{2+}	0.01779	0.0089	PO_4^{3-}	0.03159	0.01053
H^+	0.99209	0.99209	HPO_4^{2-}	0.02084	0.01042
Fe^{2+}	0.03581	0.01791	S^{2-}	0.06238	0.03119
Fe3+	0.05372	0.01791			
Li^+	0.14411	0.14411			
Mn^{2+}	0.0364	0.0182			
Zn^{2+}	0.0306	0.0153			
Sr^{2+}	0.02283	0.01141			

(Milligram/liter) xF1 =mill equivalent/liter
Mg/l x F2 =mill moles/liter

Annex 7.3 Recalculated major ions (in meq/l)

	Cations				Anion				Dominant ion		
source	Ca2+	Mg2+	Na+ +K+	Total	HCO3- +CO3=	Cl-	SO42-	Total	Cation	Anion	water type
BHK1	55.6	19.8	24.6	100	79.59	9.85	10.6	100	Ca2+	HCO3	Ca-Na-HCO3
BHK2	65.9	21.5	12.6	100	96.94	2.7	0.36	100	Ca2+	HCO3	Ca-Mg-HCO3
BHK3	42	14.57	43.43	100	76.47	14.74	8.79	100	Na+ + K+	HCO3	Ca-Na-HCO3
BHD1	60.75	27.76	11.49	100	66.59	33.03	0.38	100	Ca2+	HCO3	Ca-Mg-HCO3-Cl
BHD3	39.26	24.8	35.94	100	89.79	5.8	4.41	100	Ca2+	HCO3	Ca-Na-Mg-HCO3-Co3
BHD4	50.01	22.91	27.08	100	96.74	3.26	0	100	Ca2+	HCO3	Ca-Na-Mg-HCO3
HD1	68.82	20.48	10.7	100	99.35	0	0.65	100	Ca2+	HCO3	Ca-Mg-HCO3
HD7	64.76	23.44	11.08	100	85.92	0	14.1	100	Ca2+	HCO3	Ca-Mg-HCO3
SP1	65.49	21.28	13.23	100	88.07	3.86	8.07	100	Ca2+	HCO3	Ca-Mg-HCO3
SP2	67.73	18.98	13.29	100	100	0	0	100	Ca2+	HCO3	Ca-Mg-HCO3
St1	63.59	24.56	11.85	100	86.67	3.46	9.87	100	Ca2+	HCO3	Ca-Mg-HCO3
St2	56.46	36.84	6.7	100	95.31	4.69	0	100	Ca2+	HCO3	Ca-Mg-HCO3

Annex 7.4 Calculated %RE (all ions in meq/l)

source	TSC	TSA	|TSC--TSA|	TSC + TSA	%RE	Remark
BHK1	6.780615	7.069974	0.289359	13.850589	2.1	Accepted
BHK2	9.707079	9.2935661	0.4135129	19.0006451	2.18	Accepted
BHK3	5.815347	6.05140583	0.23605883	11.866753	1.99	Accepted

BHD1	5.61786927	5.808995	0.19112573	11.4668643	1.67	Accepted
BHD3	3.813167	4.0496244	0.2364574	7.8627914	3.01	Accepted
BHD4	3.6618798	3.47042416	0.19145564	7.13230396	2.68	Accepted
HD1	7.1344386	6.6045644	0.5298742	13.739003	3.86	Accepted
HD7	1.895356	1.7332416	0.1621144	3.6285976	4.47	Accepted
SP1	3.7565352	3.6020065	0.1545287	7.3585417	2.1	Accepted
SP2	7.073353312	6.449956	0.623407712	13.52329891	4.61	Accepted
St1	3.248843	3.1656776	0.0831654	6.4145206	1.3	Accepted
St2	0.848414512	0.7296016	0.118812912	1.678016112	7.08	Rejected

Annex 7.5 Calculated SAR (all ions in meq/l)

source	Na	Ca	Mg	(Ca+Mg)/2	√(Ca+Mg)/2	SAR	water quality
BHK1	1.5225	3.77244	1.342483	2.5574615	1.5992065	0.952	Excellent
BHK2	1.131	6.39718	2.089404	4.243292	2.059925	0.549	Excellent
BHK3	2.3055	2.44011	0.847278	1.643694	1.2820663	1.79827	Excellent
BHD1	0.507995	3.41316	1.55965	2.486405	1.57683385	0.3222	Excellent
BHD3	1.303695	1.497	0.94599	1.221495	1.105213	1.17959	Excellent
BHD4	0.92855	1.83133	0.83905	1.33519	1.1555042	0.80359	Excellent
HD1	0.717315	4.91016	1.46094	3.18555	1.784811	0.4018997	Excellent
HD7	0.1827	1.22754	0.444204	0.835872	0.9142604	0.199834	Excellent
SP1	0.4611	2.46007	0.799567	1.6298185	1.2766435	0.3611815	Excellent
SP2	0.892882	4.7904	1.34248	3.06644	1.7511254	0.5098904	Excellent
St1	0.32625	2.06586	0.797922	1.431891	1.1966165	0.272644	Excellent

