ADDIS ABABA UNIVERSITY
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SURFACE AND GROUNDWATER RESOURCE EVALUATION OF UPPER GUMA SUB-CATCHMENT
(BONGA)

By

MESERET ADEKO

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Declaration

This thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

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Date and place of submission, July 2005, Addis Ababa.

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ABSTRACT

The development of a balanced plan for water resources utilization requires full knowledge of quantity, quality and distribution of water resources and also the changing pattern of land use in the entire water shade of and its influence on the river flows in the study area (Guma Sub Catchment) which is located and is bounded within$7^{0}10'$ N- 7^{0} $25'$ N latitude and 36^{0} 05' E - 36^{0} $30'$ E longitude.

The total aerial coverage of the study area is about 876 km^{2}study area. Prior to this research work, the contribution of information about the water resources and water budget components were not known.The combined effects of climate and geology on the catchment topography yield an erosion pattern which is characterized by a net work of channels or streams. Topography of the area ranges from flat to mountains and gorges. The average monthly rainfall ranges from about 253.51 mm in the highlands in the northeastern part of the study area and 48.86 mm in the northwestern part of the area.

Hydrologic and hydrogeologic investigation and water balance calculation were used to study the surface-ground water interaction in Upper Guma Sub-Catchment with emphasis given to hydrochemistry.Classification of water types in the area according to the tri-linear piper diagram plots show that, most of the hand dug wells are $Ca\text{-}Na\text{-}HCO_3$ and Ca-Mg-Cl water type where as springs show, $Ca\text{-}Na\text{-}HCO_3$ and $Ca\text{-}Mg\text{-}HCO_3$ water type**.** The borehole result has a water type of $Ca\text{-}Mg\text{-}HCO_3$ and $Na\text{-}Ca\text{-}HCO_3$ which signifies the dominancy of volcanic terrain. Based on major cations and anions, the general water quality for public supplies, irrigation and industry are identfied in the study area.

Values of net groundwater recharge estimate is determined from water balance calculation and found to be 110.7 MCM annually accounting not greater than ten percent of the annual precipitation indicating that groundwater resources should be wisely exploited giving due attention to the integration of the surface water resources of the area. The result of this study can be used as data source for future sustainable development and management the catchment area.

CHAPTER 1

INTRODUCTION

1.1. Background

The need for water is strongly ascending, as it is vital for any developmental activities. It gets more complex due to population growth, urbanization and industrialization. Any development is related either directly or indirectly with water utilization. Due to this dependency on water, its unavailability and scarcity will result in retarded economic development, which in turn leads to the deterioration of human life. Scarcity in water is the reflectance of rainfall shortage for both surface water and groundwater accumulation.

In a country like Ethiopia which is affected by recurrent drought, evaluation of water resource for appropriate utilization of both surface and ground water should be basic and primary issue to bring significant socioeconomic development. Integrated development approach is essential to a given country. Among many other activities, irrigation is the one, which is the most effective practice in highly developed countries. Both surface and ground water play an important role in such activities. Ground water is a precious and the most widely distributed resource of the earth and unlike any other mineral resource it gets its annual replenishment from rainfall. At present nearly one fifth of all the water used in the world is obtained from ground water resources (Raghunath, 1987). In an area where surface water is not available groundwater is the second alternative for irrigation purpose if the demand for irrigation and groundwater potential is promising with out significant negative environmental effect.

To use water for intended purpose, it should be analyzed in terms of quantity, and quality. By doing so, obtaining health, productive and prosperous community will be the final output of supplying potable water. As that of water supply needs chemical, physical and bacteriological analysis, irrigation water also needs biochemical analysis for different major cations and anions. After this analysis, the result will guide whether the water is allowable for irrigation or not. Almost all parts of this study area are dependant on rain water; because of this the people are not utilizing the available resource properly and contributing to the development in this regard. But within the basin there is large possibility to integrate both the surface and ground water and make use of it for irrigation and other utilities if traditional farming system (rain fed agriculture) is supported by irrigation. And therefore, to use this technology, there is a basic need of ground water and surface water potential evaluation.

The hydrology, hydrogeology, and geology of this study area, Guma sub catchment, as a whole is not studied separately and in detail except the regional study of the Omo Gibe River basin master plan for different developmental activities at a scale of 1:250,000 published in 1996. Generally, the project area lacks a detailed hydrological, hydro chemical and hydrogeological study in order to launch developmental activities using integrated groundwater and surface water in the sub catchment, and therefore, this research will have important role towards the sustainable use of water resources in the area.

1.2 OBJECTIVE

The main objectives of the research are:

- To produce hydrogeological map of the area at the scale of 1:50,000.
- To analyze spatial variation of hydrochemistry in the basin.
- To establish physical parameters of the aquifer.
- To determine groundwater flow directions in the basin.
- To assess and evaluate possible sources of water pollution (if there is any).
- To delineate potential sites for immediate development.
- To suggest possible future sustainable integrated utilization of the surface and groundwater resources.

1.3 METODOLOGY

As it is common for the most part of the country, the scarcity of available data for the intended research was a problem to use certain methods of calculating basic parameters for the evaluation of water resources, and even hydro meteorological data are not continuous for different purposes. However, by using long term meteorological data and applying different techniques of supplementing and adjusting missing data the research has been accomplished. For this study different materials and equipments have been used.

- Aerial photographs obtained from Ethiopian Mapping Authority.
- 1:50,000 topographic maps of Bonga , Chiri, Felegeselam and Gojeb were used
- Satellite image of thematic mapper of land sat TM 5 and others.
- Geological and hydrogeological map of Ethiopia at the scale of 1:2,000,000
- GPS for locating water samples and water points (spring, hand dug well , borehole and river samples)
- Measuring instruments for (EC, Eh, Temperature, pH meter dissolved oxygen(Do)
- Plastic bottles for water samples and compass ,pocket lens and hammer

While trying to select a project area for this study, basin area delineation and most of the inventory work of water point identification field work has been done and the main fieldwork was accomplished from 2 February to 30 March (2005) covering most of the inventory work of water points, collection of water samples from springs, hand dug wells, boreholes and rivers. The remaining data collection and works in field are accomplished and during this stay, the following activities had been done.

- Detail geological and hydrogeological map at a scale of 1:50,000.
- Water point locations and level measurements in hand dug wells and bore holes.
- Prior knowledge of the area by the researcher was used for data collection. And refining boundary conditions.

Hydro meteorological data were collected from the metrological office for the analysis of hydrological parameters of the study area. With in the basin there are many hand dug, drilled shallow wells, springs and deep bore wells of which several of them are not giving proper function at the prevailing conditions.

CHAPTER 2

GENERAL OVERVIEW OF THE STUDY AREA

2.1 Location and accessibility

The Omo Gibe basin covers an area of some 78 000 Km^2 with a length of 550km and an average width of 240 km, varying between 100-245 km. The basin extends from 9^0 22’ N in the north to 4 ^{0} 27’ N in the south and from 35^0 00 E in the west to 38^0 24’ E at its eastern most extent. Figure 2.1 shows the location of the basin. It is an enclosed river basin that flows into Lake Turkana in Kenya which forms its southern boundary. The western water shade of this basin is the range of hills and mountains that separate the Omo Gibe from Baro- Akobo Basin. It is in this part of the basin that the study area (Guma Sub Catchment) is located and is bounded within$7^0 10'$ N- $7^0 25'$ N latitude and 36^0 05’ E - 36^0 $30'$ E longitude and is totally in the kafa zonal administrative region of the SNNNRS (Figure 2.1).

The study area is 440km south west of Addis Ababa and it has a temperate (Weynadega) climate. The total aerial coverage of the study area is about 876 km^2.

The elevation in the basin ranges from 1880 meter above sea level (m.a.s.l) at the Buta forest in the south west of the basin and 1580 m.a.s.l at the convergence part of the Dincha and Guma rivers. The area is accessible by all weather roads and dry weather roads. Bonga is the zonal town in the study area and is 440 km far from Addis Ababa in the south west direction.

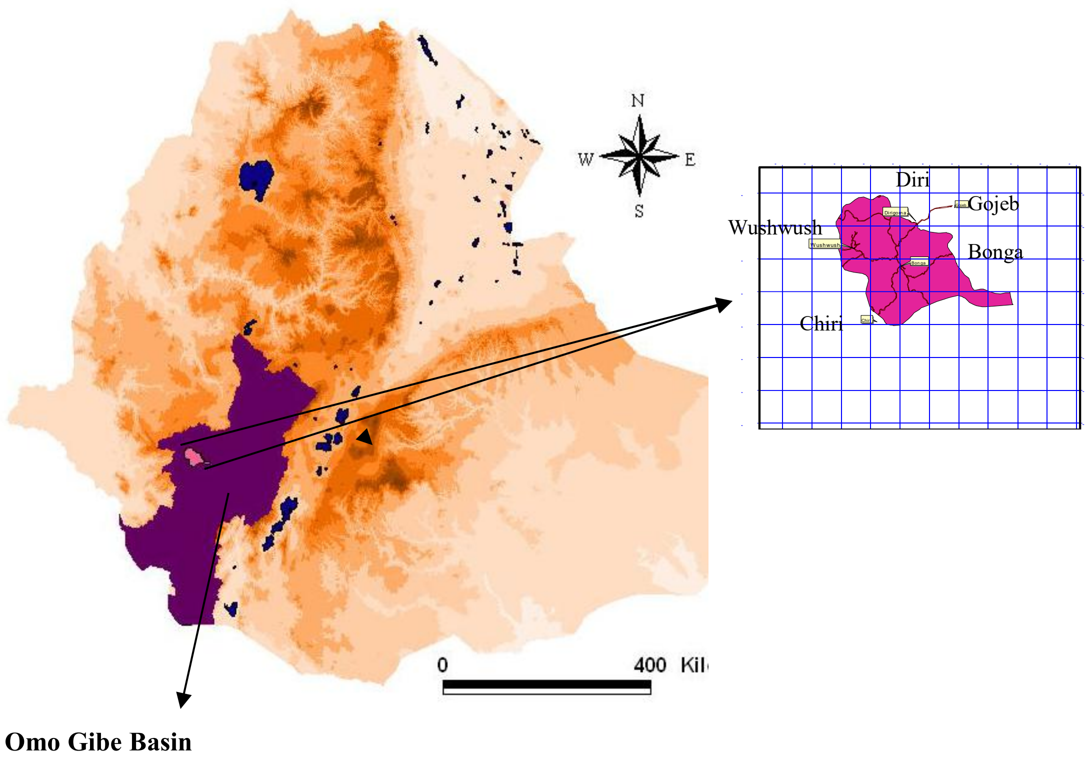


Figure 2.1 Location map of Upper Guma Sub-Catchment

2.2 Climate

The climate of Guma catchment is classified as temperate (weynadega) climatic zone.

Monthly mean maximum temperature in the study area is 28.2 ^{o}c in the month of March where as the monthly mean minimum temperature is 11.8^{o}c in the month of January. The area attains its mean minimum and maximum monthly temperature as most of the stations (the five stations) confirmed within the study area. This condition related to the rainy season as temperature falls with the entrance of rain season and increases with the dry season. Temperature with in the study area shows altitudinal variations with a general trend of increasing rainfall with increasing altitude, which is directly the inverse of temperature.

The average monthly rainfall ranges from about 253.51 mm in the highlands in the northeastern part of the study area and 48.86 mm in the northwestern part of the area.

Rainfall distribution with in the area is unimodal (Figure 3.3), which has only one peak period of rainfall and one lowest period. The lowest period of rainfall covers the months of November to February where as the rainy season covers the months of March to October.

2.3 Topography and Drainage

Tertiary volcanism and the subsequent faulting, weathering and denudational processes are responsible for the present landscape of the study area. The high to low relief, dissected hills and mountains are the result of volcanisms. Erosion and deposition by the major rivers are forming relatively wide to flat and marshy flood plains. Faulting and fracturing in eastern and southeastern part are forming vertical scarp zones and steep hill slops. The basin characteristics such as the area, land surface topography and other morphological properties vary only with respect to geological time and this may be treated as constant. Topography of an area plays an important role for subsurface groundwater percolation and soil erosion rate. The sloppy the area is more susceptible for erosion and surface run off rather than infiltration and deposition.

Topography of the area ranges from flat to mountains and gorges. The flat area covers the lowland areas that are surrounded locally in several locations and ruggedness characterize the basin. Southern and Eastern part of the basin is dominantly rugged and hilly with deeply cut gullies where as the Northern part is more gentle except the cliff or ridge of the extreme part along the water divide of Woshi river catchments.