Annex 7.6 Calculated %Na (all ions in meq/l)

source	Na	K	Ca	Mg	Na+K	Ca+Mg Na+K	(Na+K)/(Ca+Mg Na+K)	%Na	water quality
BHK1	1.5225	0.143192	3.77244	1.34248	1.665692	6.780615	0.245655	24.57	Good
BHK2	1.131	0.089495	6.39718	2.0894	1.220495	9.707079	0.1257325	12.57	Excellent
BHK3	2.3055	0.222459	2.44011	0.84728	2.527959	5.815347	0.434705	43.47	Permissible

BHD1	0.508	0.137065	3.41316	1.55965	0.64506	5.61786927	0.114823	11.48	Excellent
BHD3	1.3037	0.066482	1.497	0.94599	1.370177	3.813167	0.3593278	35.93	Good
BHD4	0.92855	0.06495	1.83133	0.83905	0.9935	3.6618798	0.2711606	27.12	Good
HD1	0.71732	0.046026	4.91016	1.46094	0.763341	7.1344386	0.106994	10.7	Excellent
HD7	0.1827	0.040912	1.22754	0.4442	0.223612	1.895356	0.1179789	11.8	Excellent
SP1	0.4611	0.035798	2.46007	0.79957	0.496898	3.7565352	0.1322756	13.23	Excellent
SP2	0.89288	0.047588	4.7904	1.34248	0.94047	7.07335331	0.1329596	13.3	Excellent
St1	0.32625	0.058811	2.06586	0.79792	0.385061	3.248843	0.1185225	11.85	Excellent

Annex 7.7 Calculated RSC (all ions in meq/l)

source	$CO_3^{=}$	HCO_3^-	Ca^{2+}	Mg^{2+}	Ca + Mg	$CO_3^{=}+HCO_3^-$	RSC	water quality
BHK1	0	5.51851	3.77244	1.34248	5.114923	5.51851	0.403587	Good
BHK2	0	8.81782	6.39718	2.0894	8.486584	8.81782	0.331236	Good
BHK3	0	4.492499	2.44011	0.84728	3.287388	4.492499	1.205111	Good
BHD1	0	3.63924	3.41316	1.55965	4.97281	3.63924	-1.33357	Good
BHD3	1.16655	1.8029	1.497	0.94599	2.44299	2.96945	0.52646	Good
BHD4	0	3.34356	1.83133	0.83905	2.67038	3.34356	0.67318	Good
HD1	0	6.398656	4.91016	1.46094	6.3711	6.398656	0.027556	Good
HD7	0	1.435764	1.22754	0.4442	1.671744	1.435764	-0.23598	Good
SP1	0	3.023955	2.46007	0.79957	3.259637	3.023955	-0.235682	Good
SP2	0	6.35768	4.7904	1.34248	6.13288	6.35768	0.2248	Good
St1	0	2.683043	2.06586	0.79792	2.863782	2.683043	-0.180739	Good

Annex 7.8 Hydro-chemical laboratory data results

	BHD 1	BHD 3	BHD4	BHK 1	BHK 2	BHK 3	HD1	HD2	HD3	HD 4	HD 5	HD6	HD7	SP1	SP2	St1	st2
color	Nil	<10	Nil														
turbidity	Nil	Nil	Nil			1											
PH	7.8	8.54	7.47	7.33	7.21	7.88	7	7.07	7.47	6.9	6.38	6.5	7.19	7.15	7.1	7.42	7.9