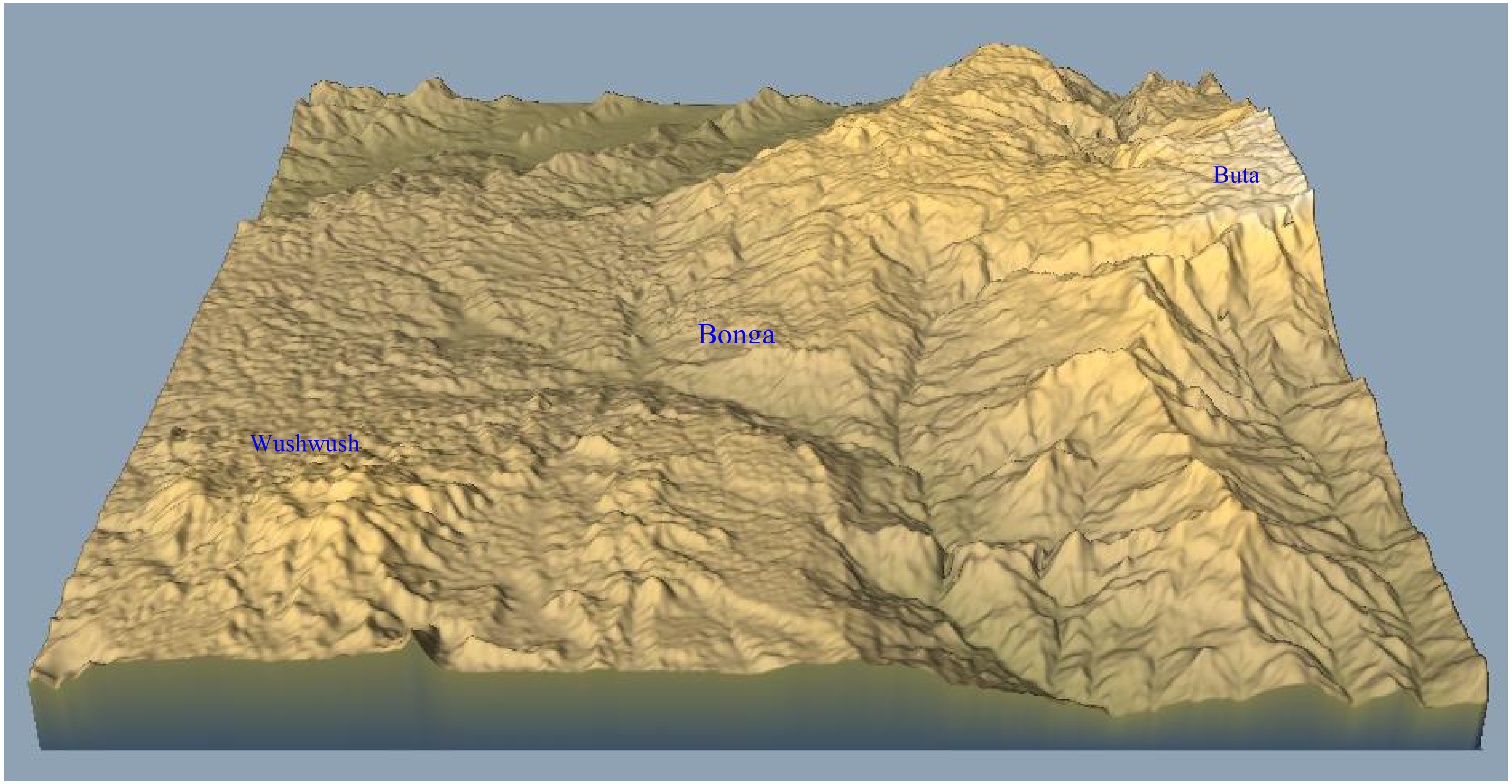


Figure 2.2 Digital Elevation Model of the study area.

The combined effects of climate and geology on the catchment topography yield an erosion pattern which is characterized by a net work of channels or streams. The drainage pattern and density in the study area is dominantly represented and characterized by dense drainage with dendrtic pattern. This is governed by shallow weathering layer and uniform geology of the area. Most of the precipitation in this category is not allowed to infiltrate and then to percolate in enormous amount (Figure 2.3).

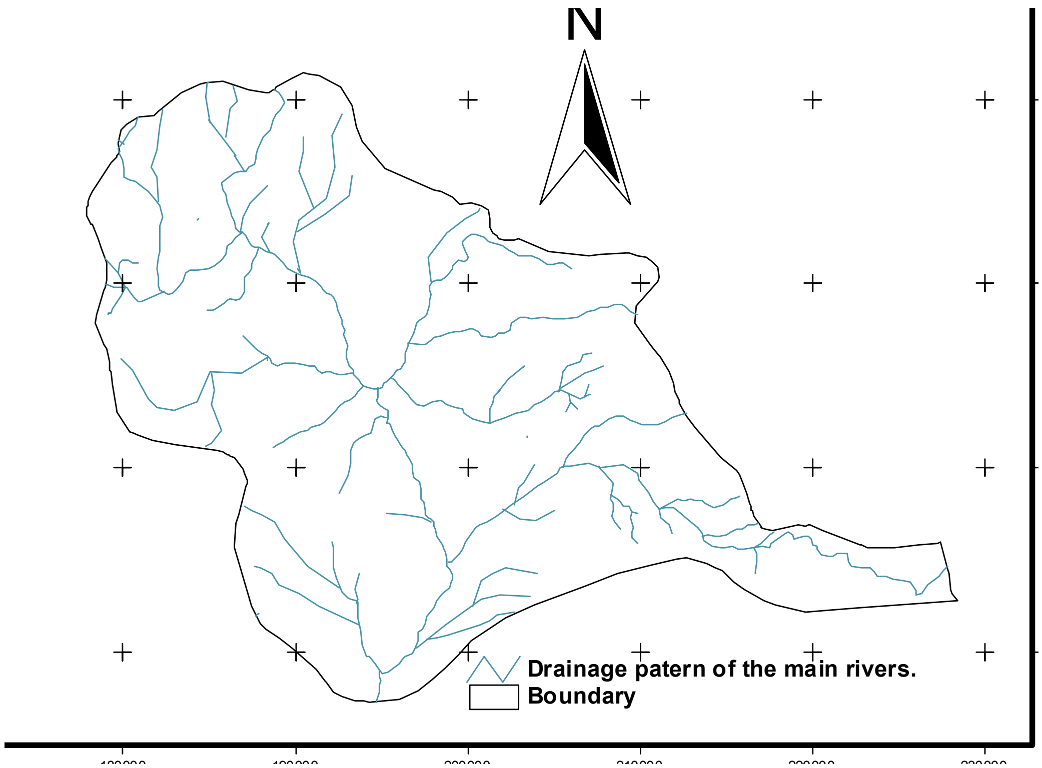


Figure 2.3 Drainage map of the study area

2.4 Soil and Land use

2.4.1 Soil classification

Previous soil studies of the basin range from the general to the specific. More specific soil studies in the Basin have concentrated on the irrigation potential evaluations. For Wushwush Tea Plantation a report and map at 1:50000 scale exists for the plantation of about some 2000ha and above. The genesis of all soils is governed by the soil forming factors of climate, organisms, relief/topography, parent material and time .The inter play of these various factors within the study area has determined the nature of its soils. Parent materials such as basalt and other basic igneous rocks are rich in ferromagnesian minerals which break down to clay minerals resulting in clay textured soils. In the study area almost all of the parent materials are volcanic rocks which under the influence of a pluvial regime and relatively warm temperature, have weathered to form deep, well drained clay soils over almost all of the highland areas. Soil morphology relates to the appearance of the soil in the field in terms of depth, color, texture, structure, consistency, drainage and the presence or absence of stones and carbonates. These, together with chemistry, are the criteria to categories the soils into soil units by earlier studies. The dominant soil units of the study area fall into three main soil groups. These classifications are taken from the study of Omo Gibe basin land resource development master plan (1996) and supplemented by field visit.

Well drained red and brown clays

This type of soil is a larger unit that describes the mountainous wet forested areas of the basin covering some 60% of the study area .Topographically the area is hilly to mountainous with most slopes 15-30%.The soils are a complex to deep well drained red and brown clays with some shallower areas corresponding to steeper slops and locally poorly drained bottom lands. The land use is still primary high forest but is rapidly being encroached by rain feed agriculture, Tea, and coffee plantation.

Sandy loam- These soils are developed in fluvial red and brown soils found only on almost flat surface on which during high rainy season, water will stay for certain days as a stagnant water. It is situated on the central and north eastern parts and by sides of stream banks with 10% aerial coverage of the study area. These soils represents poorly drained alluvial of low lying areas in high rain fall areas around Bonga that are water logged and do not dry out.

Clay loam- These soils are developed on slightly to moderately dissected undulating to rolling low relief hill side slopes and plantation areas. The soils are moderately deep to deep, well drained, dark yellowish brown or dark grayish brown in colors. Southeast of the basin is dominantly covered with this soil unit.

No	Soil type	Area coverage (km2)	Weighted area (%)
1	Drained red and brow clay	542.81	60.2
2	Sandy loam	90.62	10.35
3	Clay loam	257.834	29.45

Table2.1 Soil type and their actual coverage in the basin

2.4.2 Land use/ Land cover

Based on the type of covering material of the area with their present services, major land cover/land use units of the study area are described as three units.

1. Moderately cultivated areas with shrub lands
2. Dense natural and man made protected forest coverage.
3. Plantation with cultivation, grasses, bush and significant shrubs.

Moderately cultivated areas cover the area with moderately steepy slopes. Shrubby grass land with scatter cultivation and open wooded land with bush covers northern peripheral part of the study area which is not suitable for cultivation due to its rugged and dissected terrain. Plantation together with other bushes according to land cover classification is categorized in Afro alpine occupied zone of high land area. In general the basin is occupied more by relatively dense natural and man made forest followed by moderately cultivated with shrubby grass land, bush, open shrubby grass land. Plantation and Alpine vegetation takes the least coverage.

No	Land use/Land cover	Coverage (km^2)	Weighted area (%)
1	Moderately cultivated with open shrubby grass land, and afro alpine	214.2	29.45
2	Dense natural broad leaved forest coverage	543.12	60.2
3	Plantation with cultivation and open wooded land	90.7	10.35

Table 2.2. Aerial coverage of land use/land cover.

Major crops growing in the basin are Teff, Maize, Bean, Barley, Wheat and other highland areas are dominated by highland broad leaved trees, Junipers and other bushes. Moderately sloping areas are covered dominantly with:

- Acacia species,
- Lowland eucalyptus
- Ficus species (Shola, Warka and others)

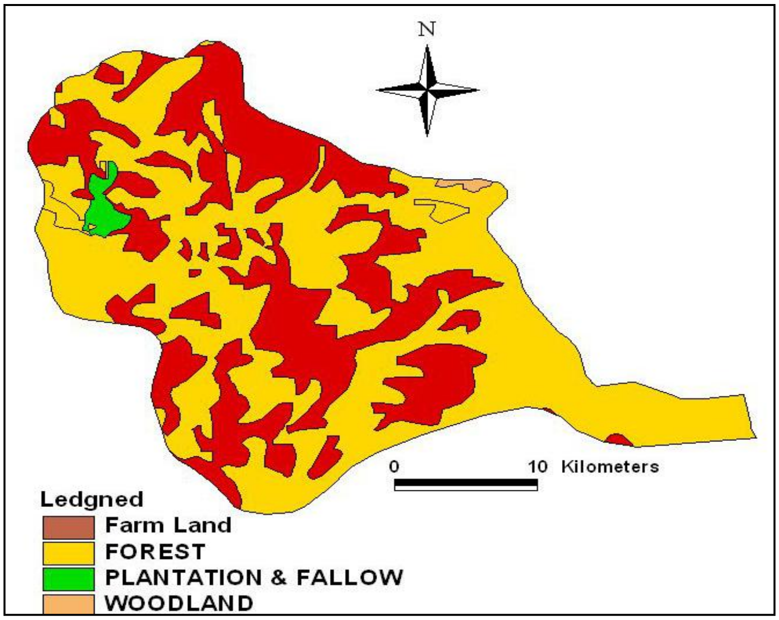


Figure 2.4 Land use/land cover map of the study area

No	Stations	Location UTM		Altitude m.a.s.l	Recording period(year)
		Latitude	Longitude		
1	Bonga	195602	803396	1650	since1953 ˚2
2	Wushwush	183930	808454	1950	since1954 ˚1
3	Chiri	189766	787833	2000	1987------2000 ˚1
4	Dirigoma	199882	816624	1760	since1988 ˚2
5	G0jeb	210386	820515	1250	1972------1990 ˚1

Table3.1 Meteorological stations in and around Upper Guma Sub Catchment

˚1 Records temperature, wind speed, relative humidity, sunshine hours and rainfall

˚2 Records temperature and rainfall

Metrological stations are located in such a way that, in the periphery of the basin there are three stations and with in the basin there are two stations. Of these stations, class-A meteorological station which can measure all parameters currently is that of Wushwush only and the other one which was established to serve as class-A in Chiri is abounded since 2000. The other stations measure only temperature and rainfall. Two of the stations within the basin are Bonga and Wushwush, where as, the peripheral ones are Chiri, Gojeb and Dirigoma. Wushwush is class A- station and the data are used in the calculation of long term average wind speed and sun shine hours from stations. Meteorological Stations are not evenly distributed in the basin, but are sufficient. Except in the south - eastern part of the basin, the study area is bounded by meteorological stations. This distribution makes the result of rain fall (precipitation) calculation or analysis to apply appropriate method to obtain reasonable value for the basin. Similarly other parameters are the result of these stations at different altitudes. The only problem here is that for different reasons, the stations do not have continuous records and there are gaps for different years. However, the mean values of the days or months, which are recorded in the five stations, are reasonably adjusted using different techniques for the purpose of the study.

Mean monthly minimum and maximum temperature of the five stations, Bonga, Wushwush, Chiri, Dirigoma and Gojeb are 52,51,13,18 and 17, years of recorded data respectively. Other basic parameters in addition to the above once such as wind speed, relative humidity and sunshine hours are recorded at Wushwush station. Though not currently functional, Chiri and Gojeb stations have recorded several of these parameters.

Monthly mean wind speed at Wushwush, Chiri and Gojeb stations have records of seven years each and sunshine hours at Wushwush and Chiri stations has been recorded for seven years. Relative humidity is recorded at Wushwush and Gojeb with a total recording data of seven and ten years respectively. The Chiri station has also records of Pan Evaporation for eight years .The data obtained from these stations are used to represent the study area.

River discharge measurements are made in four gauging stations distributed along the river course at different location (at Gicha near Bonga with coordinates 7^0 17’ N and 36^0 13’E covering drainage area of 175 km^2, Sheta near Bonga located at 7^0 17’ N and 36^0 14’E with a drainage area of 190.6 km^2, Dincha near Bonga with coordinates at 8^0 11’ N and 37^0 28’E with a drainage area of 286 km^2, and Guma near Anderacha with coordinates 7^0 9’ N and 36^0 15’E draining an area of 231.25 km^2) to know its annual discharge. Gicha and Sheta records just the upper extreme catchments draining from north western and north eastern part where as Dincha accounts middle part while Guma gauging is for lower and south eastern part of the study area. Four of the gauges have maximum and minimum discharge in M^3 /s and monthly mean river discharge records of 20 years data taken in to account for this study.

3.2 Precipitation analysis

Precipitation is the out put or result of hydrologic process through a combination of circumstances when water vapor changes back to the liquid state through the process of condensation to form clouds. Of all the components of the hydrological cycle, precipitation is the most commonly measured. It would appear to be a straight forward procedure to catch rain fall as it falls. The rainfall obtained from a single rain gauge station is known as the point rain fall or station rainfall. Precipitation for a given duration over a particular area rarely produces uniform rainfall depth over the entire area. Maximum rainfall at certain gauge could not represent the whole area for different reasons.

3.2.1 Determination of aerial depth of precipitation

Based on the available rainfall data taken from different stations analyses should be done to obtain representative aerial depth over the whole study area. Since most hydrological problems require knowledge of the average depth of rainfall over a significant area, such as river basin some procedures must be used to connect the rainfall measured at the individual rain gauges to the aerial averages. The average depth of rainfall is also termed as equivalent uniform depth of rainfall (Jayarami, 1996). The three methods to arrive at an approximate average depth of rainfall are

1. Arithmetic mean method
2. Thiessen polygon method
3. Isoheytal method

Arithmetic mean method is the simplest of the three methods and the result is obtained by dividing the sum of the rain fall amounts recorded at all the rain gauge stations which are located with in the area under consideration by the number of stations (Wilson1983).

That is:

$$P = \frac{P1 + P2 + - - Pn}{n}$$

Where P is the average depth of rain fall and p1, P2--Pn are the rain falls recorded at stations 1, 2, --- etc. and n is the number of rain gauge stations with in the area. There fore, P = 1663.6mm is the average depth of rain fall using arithmetic method. This method is accurate as other methods if the area is flat and the Gauges are distributed uniformly over the area and the variation of individual gauge records from the mean is not too large (Shaw, 1988 and Jayerami, 1996). But these conditions are not fulfilled in the study area for the reason that the area is not flat (with altitudinal variation of 2300m.a.s.l) and the gauges are only two in addition to their non uniformly distribution. Hence the result obtained using arithmetic could not represent the average areal depth of the whole area.

The second method (Thiessen polygon method) attempts to make allowance for irregularities in gauge locations by weighing the record of each gauge in proportion to the area which is closer to that gauge than to any other gauge (Figure3.1).

The method is given by

$$P = \frac{A1P1 + A2P2 + - - - AnPn}{\sum Ai}$$

Where P=average aerial depth rain fall.

P1, P2---Pn=mean annual rain falls recorded at each rain gauge stations.

A1, A2 ---An=Polygonal areas around each stations with in the basin

Using this method, the result obtained is 1701.765mm (Table3.2)

Station	Mean annual rainfall(mm)	Area of influence(km^2)	Weighted area (%)	Weighted rainfall(mm)
Bonga	1623.8	413.262	0.472	766.434
Wushwush	1928.13	227.88	0.260	501.314
Chiri	1647.67	8.847	0.101	166.415
Dirigoma	1628.7	137.343	0.157	255.706
Gojeb	1489.63	8.865	0.010	14.896
Total	8317.93	875.8820	1	
Thiessen				1701.765

Table3.2 Theissen polygon method to calculate annual rainfall in Upper Guma Sub Catchment

The third method is called Isoheytal method which is perhaps the most accurate method of computing the average depth of rainfall. Isohyets may be defined as lines joining points of equal rainfall (Figure 3.2). In other words all the places along an isohyets experience the same amount of rain fall. The basin areas along with the rain gauge station locations in and around the areas are drawn to a suitable scale. According to this method the annual precipitation in the Sub catchment is equal to 1692.213mm (Table3.3)

Isohyetal range mm	Average isohyetal value (mm)	Enclosed area km^2	Weighted area (%)	Weighted rainfall mm
<1600	1575	10.6	1.21	19.06
1600-1650	1625	374.93	42.8	695.5
1650-1700	1675	223.8	25.55	427.96
1700-1750	1725	69	7.88	135.93
1750-1800	1775	57	6.51	115.55
1800-1850	1825	55.6	6.35	115.89
1850-1900	1875	59.7	6.81	127.69
>1900	1925	25.4	2.89	55.63
Total		875.93	100	1693.213

Table 3.3 Isohyetal method of calculating annual rain falls in Upper Guma Sub Catchment.

Among the above methods the arithmetic mean method is fur less than the Theissen polygon and Isohyetal methods. Isohyetal method gives intermediate value owing to the topographic effect in calculating the monthly weighted rainfall and therefore the arithmetic, Theissen, and Isoheytal methods are averaged to fit best for the study area and hence, the annual precipitation in the basin is found to be 1686.mm.

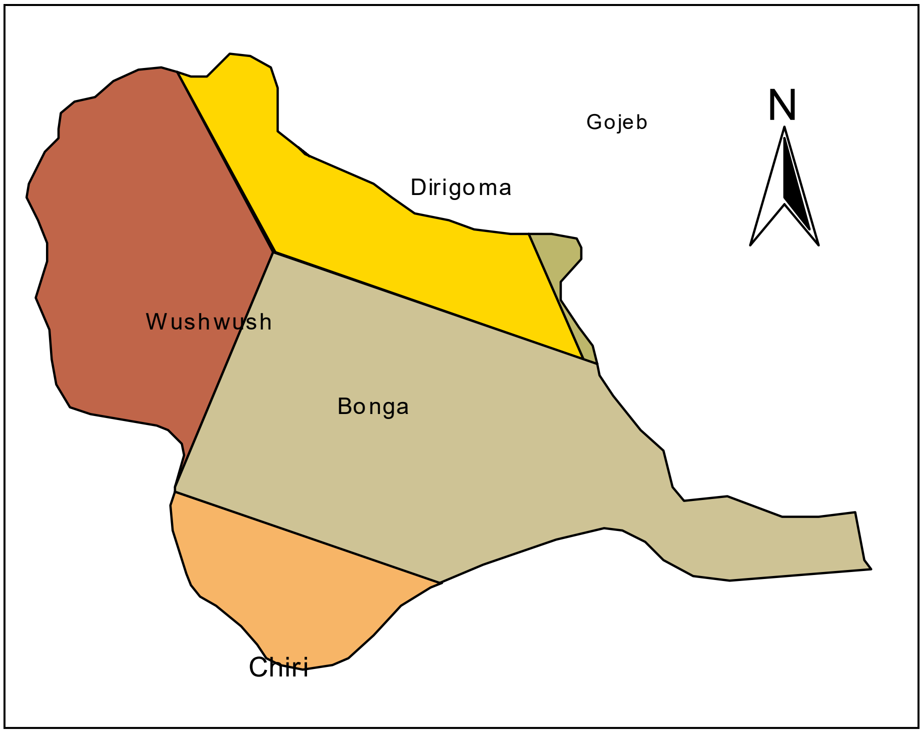


Figure 3.1 Theissen polygon method

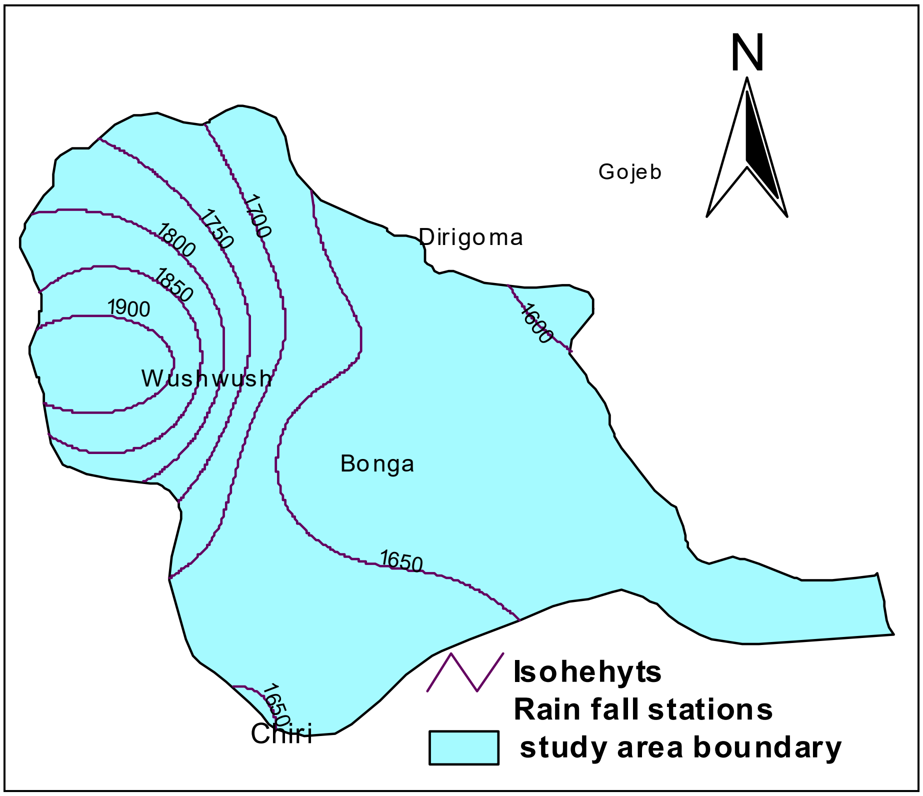


Figure 3.2 Isoheytal map of the study area

3.2.2. Rainfall characteristics

Precipitation process in nature is subjected to spatial and temporal variation. We can not predict with certainty what would be the rainfall for any given period in future. The rain fall magnitude can be estimated only with some probability attached to them. Therefore the analysis of the rainfall data obtained over a long period in the past would help to make reasonable estimates of rainfall to be used in various developmental activities.

The rainfall distribution in the study area is not uniform which ranges from 1489.63mm to 1928.13mm.The highest rainfall is recorded in Wushwush and the lowest rainfall record is from the north eastern part closer to Gojeb area. As it is displayed in the precipitation bar graph, the maximum rainfall is recorded in the month of July and the minimum rainfall is recorded in the month of January. Then majority of the rainfall in the basin is obtained during the summer time (Kiremt) May, Jun, July, and August which covers 71% of the total annual rainfall (Table 3.4). The minimum records are in the months of December, January, and February with unimodal rain fall characteristics (Figure.3.1).