TDS	138	175.6	243	387	479	356	735	308	296	182	128	252	182.9	355	770	297	308
EC	276	280	508	596	789	544	367	154	148	91	64	126	180.2	209	380	178	185
TH asCaCo3	175	123	230	256.2	424	164.3	320	…..	……..	……	…..	….	83.6	163	308	143	40
Ca2+	68	30	152	75.6	128.2	48.9	98.4	…….	……..	……	…..	…….	24.6	49.3	96	41.4	9.6
Mg2+	19	11.5	78	16.32	25.4	10.3	17.76	…….	…….	….	….	…	5.4	9.72	16.3	9.7	3.8
Mn2+	0.2	Nil	Nil	….	….	Nil	0.003	……	…….	……	….	…	…..	…	0	….	…..
Total .Fe	0	0.03	0.021	0.019	Nil	0.04	…..	0.2	0.1	Nil	Nil	0.1	…..	…..	0.45	…	0
Na+	12	29.97	21.3	35	26	53	16.49	…….	……	…..	…	…	4.2	10.6	2.53	7.5	1.28
K+	5.4	2.6	2.54	5.6	3.5	8.7	1.8	……	……	…..	…	…	1.6	1.4	1.86	2.3	0.05
NH4+	Nil	Nil	0.036	……	……	0.25	0.17	…..	…..	……	…	…	…..	…..	0.15	…	….
alkalinity	182	145	204	276	441	224.7	320	……	……	…..	…..	….	71.8	151	318	134	42
No3	17	0.48	Nil	7.48	11.75	8.75	10.12	11.4	28.2	0.6	Nil	0	3.4	10.5	10.6	4.3	5.1
No2	…..	0.003	….	……	……	….	0.003	……	……	……	…..	…	…..	….	0.04	…	…
Co3	Nil	35	Nil	Nil	Nil	Nil	Nil	……	……	…..	…	…	Nil	Nil	Nil	Nil	….
HCo3	222	110	204	336.7	538	274.1	390.4	……….	……	…..	….	….	87.6	185	388	164	42
SO4	1	7	Nil	35.2	1.58	24.8	2	Nil	16	12	12	7.1	11.3	13.3	2	14.6	Nil
F-	1	1.3	0.18	0.29	0.15	0.5	0.2	0.2	0.6	0.5	0.03	0	0.14	Nil	0.19	0.04	0.1
Cl-	64	6.8	4	24.2	8.7	30.7	Nil	…..	…….	……	….	….	Nil	4.7	Nil	3.8	1.2
PO4	0.7	1.6	0.144	…..	….	0.287	…..	……	…..	……	…..	…	……	…	….	….	….
Cu2+	0	0.13	<0.0014				0.01	……	……	….	….	…	….	….	0.01	….	…
Chromium	0.1		<0.006				0.01	……	…..	…	…	…	……	…..	0.01	….	….
Br2							0.07	……	….	…	…	..	….	….	0.05	….	….
I2							0.3	……..	…..	…	…	…	…..	…	0.06	…	….
NH3							0.16	0.14	2.09	0	0.07	0.1	…..	…	0.15	….	…
E.coly/100	…..	….	…	….	…..	….	0	0	0	0	0	0	…..	0	…..	….	….
F.coli/100	…..	…..	….	…..	….	….	0	90	6	Nil	Nil	Nil	…..	0	……	…..	……

…... = missed data

Annex 7.9 In-situ physicochemical measured data

Water source	Name	PH	EC(Ns/cm)	TDS(mg/l)
Borehole	BHK1	7.33	596	387
	BHK2	7.21	789	479
	BHK3	7.81	552	331
	ITEYA1	7.85	342	205

	ITEYA2	7.18	372	229
	BENTE1	7.13	362	218
Hand dug well	Effeberi	6.35	372	172
	Gegebso	6.69	186.8	112.4
	Keresa-Boru	7.23	180.2	108.7
	Burka-Adi	7.43	356	214
	Gebeya-Jimata	7.21	798	482
	Kerbo-3rd	7.19	182.9	108.2
Spring	Badeg	7	224	148.2
	Seppera	6.84	311	187.3
	Burka-Shinkurty	7.15	355	209
	Rob-Gebeya	6.82	143.7	187.5
	Aba-Simbo	7.36	314	189.1
	Gelila-Gebreal	6.93	661	395
	Abo-spring	7.08	492	294
	Ras-Mulugeta	6.68	416	256
stream	Chacho	7.78	230	137.8
	Gerado	7.51	323	193.8
	Jello	7.26	288	170.4
	Berga at Jello	7.02	274	163.7
	Berga at Bekete	7.31	308	185.2
	Hidia-Billo	7.42	297	178
	Dillo	7.3	282	164.6
	Berga at Hinne	7.45	297	182.4
	Dobbi	7.52	202	125.6
	Addama	7.41	364	184
	Berga at Kimoye	7.92	308	185.2