Station	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
Bonga	50.1	50.9	105.5	177.2	187.1	192.	204.5	204.2	186	144.3	62.9	59.3	1623.8
Wushwush	42.8	45.4	126.9	189.1	207.9	218	211.0	413.6	208.	141.5	55.7	65.6	1928.1
Chiri	56.8	59.29	121.1	194.6	174.	175	193.1	201.6	166	150.7	67.1	64.2	1647.7
Dirigoma	59.1	37.9	98.0	166.2	210.0	233	218.3	213.5	186	112.3	40.66	53.7	1628.7
Gojeb	32.4	55.8	91.3	120.2	194.29	222	200.	170.8	81.7	66.5	66.54	41.8	1489.6
Arithmetic mean.	48.2	49.8	108.6	169.5	194.8	208	205.3	240.7	165.	123.06	58.58	56.9	1663.6
Theison polygon.	49.7	51.4	111.4	173.7	200.2	214	210.9	255.6	188.	129.39	60.32	56.6	1701.6
Isoheytal mean	48.8	50.5	110.3	172.3	203.2	211	209.1	253.5	186	128.13	58.78	60.7	1693.2
average	48.9	50.5	110.1	171.8	199.4	211	208.4	249.	179	126.8	59.2	58.6	1686

Table 3.4 long terms mean monthly rainfall (mm) of the five stations in and around the basin

The monthly Rainfall intensity of the area is clearly depicted in the graph shown below

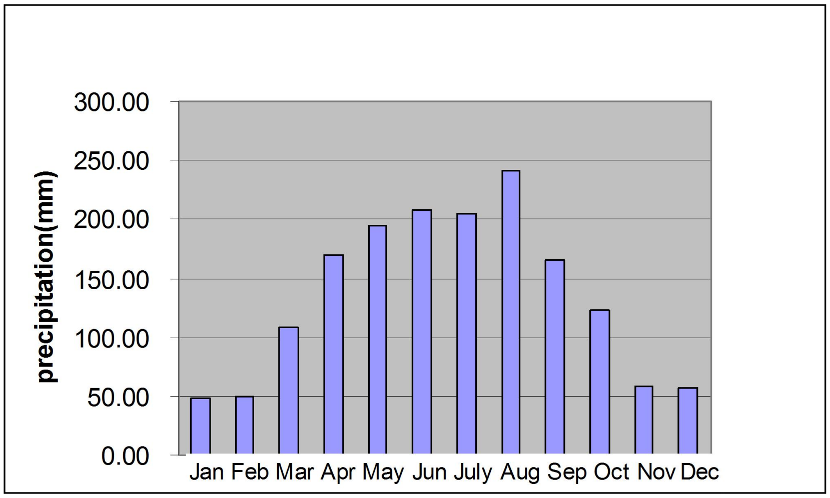


Figure 3.3 Monthly rainfall distribution in upper Guma Sub Catchment

3.3. Temperature

Temperature is measured at five stations and the mean monthly temperature is computed as the arithmetic average of the mean daily temperature of all the days in the month. The minimum temperature of all the five stations is recorded in the month of December where as the maximum temperature recorded is during the months of March and April.

Station	Month	Jan	Feb	March	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Bonga	Maximum	27.7	28.3	28.2	27.6	27	26.2	25.5	25.5	26.2	27.2	27.7	27.8
	Minimum	10.2	11	12	12.7	13	12.5	12.3	12.6	12.6	12	11.4	10.7
	Average	19.1	19.7	20.2	20.1	20	19.3	18.9	19.1	19.4	19.6	19.6	19.2
Wushwush	Maximum	26.2	25.9	26.4	25.5	25	23.2	21.4	21.9	23.2	24.7	25.5	25.5
	Minimum	10.4	10.9	11.8	12.6	12.5	12.1	12.0	11.9	11.6	11.1	10.7	10.4
	Average	18.2	18.4	19.1	19.1	18.7	17.6	16.7	16.9	17.4	17.9	18.1	17.9
Chiri	Maximum	26.2	26.4	26.6	25.6	25.3	24.3	23	23.1	23.3	24.4	24.9	25.2
	Minimum	12.4	13.2	12.6	12	11.6	11.4	10.5	10.6	11.1	10.9	11.9	12.4
	Average	18.3	19.8	19.6	18.8	18.4	17.9	16.7	16.9	17.2	17.7	18.4	18.8
Dirigoma	Maximum	25.8	27.2	27.3	26.7	25.7	25.1	24	24	24.5	25.3	25.3	26.3
	Minimum	13.8	14.2	14.5	14.5	14.1	13.6	13.9	13.3	14.1	13.9	13.7	13.2
	Average	19.8	20.7	20.9	20.6	19.9	19.4	18.9	18.9	19.3	19.6	19.5	19.75
Gojeb	Maximum	32.3	32.2	32.1	31.3	30.5	28.8	28.1	28.1	28.7	29.7	30.8	31.41
	Minimum	12.5	14.1	15.5	15.8	16.5	16.1	15.6	15.5	15.4	14.6	13.1	12.9
	Average	22.4	23.1	23.8	23.5	23.5	22.4	21.9	21.7	22.1	22..2	22	22.1

Table 3.5 Monthly mean max. and mean min. temperature variability of the five stations

Temperature varies spatially with altitude with a general trend of decreasing with altitude, although there are some variations in some stations at certain months (Table3.6).

Station	Jan	Feb	March	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Bonga	19.1	19.7	20.2	20.1	20	19.3	18.9	19.1	19.4	19.6	19.6	19.2
Wushwush	18.2	18.4	19.1	19.1	18.7	17.6	16.7	16.9	17.4	17.9	18.1	17.9
Chiri	19.6	19.8	19.6	18.8	18.4	17.9	16.7	16.9	17.2	17.7	18.4	18.8
Dirigoma	19.8	20.7	20.9	20.6	19.9	19.4	18.9	18.9	19.3	19.6	19.5	19.75
Gojeb	22.4	23.1	23.8	23.5	23.5	22.4	21.9	21.7	22.1	22..2	22	22.1
Average	19.7	20.34	20.72	20.42	20.1	19.32	18.62	18.7	19.08	18.7	19.52	19.55

Table3.6.Monthly mean of max. and minimum temperature of the five stations.

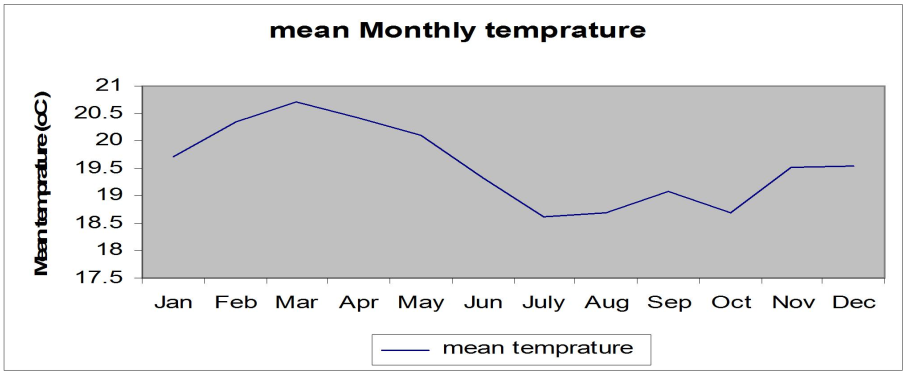


Figure 3.4 Monthly mean temperature variability of the Upper Guma Sub-Catchment.

3.4 Relative Humidity

Relative humidity is the relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature (Shaw, 1988). Available data of relative humidity is from two stations one in Gojeb which has a total of 11 years data and the other in Wushwush with 7 years of data and the average is used for the calculation. It attains its maximum and minimum values in the months of July and February respectively. This is related to the rainy season and dry season in the study area during summer its value raises and during winter its value lowers (Table3.7).

Stations	Mean	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Gojeb	mean at 600	93.9	90.9	90.3	91.5	91.2	95.4	90.8	92.3	92.8	93.4	91.7	93.7
	mean at 1200	78	74.5	76.8	77.1	80	79.5	80.7	79	78.9	80.2	74	74.8
	mean at 1800	77.7	75	78	80	79.2	81.1	80.9	81.5	81.9	84.2	78.6	78.3
	average	83.2	80.1	81.7	82.7	83.5	85.3	84.1	84.6	84.6	86	84.4	82.3
	mean at 600	80.1	81.7	82.8	83.5	85.4	84.2	84.3	84.6	85.9	82.2	82.3	83.2
	mean at 1200	78.4	80.5	81.8	82.1	84	82.1	83.5	83.7	85.4	81.8	81	81.4
	mean at 1800	79.6	81.3	82.5	83	84.9	83.8	84.1	84.3	85.8	82.7	83	82.6
	average	79.4	81.2	82.4	82.9	84.8	83.7	84	84.2	85.7	82.3	82.1	82.4
Average Total		79.8	81.2	82.6	82.9	85.1	83.7	84	84.2	85.9	83.4	82.1	82.3

Table3.7 Monthly mean relative humidity at the study area

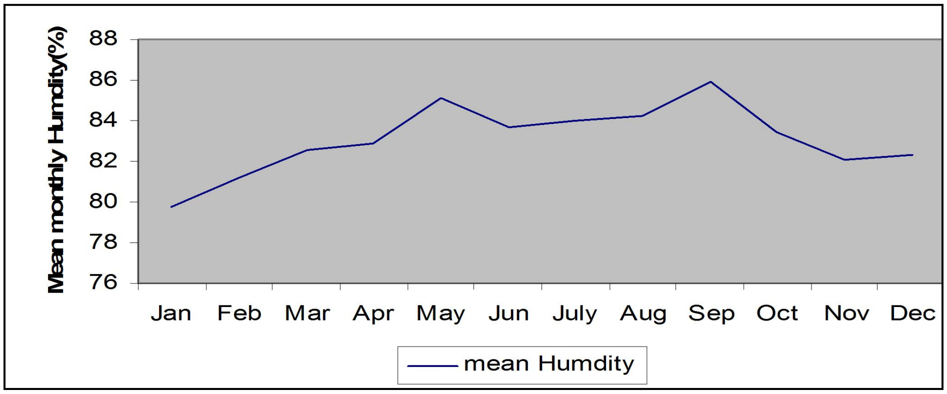


Figure 3.5 Monthly mean relative humidity at the study area

3.5. Wind speed

Data on wind velocity is required in the evaporation studies. Wind speed varies with the height above the ground. However, the wind speed at any height can be approximately obtained from the known wind speed at the known height of observation. Wind speed in the study area and near by station is measured at 2m above the surface of ground.

Available data sources are from three stations (Wushwush, Chiri, and Gojeb) which are averaged and used for the calculation of evaporation. Wind speed shows decreasing spatial variation with altitude and gets its maximum and minimum value in the months of January and September respectively (Table3.8).

Station	Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Wushwush	82.7	79.3	81.1	82.3	82.8	84.7	83.3	84	84.1	85.7	82.6	82.1	82.7
Chiri	82.4	79.4	81.1	82.4	82.9	84.8	83.5	84	84.2	85.7	82.5	82.1	82.4
Gojeb	82.5	79.5	81.1	82.4	82.8	84.9	83.5	84	84.2	85.8	82.8	82.1	82.5
average	82.5	79.4	81.1	82.4	82.8	84.8	83.4	84	84.2	85.7	82.6	82.1	82.5

Table3.8 Average means wind speed of the study area (in m/s)

Wind speed has a great effect on the rate of evaporation in that the higher the wind speed takes away the moisture in the air which facilitate or favors evaporation when its movement is turbulent. Laminar movements have not significant effect.

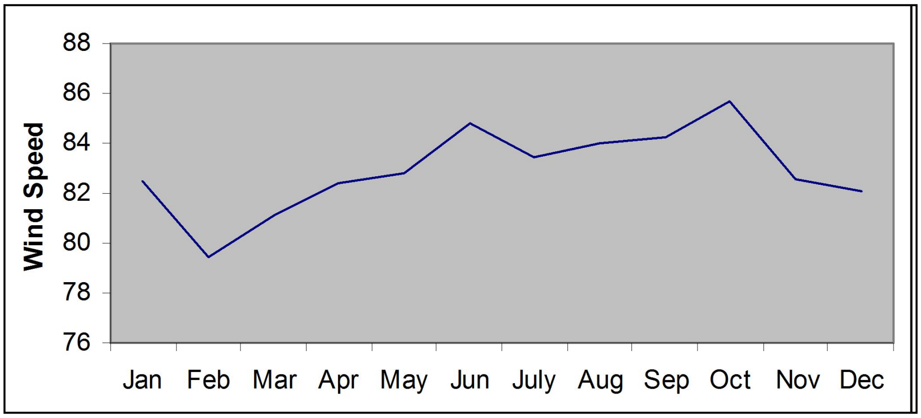


Figure 3.6 Average mean wind speed of the study area

3.6. Sunshine hours

It is the duration of sunshine in a day. It plays the main role as evaporation factor and it has a direct relationship with evaporation. This data is available only from Wushwush, Chiri and Bonga.

stations	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	total
Wushwush	6.7	5.1	6.5	5.7	6.1	3.8	2.7	3.3	4.4	6.8	7.5	7.2	6.7
Chiri	6.3	5.6	6.6	5.4	4.3	3.2	2.5	2.2	4.5	6.1	7.5	7.1	6.3
Bonga	7.6	6.6	6.4	6.6	6.0	4.9	3.1	3.6	4.9	6.8	7.6	8.0	6.0
average	6.9	5.8	6.5	5.9	5.5	3.4	2.8	3	4.5	6.6	7.5	7.4	6.9

Table3.9 Mean monthly sunshine hours of the three stations

The area attains its maximum and minimum sunshine hours during January and July respectively (Table3.9). It's maximum and minimum is the reflection or result of cloud cover during summer and winter.

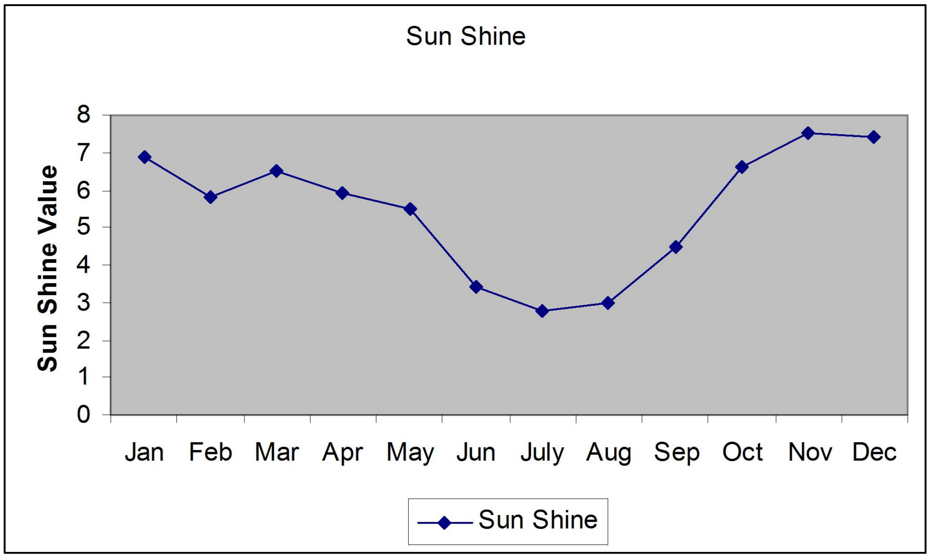


Figure 3.7 Mean monthly sunshine hours of the Study area.

3.7. Estimation of Evapotranspiration

Evaporation is the process by which water from land and water bodies escapes in to atmosphere. It is one of the most complicated hydrologic processes and deserves more elaborate treatment. The nature of evaporating surface affects evaporation by modifying the wind pattern. Over a rough, irregular surface, friction reduces wind speed but has a tendency to cause turbulence, so with an induced vertical component in the wind, evaporation is enhanced. Over an open water surface, strong winds cause waves which provide an increased surface for evaporation in addition to causing turbulence. As wind passes over smooth, even surfaces there is little friction and turbulence and the evaporation is affected predominately by the horizontal velocity (Shaw, 1988).

Direct measurement of evaporation from open water body or pan evaporation in the study area is of no interest for the reason that natural or man made large open water body in the form of lake or reservoir does not exist therefore, the roll of evaporation will not be treated separately rather, it will be dealt in the combined effect of evapotranspiration. Calculation of evaporation from open water body combines the two approaches to evaporation calculation, the mass transfer method and the energy budget method. The basic equations are modified and rearranged to use meteorological constants and measurements of variables made regularly at climatological stations

$H=Eo + Q$---3.1 (Simplified energy balance equation)

$Eo=f(u)(e_s-e_d)$ ---3.2 (Mass transfer method)

Where H= the available heat

Eo= Energy for evaporation=rate of evaporation

Q=energy for heating the air

f(u)= a function of wind speed

e_s-e_d=Saturation deficit

e_s=saturated vapor pressure of air at water surface

e_d=saturated vapor pressure of air above the water surface

After rearranging of different parameters based on the above two methods (eq.3.1 and 3.2), penman arrived at his final equation for open water evaporation. The corresponding formula is

$Eo = (\Delta/\gamma\ H + Ea)/\ (\Delta/\gamma + 1)$ --------------------------------3.3

Where Eo=evaporation rate (mm/day)

Δ= Slope of the curve of saturated vaprer pressure plotted against temprature.

γ= hygrometry constant (0.27 mm of mercury)

$H = R_I(1-r) - Ro$--3.4

Where R_I = incoming solar radiation

Ro=out goring solar radiation

r= the Aledo equals 0.05 for water

But $R_I(1-r) = 0.95\ Ra\ fa\ (n/N)$ ---3.5

$fa\ (n/N) = 0.18 + 0.55\ n/N$-- 3.6

Where Ra = solar radiation arriving at the atmosphere (fixed by latitude and season)

n= bright sun shine hours per day

N= maximum possible sunshine ours obtained from standard meteorological tables.

And $Ro = \sigma T^4_a(0.56 - 0.09\sqrt{e_d})\ (0.10 + 0.9n/N)$----------------------------------3.7

Were: σT_a is theoretical black body radiation at temperature Ta of air

σ = Stefan-Boltzman constant $5.67X10^{-8}wm^{-2}\ k^{-4}$

(T must be converted to ^{o}k)

e_d= mean vapor pressure for the same period.

Next, Ea in equation 3.5 is found using the coefficients derived by experiment for open water. $Ea = 0.35\ (0.5 + U_2/100)(\ e_a - e_d)$--------------------------------3.8

Where: U_2 =mean wind speed at 2m above the surface in miles per day

e_a=saturated vapor pressure at air temperature.

e_d = saturated vapor pressure at dew point t_d = actual vapor pressure

Saturated vapor pressure (e_a)**:** This value can be obtained from the standard curve drawn for the relation between temperature and saturated vapor pressure or from the standard table. But empirically it can be calculated as:

$$e_a = 6.11\exp\left(\frac{17.3T}{T+237.3}\right) \text{ -------------------------------------3.9}$$

Where T is temperature in ^{o}c and e_a in mill bar.

Actual vapor pressure (e_d)**:** This value is calculated from the relation of relative humidity and temperature given by:

$$RH\% = e_d/e_a \text{ --- } 3.10$$

Δ (Slope of the saturated vapor pressure curve corresponding to the air temperature) can be obtained from the approximate equation 3.11. (Jayarami, 1996

$$\Delta = \frac{4098ea}{(237.3+T)^{2}} \text{ ------------------------------------ } 3.11$$

Where e_a in mm and T in ^{0}c. Hygrometer constant (γ) has a typical value of 0.4859 mmHg / ^{0}c (Maidment, 1993).

Where e_a =saturation vapor pressure (mmHg)

e_d =actual vapor pressure (mmHg)

RH =relative humidity (%)

U_2 =wind speed (mile/day)

n =daily mean bright sunshine hour (hr/day)

N =maximum possible sunshine hours determined by latitude and season (12° N Latitude is for the study) from standard tables.

fa =a function of sun shine hour

Ra =solar radiation which depends on latitude and season (mm of water /day)

R_1 =incoming solar radiation (mm/day)

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

σ =Stephan-Boltzman constant ($5.67 \times 10^{-8} \times Wm^{-2} T^{-4}$)

T =temperature (^{o}c)

TK=temperature in Kelvin

Ro =out going solar radiation (mm/day)

H =available heat (mm/day)

Ea =energy for evaporation (mm/day)

σT^4 =theoretical black body radiation (mm/day)

Δ =slop of saturation vapor pressure plotted against temperature

γ =hygrometric constant (0.27mmHg/^{o}c)

Eo =open water evaporation (mm/month)

The overall explanations of all the above mathematical derivations of Penman method of calculations is important for the understanding of the interrelated meteorological entity to be described. Evapotranspiration, denoted by ET, which is the sum of the water used by plants in a given area in transpiration and the water evaporated from the adjacent soil in the area in any specified time. In an area covered with vegetation, it is difficult from practical point of view to separately evaluate evaporation and transpiration. Transpiration is the process by which water vapor escapes from the living plant and represents the most important aspect of water loss in the hydrologic cycle.

3.7.1.2 Estimation of potential evapotranspiration (PET)

Potential evapotranspiration is that which would occur if there was always adequate water supply available to a fully vegetated surface. It is the upper limit of ET for a crop in a given climate. Potential evapotranspiration tends to increase as the temperature, sunshine, and wind speed increase and as the humidity decreases. Calculations of potential evapotranspiration can be done by using different formula and for this research, Penman modified method, Thornthwaite, and Turk are considered and to minimize the contribution of error from each single method the average of the Penman and Thornthwaite values are used in the study area.

Penman modified method is used based on the available data. Resulting from later experience, the evaporation rate formula was modified (MAFF, 1967) to allow the condition under which evaporation plus transpiration takes place from a vegetated surface (Shaw, 1988) and it is given by:

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

Where the extra subscript t signifies inclusion of transpiration effects from equation 3.3.

$$H_t = R_I(1-r) - Ro \text{------------------------------------} 3.13$$

Where: r = the reflective coefficient for incident radiations the Albedo, from the basin depending on the nature of the surface. There fore the value of r for Guma Sub Catchment case is averaged as 0.185

$$Eat = 0.35\,(1+U_2/100)\,(e_a-e_d) \text{----------------------} 3.14$$

This is similar to that of equation 3.10 except the coefficient 0.5 being replaced by 1 to allow for extra roughness in the wind speed function.

$R_l (1-r) = (1-r)$ Ra. fa (n/N) ------------------------------3.15

In addition to the Albedo modification in equation 3.5 to equation 3.16, equation 3.6 takes the form fa (n/N) = (0.16+0.62n/N)--------------------- - ---------------3.16

For latitudes south of 54 .5 ^{0}N, the empirical equation for the out going radiation in the calculation takes the form:

$Ro= \sigma Ta^4 (0.47-0.075 \sqrt{e_d}) (0.17+0.83n/N)$--------------3.17

Albedo (short wave-reflection coefficient) of any basin can vary widely with time of day, season, latitude and cloud cover. In the absence of knowledge on crop the value of r (reflection coefficient), is recommended to be 0.23 (Maidment, 1993)

In the study area however , the average and dominant crops, forests, soil and grass are cereals, plantations, clay soil, deciduous broad leaved and coniferous tree, and grasses with their Albedo, 0.24, 0.13, 0.3, 0.2 , 0.23and 0.22,0.1 respectively (Dunn and Leopold (1978) and Maidment (1993)). Therefore by averaging the above Albedo the value of r is taken as 0.185. Using this Albedo, the value of $R_l (1-r)$ will be

$R_l (1-r)=0.783$ Ra fa(n/N)-----------------------------------3.19

According to penman equation the study area has a lower potential evapotranspiration during summer time in the month of Jun (PET=50.5mm/m) because of the cloudy weather while the maximum evapotranspiration on the contrary occurs during winter time in the month of March (PET= 90 mm/month) (Table3.10).

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Ave.temp.	20.34	20.72	20.42	20.1	19.32	18.62	18.7	19.08	18.7	19.52	19.55	19.7
R.H%	81.2	82.6	82.9	85.1	83.7	84	84.2	85.9	83.4	82.1	82.3	79.8
Sun(hrs)	5.8	6.5	5.9	5.5	3.4	2.8	3	4.5	6.6	7.5	7.4	6.9
Wind(m/s)	70.4	81.1	82.4	82.8	84.8	83.43	84	84.2	85.7	82.6	82.1	82.5
PET(mm)P	83	99.5	90	83	62	50.5	54.5	63.5	83	76	78	84
Thornthwaite	71.6	70.9	76.7	76.5	50.6	65.8	60.9	61.9	71	60.6	65	60.3
Aver PET	77.3	85.2	83.35	79.75	56.3	58.15	57.7	62.7	77	68.3	71.5	72.15

Table 3.10 Potential evapotranspiration of the study area.

In addition to the above well known method there are several empirical formulas for a general estimate of evapotranspiration for the catchment.

Turc method: - this method uses a formula to estimate annual values of evapotranspiration for catchment taking mean annual precipitation in mm and mean temperature in degree centigrade data and the potential evapotranspiration is found to be 970.3mm annually.

Thornthwaite method:- this also uses an empirical formula for evapotranspiration calculation and accordingly the annual value for the study area is calculated to be 885.9mm.

Potential evapotranspiration of the area is calculated by taking the average of these methods and the result is indicated as shown in table (3.10) above.

3.7.2 Actual evapotranspiration

Actual evapotranspiration(AET) over a catchment is often obtained by first calculating the potential evaporation plus transpiration (PET),that is assuming an unrestricted availability of water, and then modifying the result by accounting for the actual soil moisture content (Shaw,1988). The term actual evapotranspiration is used to describe the amount of evapotranspiration that occurs under field conditions. The majority of the water loss due to evapotranspiration takes place during the winter months while little loss is during the summer. Always actual evapotranspiration is less or equal to potential evapotranspiration. When the vegetation is unable to abstract water from the soil, then the actual evapotranspiration becomes less than potential.

If a soil is saturated then, it will hold no more water. In this conditions, actual evapotranspiration is equal to potential evapotranspiration (AET=PET) (Shaw, 1988). If there is no rain to replenish the water supply, the soil moisture gradually becomes depleted by the demand of vegetation to produce a soil moisture deficit (SMD). As soil moisture deficits increases, actual evapotranspiration becomes increasingly less than potential evapotranspiration. The values of soil moisture deficit and actual evapotranspiration vary with soil type and vegetation.

Penman (1950) introduced the concept of ‘root constant’ that defines the amount of soil moisture (mm depth) that can be extracted from a soil without difficulty by given vegetation. A soil moisture budget can be made on a monthly basis for various types of vegetation classified according to their root constants. There fore to evaluate actual evapotranspiration over a basin area, the proportions of different types of vegetation covering the basin must be known.

Accordingly, the study area has been classified in to three major groups of soil type with their vegetation cover. Based on these categories and meteorological data the actual evapotranspiration of the basin is calculated using Thornthwaite and Mather soil water balance model. This model considers that soil is always saturated and that vegetations can take the amount of water they require for growth.

The method employed for calculating the actual evapotranspiration is modified Thornthwaite water balance method with monthly precipitation(P) values for the area are listed in row one of the tables .the potential evapotranspiration(PET) which has been calculated in previous section is in row two. In row three the difference between P and PET showing two seasons of dry and wet seasons of the year.

Month	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Au	Sep	Oct	No	Dec	Annul
P	48.9	50.5	110	172	199	211	208	249	180	127	59.2	58.67	1686
PET	77.3	85.2	83.5	79.8	56.3	58.2	57.7	62.7	77	68.3	71.5	72.15	849.4
P-PET	-27.4	-34.7	26.6	92.2	143	153	150	186	103	59	-12.3	-13.48	
AcPwL	-86.5	-129									-12.3	-25.8	
Sm	307	258	259	331	441	481	500	500	500	500	487	461	
ΔSM	-18	-20	0.2	12.8	+11	+14	+19	0	0	0	-10	-8.6	
AET	66.9	70.5	83.5	79.8	56.3	58.2	57.7	62.7	77	68.3	69.2	67	816. 2
D	1.3	4.7	0	0	0	0	0	0	0	0	2.3	5.15	13.45
S	0	0	26.4	79.4	123	119	130	106	103	59	0	0	745.8
Taf RO	1.3	12..2	18.2	73.5	47	110	123	99	95	51	0	1.5	
RO	.7	6.1	9.1	39	24	55	62	50	43	26	0	.8	314.3
Detn.	.6	6.1	9.1	36	23	55	61	49	42	25	0	.7	

Table 3.11 Calculated actual evapotranspiration using water balance model for the clay loam soil covered with, matured forest. The maximum water capacity of the root depth is 500mm.

Where, p=precipitation ΔSM=change in soil moisture during the

AET=Actual evapotranspiration month indicated

D=Soil moisture deficit
S=Moisture deficit
Ac PWL=accumulated potential loss
Taf RO =total available for run off
RO=direct runoff
PET=Potential evapotranspiration
Sm=maximum soil moisture
Detn.= detention

For soil moisture which depends upon the texture of the soil and rooting depth of the vegetation and taking the required parameters in to consideration, Thornthwaite water balance method is used for calculation of soil moisture in row five. Change in soil moisture (Δsm) taking the difference in row six is calculated the difference in successive months, when P>PET, the actual evapotranspiration (AET) = PET and when P<PET, AET = P + Δsm. The fraction of soil moisture surplus which will leave the catchment as runoff varies with the depth and texture of the soil and the physiographic condition of the catchment. An estimate can be made by examining the relative amount of stream flow during successive wet seasons. Ro and D each are obtained by taking 50% of the available for total runoff.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Au	Sep	Oct	No	Dec	Annu
P	48.9	50.5	110.1	172	199	211	208	249	179.7	127	59.2	58.67	1686
PET	77.3	85.2	83.5	79.8	56.3	58.2	57.7	62.7	77	68.3	71.5	72.15	849.4
P-PET	-27.4	-34.7	26.6	92.2	143	153	150	186	103	59	-12.3	-13.48	
AcPwL	-86.5	-129									-12.3	-25.8	
Sm	4.4	1.1	11.4	90.7	97,5	97.5	97.5	97.5	97.5	97.5	51.1	23.6	
ΔSM	-20.4	-3.3	10.1	79.3	0	0	0	0	0	0	046	-12.7	
AET	68..9	53.5	83.5	79.8	56.3	58.2	57.7	62.7	77	68.3	60	71	796.9
D	11.8	39.3	0	0	0	0	0	0	0	0	3	2.5	
S	0	0	26.6	92.2	103	103	120	106	103	59	0	0	712.8
Taf RO	21	10	9.7	11	115	97	197	162	154	170	85	42	
RO	11	5	5	6	58	49	99	82	77	85	43	21	541
Detn.	10	5	4.7	5	57	48	98	80	77	85	42	21	

Table3.12 Calculated actual evapotranspiration (AET) using water balance model for the clay soil covered with moderately deep rooted cereal crops having water holding capacity of 150mm.

Month	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Au	Se	Oct	Nov	Dec	Annu.
P	48.9	50.5	110.	172	199	211	208	249	180	127	59.2	58.67	1686
PET	77.3	85.2	77.3	85	84	80	56	58	58	63	71.5	72.15	849.4
P-PET	-27.4	-34.7	26.6	92.2	143	153	150	186	103	59	-12.3	-13.48	
AcPwl	-86.5	-129									-12.3	-25.8	
Sm	0.16	0	0.3	43	43	43	43	43	43	431	31.3	5.5	
ΔSM	0.1	0.02	0.3	42.7	0	0	0	0	0	0	10.1	-9.6	
AET	49	50.6	77.3	85	84	80	56	58	58	63	71	68	722.9
D	30.8	42.6	0	0	0	0	0	0	0	3	8	11.5	96
S	0	0	26.6	92.2	103	123	150	136	103	51	0	0	784
Taf RO	30.8	42.6	19	43	123	144	142	179	95	51	8	11.5	
RO	16	22	10	22	62	72	71	89	43	26	4	8	445
Detn.	14.8	20.6	8.7	21	61	72	71	90	42	25	4	7.5	

Table3.13 Calculated actual evapotranspiration using water balance model. The soil is fine sand loam with shallow rooted crops and plantation, open grass, shrubs and cultivated which has a maximum water capacity of root zone 75 mm.

The above tables are the results of different parameters considered to play a great role in the system of evapotranspiration of a given basin. As a summary the relations of soil type, land use/land cover and actual evapotranspiration is described below.

No	Soil type	land use/land cover	Aerial(%) proportion	AET (mm)	Weighted AET(mm)	S(mm)	Weighted S (mm)
1	Clay	moderately cultivated for cereals with open grass land	29.45	796.9	234.68	712.8	209.9
2	Sandy loam	plantation with cultivation ,grass and significant shrubs	10.35	722.9	74.8	784	81.14
3	Clay loam	Matured forest cover with cultivation, shrubby and open wooded grass	60.2	816.2	491.3	745.8	448.9
Tota					800.7		739.3

Table3.14 Relation between soil type, land use/land cover and actual evapotranspiration.

Finally, the calculated amount of evapotranspiration and surplus water in the basin gives that the basin losses water in the form of actual evapotranspiration having an amount of 800.7 mm. (Tabl3.14).

3.8 Runoff Rainfall Relationship

For hydrological analysis and design, it is often necessary to develop relations between precipitation and runoff. Such relations are use full for extrapolation or interpolation of run off records, which are generally available for long periods (Jayarami, 1996). In addition to its usefulness for analysis it is also possible to understand the geological and hydrogeological characteristics of the basin as runoff depends on soil infiltration capacity, intensity and duration of precipitation and topography and shape of the basin.

The rivers in the study area are gauged at four stations ,but two of the four stations covering the northern and north eastern, western and north western part of the drainage area with 512 km^2 area is gauged by Dincha gauging station and southern and south western part with 231.25km^2 area by Guma gauging stations.

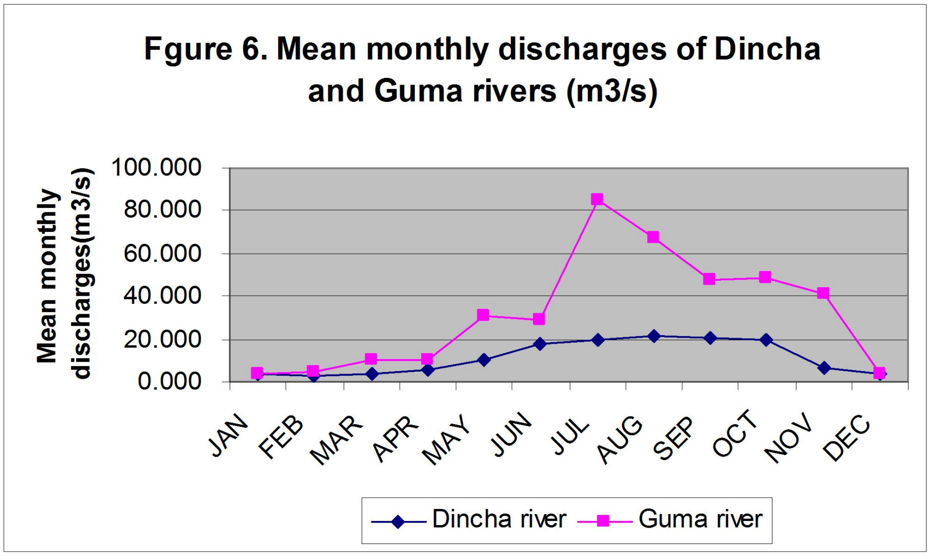


Fig 3.8 Flow nature of Dincha river as it flows down stream during dry season

From the above figure it is possible to conclude that the gauging station with minimum areal coverage, the Guma Station, has greater discharge as compared to the Dincha gauge owing to its fun shape and greater percent of steeply slope.

In the study area the highest precipitation is mostly recorded in the months of June, July and August. As a result of this highest rain fall, the maximum river discharge or runoff is recorded in the month of August (Table3.15). Here the month of maximum precipitation and month of maximum runoff fall in the same month. From hydrogeological point of view, this condition has its own meaning that, the area or the basin is not by major permeable which allows the initial rain fall up to the maximum amount to infiltrate till saturation and the runoff will start immediately. The relationships of the two parameters are shown below from the hydrograph (figure 3.8).

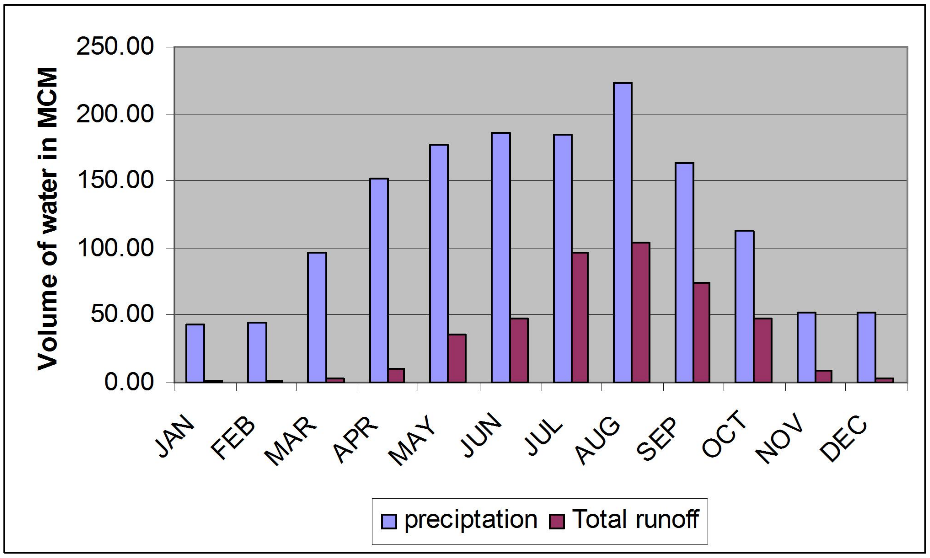


Figure 3.9 Relation ship between surface runoff and precipitation.

Generally, of the total precipitation (1486.6 mcm) in the basin, the river flow (435.7 mcm) annually covers 29.3 % (Table 3.15).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nv	Dec	Annu
P(mcm)	43.1	44.6	97.1	151.6	176.6	186.2	183.9	222.9	164	112.7	52.2	51.4	1476.6
TRO(mcm	1.79	1.36	3.5	10.5	36.1	47.8	96.8	104.2	73.9	47.4	9.47	2.8	435.8
GOF(mcm	10.2	8.02	9.8	12.8	17.	21.	26.1	34.6	41.1	30.3	17.3	11.5	239.7

Table 3.15 Runoff and base flow components from precipitation in MCM.

Depth of ground water in a basin is a reflection of hydrogeological, geological and hydrological characteristics of the area. Shallow ground water indicates that the area is permeable with enough Precipitation to saturate or raise the water table in the permeable hydrogeologic unit in the study area. On the contrary if the ground water is deep, the area might be either suffering from precipitation shortage or the area is impermeable at the surface and is recharged not from local recharge but from regional. Depth to ground water has its own manifestations such as depth of hand dug wells, shallow wells, deep wells, and springs, in the area.

3.9 Surface water and Groundwater interaction

Groundwater and surface water are not isolated components of hydrologic system and hence, understanding their interrelation is needed for effective management of water resources. In recent years, as winter (1995) points out, studies of surface and groundwater interactions have expanded in scope to include studies of head water streams, lakes, wetlands and estuaries. As Hubbert (1940) shows, given an aerially uniform precipitation and infiltration over undulating surface, a groundwater flow system will develop driven by a water table surface that is a subdued replica of the land surface. In any basin, surface water (River or stream) is either gaining stream or losing stream. The readings from the river (see run off section) show that the region is generally characterized by humid climates and have shallow water tables and gaining steams. Aquifers are often saturated and groundwater is usually discharged through evapotranspiration and base flow to streams. Recharge rates in these regions are often limited by ability of aquifer to store and transmit water, processes that are strongly affected by sub surface geology. During summer, there is high amount of rain fall that can saturate the subsurface formation and that leads to the flow of river without losing its initial volume rather gaining down stream.

3.10 Groundwater Recharge estimation

In regions where water supplies rely heavily on groundwater, knowledge of natural recharge is important for quantifying safe yields of aquifers to avoid unacceptable decline in water tables (Bouwer 1989; sophocleous 1991). Groundwater recharge can be defined as the entry of water into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table with in the saturated zone (Freeze and cherry, 1979).Estimating amount of groundwater recharge in the basin is important for efficient ground water resources management. The availability of the background information on climate; geomorphology, including topography; vegetation, soil type, and permeability; physiographic setting; geology; and hydrology (water table depth, gaining vs.

loosing streams) are important to come out with reasonable estimation and have been described in their respective chapters. To estimate ground water recharge of the area different techniques of estimation have been used

3.11 Base flow separation method

In water shades with gaining streams, ground water recharge can be estimated from stream hydrograph separation (Halford and Mayer 2000).This method is possible to do either by hydrograph method or using software.

Using hydrograph separation methods of straight line method, constant slope method and concave base flow separation method, it is possible to estimate amount of recharge with various result (McCueb, 1989). But to be logical and reasonable for this study, the constant slope method is selected. In this method, it is only necessary to select the point on the recession where direct run off ends. This point can be obtained by either using the concept of inflection point on the hydrograph recession which is the point where the hydrograph goes from being concave to convex or using an empirical formula proposed for large water shed (McCuen, 1989).

$N=A^{0.2}$ where, N=number of days from peak flood to the end of surface run off A=area of the basin in square miles.

But the draw back of this formula for this study is that since the empirical formula needs large water shed or basin it over estimate the base flow .There fore to be more reasonable inflection point method is used to separate the base flow from the runoff.

In the study area the catchment is divided in to three areas as 512 km^2 gauged by Dincha river gauging station; the 231 km^2 area gauged by Guma river gauging station and the rest 133 km^2 area being out of the gauging station for which the runoff part is calculated by considering the runoff coefficient of 0.2 and the long term mean monthly precipitation (Table 3.16).The annual ungauged runoff accordingly is found to be 45.14 mcm.

Ungaued RO	JAN	FEB	MA	APR	MAY	JUN	JUL	AU	SEP	OCT	NO	DEC	Ann.
Ppn mm	48.9	50.5	110	171.8	199.4	211	208.4	249.	179.7	126.8	59.2	58.6	1686
RO coef.	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
area	133	133	133	133	133	133	133	133	133	133	133	133	
URO mcm	1.31	1.3	2.9	4.6	5.3	5.65	5.6	6.77	4.98	3.42	1.6	1.5	45.14

Table 3.16 Calculated runoff for the ungauged part of the study area.

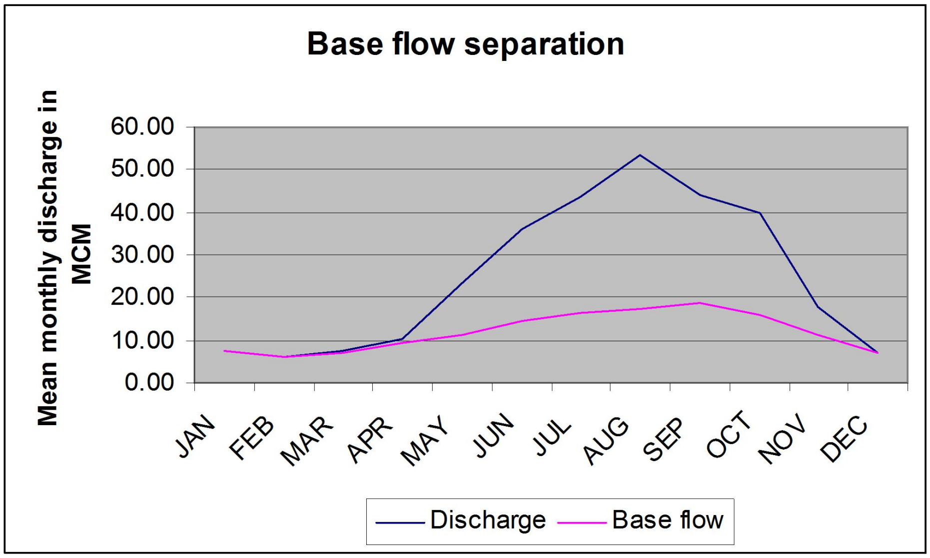


Figure 3.10 Base flow separation of Dincha River from hydrograph.

One of the methods of separating base flow from the total flow of Guma Catchment River is manually from the hydrograph. Therefore, base flow of the study area is obtained to be 104.3 MCM of the total flow 165.7 MCM and the annual runoff is 61.4 MCM per year.

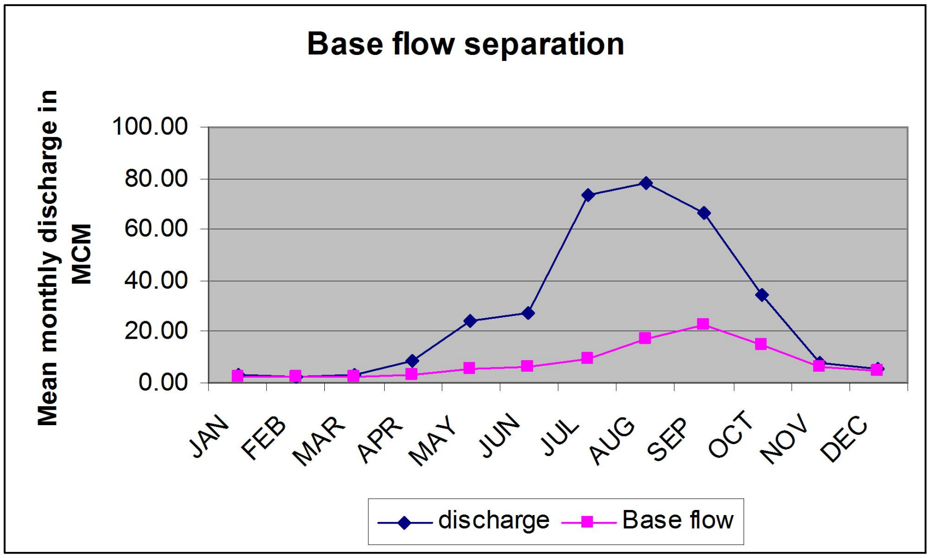


Figure 3.11 Base flow separation of Guma River from hydrograph.

Dincha river	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Ann.
discharge MCM	7.72	6.03	7.36	10.39	23.20	36.1	43.5	53.56	43.97	40.07	17.6	7.15	296.8
base flow MCM	7.60	6.03	7.20	9.40	11.20	14.4	16.5	17.30	18.70	15.80	11.2	7.15	142.5
SRO MCM	0.12	0	0.16	0.99	12.00	21.7	27.1	36.26	25.27	24.27	6.5	0.0	154.4

Table 3.17 Amount of base flow (MCM) of Dincha River from the hydrograph separation method.

Base flow from the total flow of Dincha River is manually from the hydrograph. Therefore, base flow of the study area is obtained to be 142.5 MCM of the total flow 296.8 MCM and the annual runoff is 154.4 MCM per year.

Guma river	JAN	FEB	MA	APR	MA	JUN	JUL	AUG	SEP	OCT	NO	DEC	Ann.
discharge MCM	2.92	1.99	2.9	8.3	24.5	27.04	73.7	78.51	66.08	34.26	7.5	5.6	333.4
base flow MCM	2.56	1.99	2.6	3.4	5.8	6.60	9.6	17.30	22.40	14.52	6.1	4.3	97.17
SRO MCM	0.36	0.00	0.4	4.8	18.7	20.44	64.2	61.21	43.68	19.74	1.4	1.3	236.3

Table 3.18 Amount of base flow (MCM) of Guma River from the hydrograph separation method.

Accordingly the result shows that 239.65 MCM is the total base flow and 435.79 MCM is the total runoff of the study area obtained from the above three components (Table3.19).

3.11 Water balance method

The range of recharge rates that can be estimated by different techniques varies and determines, in part, which technique to apply. The reliability of the recharge estimates is also quite variable The water balance represents the hydrological gains and losses of a given system (reservoir, column of soil, aquifer, river basin, etc) over a specific period (Tenalem and Tamiru, 2001).

For this study the use of water-budget approach is selected because it is applicable in areas of humid climate. For natural catchment, measurement of the precipitation and river discharge may be made satisfactorily with some degree of precision. But the measurement of ground water movements into or out of the drainage area cannot be made easily .In this study of water balance, the catchment's ground water inflow is assumed to be zero based on the detailed field observation around the water divide of the basin from Gojeb basin and Woshi river sub catchment. This condition made the evaluation relatively simple in avoiding the subsurface and surface movement of water across the defined watershed boundary. There fore, water balance of the basin is represented by the general equation.

Inflow=Out flow + change in storage

Here, the inflow includes precipitation and ground water inflow where as the out flow includes surface runoff, ground water out flow, Evapotranspiration and change in storage. The general water balance equation is;

$$P + Gi \quad = \quad AET + TRO + GOF \pm \Delta s$$

Then finally, the study area will have a water balance equation of:

$\Delta S = P - AET - TRO - GOF$ in mcm

Where; P=Precipitation, Gi =ground water inflow = 0, AET= actual Evapotranspiration, TRO=Total surface run off, GOF=Groundwater out flow from the catchment and ΔS = Change in storage, the values of all of these components are clearly indicated in (table3.19)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annl.
P(mcm)	43.14	44.63	97.10	151.55	176.69	186.15	183.96	222.99	164.03	112.79	52.17	51.43	1476.63
ET(mcm)	52.12	53.96	73.3	63.6	57.7	52.9	51.5	51.6	61.7	60	61.4	60.9	700.68
TRO(mcm)	1.79	1.36	3.48	10.47	36.10	47.83	96.83	104.23	73.93	47.43	9.47	2.87	435.79
GOF(mcm)	10.16	8.02	9.80	12.80	17.00	21.00	26.10	34.60	41.10	30.32	17.30	11.45	239.65
ΔS=P-ET-TRO-GOF	-20.93	-18.71	10.52	64.68	65.89	64.43	9.26	32.56	-12.2	-24.96	-36	-23.79	110.751

Table 3.19 Long terms mean monthly water balance result of Upper Guma sub-Catchment (MCM)

There fore, the amount of recharge in Upper Guma Sub-Catchment basin is calculated not to be greater than 10 percent of the total precipitation in the area indicating that the over all groundwater potential except the identified well field is not of potential groundwater availability. The results of this set of calculations are portrayed in table 4.5 which summarizes a great deal of information on the hydrology of the area. Besides showing the seasonal pattern of precipitation, evapotranspiration, and runoff, it indicates the time of moisture recharge, and moisture surplus. The water balance is therefore valuable for understanding the ecology, agronomy, and economics of growing crops.

younger Megdela group being of Miocene to Pleistocene age. Jima volcanics was named by Merla etal.(1973) to trachybasalts and rhyolites which cover most part of southwestern Ethiopia. Davdsen (1983) has reported K/Ar Age of 42.7 to 30 Ma for the Jima volcanics.Two units (Jima Basalt- pjb and Jima Rhyolite- pjr) which shows conformable relashinship were identfide.The Jima Rhyolite being the younger of the two units in south west Ethiopia are equvallent to the Megdela group.The basalt flows form unbroken succession several hundred meters thick in some places,and in others felsic rocks are interculated with basalt flow closer to the base or form a thick succession just above the basal basalts.

4.2 Geology of the study area

The steep escarpment of the volcanic landscape characterizing the area is the result of structural/faulting effects while gentle to steep slopes and the flat alluvial/marshy plains at the bottom of the valleys are due to denudational and depositional process. The geology of the study area consists of volcanics constituting acidic and basic rocks such as rhyolite, tuffs, agglomerates and basalts. The gentle to steep sloping parts of the region are covered by in-situ derived compact clayey soils. Alluvial deposits exist along the channels of the rivers particularly adjacent to the town of Bonga. The alluvial and colluvial deposits are the derivation of local geology through weathering and transportation by erosion.

4.2.1 Lithologic description

In general the geology of the area can be categorized in to 3 main rock units (Fig.4.1). These units are

1. Basalt
2. Rhyolite and trachyte
3. River bed deposits

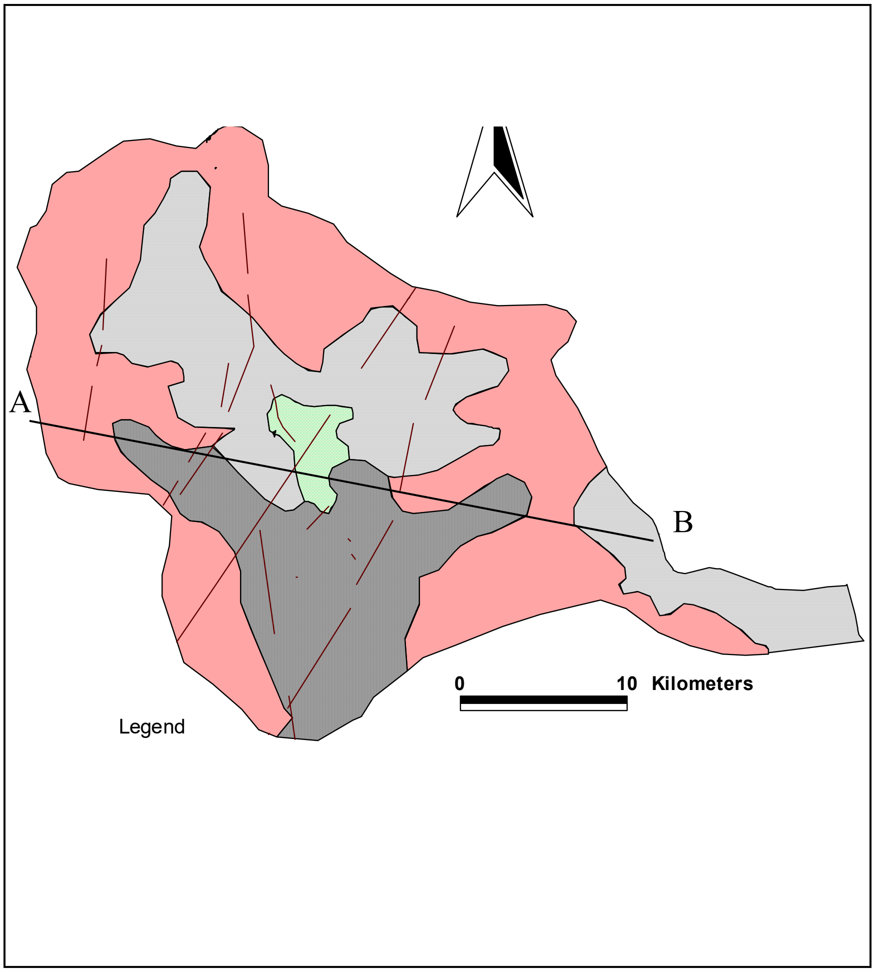


Figure 4.1 Geological map of Upper Guma Sub-Catchment (AB = Profile line for section in figure 5.3)

4.2.2 The Basalt unit

The Basalt rock units are the second dominant formation in the basin with different degree of weathering that has been resulted due to the prevailing wet climate which has no significant variation from place to place with in the study area. The high land area around south east of Wushwush town and the northeastern parts have weathered and fractured basalts including those from the western parts of the study area, and the second sub type of basalt outcrops in the southern part of Bonga with very thick fine grained basalt of an average thickness of about 50m can be observed in Gedam and its surrounding and sometimes with columnar structure and in places covered by highly jointed basalts. It is highly jointed and boulder type which is serving as a good building stone source for Bonga and the surrounding towns. It is there exposed in almost all of the lower elevations where stream banks crosses and immediately below or at the foot of high land areas. (Plate.4.1).

Highly weathered and friable basalt of the same group of basalt is common in the basin especially northern and north eastern part of it. This formation covers relatively smaller area of the basin as compared to the former one. This rock unit is sensitive to erosion due to its topographic situation and its degree of weathering (Plate 4.2).

4.2.3 Fresh to slightly weathered rhyolite and fine and course grained tuff

All these formations are the result of acidic volcanic rocks which almost in all cases rests over the basalt in the study area with the thickest exposure immediately by sides of the road at quarry sites. Fresh rhyolite formation occurs in most of the area after some excavation to remove weathered and altered materials at the elevated surroundings of the area. The degree of compaction of this unit varies from place to place with highly compacted being just above the basaltic unit. Volcanic tuff is common in Bonga area as exposed formations are with high degree of weathering. The aerial coverage of this geologic unit is extensive as compared to the other units. This rock unit is also sub- divided in to tow as weathered and fresh/un weathered rhyolitic units.

4.2.4. River bed deposits

River courses in any basin are filled with different size alluvial materials, which shows or express the nature of the basin along which they travel and degree of erosion. All the river which starts from the tope of Wushwush, Diri, and Mera areas flows with high sediment load. Along the course of the river there are three types of river beds (the silty sand, the sandy gravel, and gravel and pebbles with boulders).In the study area it is the middle part of the rivers coarse around Bonga town which covers most of the flat area occupied with silt and sand soils. Next to this formation as one goes up stream the sandy gravel soil type will take the dominancy and then followed by gravel, pebble and boulders as the river course starts to elevate. An extensive clay soil up on which marsh areas developed cover in the northeastern part of the study area.

Plate.4.1 Flow of Dincha River in its lower course and deposition along river course (alluvial deposit).

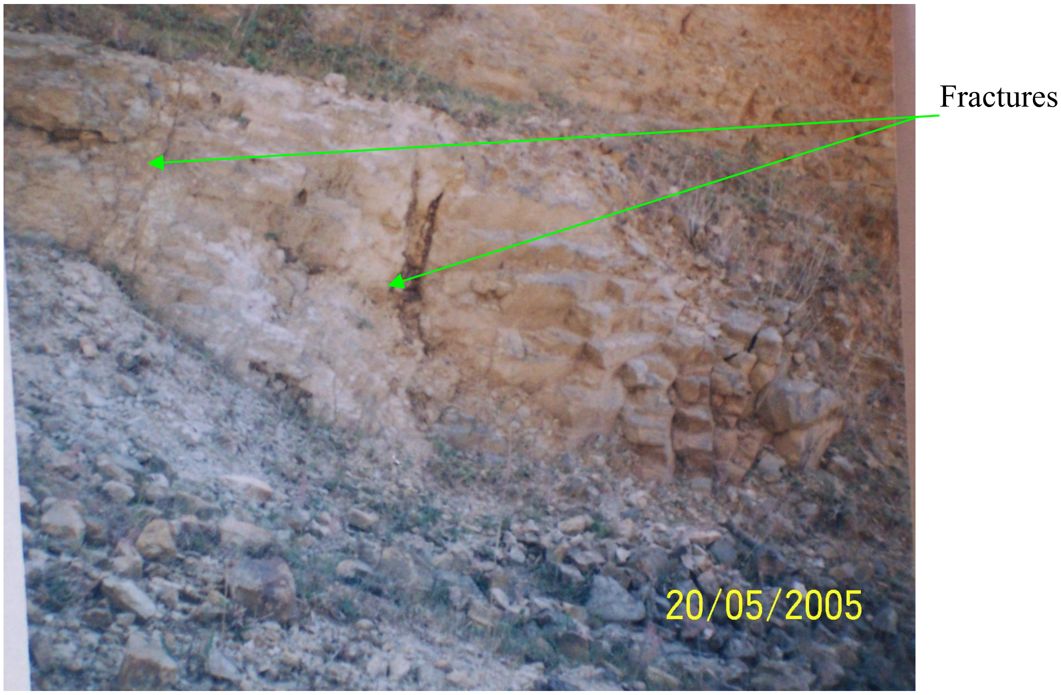


Plate.4.2 fractured and weathered rhyolite

Plate 4.4 Unweathered rhyolite unit being exposed at the quarry site

Plate 4.4 weathered rhyolite and columnar basalt exposed at the water fall cliff.

Plate 4 .5 contact between over-ling rhyolite and under-lying fresh basalt

Plate 4.6 Dry season flow of Dincha River at its gauging station.

4.2.5 Geologic structures

Identification of geologic structures is useful for any structure controlled phenomenon along which mineralization, ground water accumulation and emanating hydrothermal springs etc are prominently determined. However, unless it is studied in detail or detected properly, it may cause negative impact on the developmental activities such as construction of buildings, dams, etc.

The cause for geological structures are deep tectonic activities either regionally or locally which can change the morphology of the earth through time .In the study area different structures cross the basin with different orientations.

Aerial photographs studies and filed observations have revealed that faults, fractures and joints characterize the area. The general trend of the fault in the area is NE-SW and NW-SE direction. The vertical fault escarpment forming the water fall on the upstream stretches of the Barta river at about three km from the town is prominent fault structure. The continuation of this fault system has been observed to have reached the area of Sobra spring site and is inferred to further extend to the valley of Dincha river .There are also other minor fault/fracture systems in the area. The drainage system of the area is structurally controlled (Figure 4.1).

CHAPTER 5

HYDROGEOLOGY

General

The study of water in the earth which deals with the occurrence, distribution, and movement of water in addition to physical as well as chemical relation-ships with the surrounding environments defines hydrogeology (Sen., 1995).

The most important advances in hydrogeology to day have been stimulated by studies designed to solve problems of great economic importance. This trend will probably continue as the demand for water will undoubtedly increases with growing population and industrialization, so that the subject matter will be helping for water resource estimation, to assess water pollution risk for safe land use allocation and understanding of surface and ground water interaction conditions. Therefore, in this chapter the hydrogeologic condition affecting surface and ground water interaction in the study area will be discussed by starting with descriptions of the hydrogeological units.

Characterization of hydrogeological units of the area needs to describe and evaluate the contribution of many physical parameters such as soil cover, morphology, geology and rainfall, runoff, and evapotranspiration relationships. The geologic zones important to groundwater must be identified as well as their structure in terms of water holding and water yielding capabilities (Todd, 1980).

In the study area data from springs, hand dug wells, boreholes, and geological features and associated structures in combination with the above parameters are used for the description of different hydrogeologic units in the area. Different geological settings of the area which ranges from recent quaternary deposits comprise of alluvial, colluvial and residual deposits to Tertiary volcanics comprise of acidic and basic rocks (tuff and basalt). Many hand-dug wells, several springs, shallow boreholes and seven deep boreholes are inventoried from different formations and accordingly the following water bearing characteristics of rocks are identified.

Ground water occurrence in the area is governed by several factors such as rainfall, geology/thickness of aquifer material, topography, rate of evapotranspiration and possibility of ground water recharge etc. As can be noticed from the geological and hydrogeological descriptions of the major formations in the area the alluvial, colluvial deposits which have limited thickness, form only high to moderate productive shallow aquifer systems .These are being utilized through hand dug wells and low yielding springs at the slope breaks and in some localities combined with the top, highly weathered basalt/tuff formation. Significant quantities of groundwater exists at depth within the scoria and fractured rhyolite and basalt formations. These can be tapped for town water supply through deep wells. Therefore, the study area is characterized by three hydrogeologic units (Figure 5.1)

5.1.1 Highly permeable formation

This hydrogeologic unit of the area consists of the Quaternary sediments which are composed of gravel, sand, clay and silt mixture in various proportions and this type of formation is found at the lower elevation of the basin along Dincha and Sheta rivers. This is totally alluvial and colluvial deposits characterized by high permeability, porosity, and Transmisivity. In this part of the study area springs are observed emerging out of quaternary sediments at hill breaks, contacts between alluvial deposits and underlining weathered basalt and old landslide deposit. The discharge of the springs ranges from 0.1to 0.5 l/s do not dry through out the year. As different borehole logs show and alluvial deposit is the result of weathering of basalt which starts with moderately weathered and then decreases with depth.

This area is in the surroundings of Bonga town where the area is topographically controlled with a feature of incised narrow stretches of valleys between the adjacent hills. These geomorphological conditions combined with other hydrogeological factors govern the occurrence of deep groundwater in these valleys. Adjacent to the town significant groundwater in the locality is anticipated to be stored mainly within the scoria formation as well as weathered and fractured volcanic rocks (rhyolite and basalt) as has been revealed by wells drilled in the area. The area occupied by this formation is hydraulically interconnected with the surrounding rock formation in that the scoria revealed to exist underground has important properties from a hydrogeological point of view, due to its high porosity and permeability which make it a promising formation for groundwater occurrence. Groundwater recharge from the surrounding recharge areas could be stored and transmitted within this formation with the capacity to release significant water to wells. This condition is clearly evidenced by the presence of productive wells with a yield of greater than 6 l/s and a total draw-down of only 2.5 m, from the saturated thickness of 22m.

Pump test from Dincha bore hole (in the same formation) after through development a continuous pump test at a rate of 7 l/s for a period of 68 hrs and the well has a dynamic water level of 6.36m with a total drawdown of only 3.86m below ground level. The tranmissivity of the well is determined to be about 1.69 X 10^{-3} m^2/s and has a specific capacity of 8.31 X 10^{-2} l/s/m. From ground water storage and releasing capability or in general ground water potential assessment point of view the area is the best zone with in the basin. Within this hydrogeologic unit the roll of geologic structures is significant that, care should be taken to minimize the probability of losing a well drilled in this area.

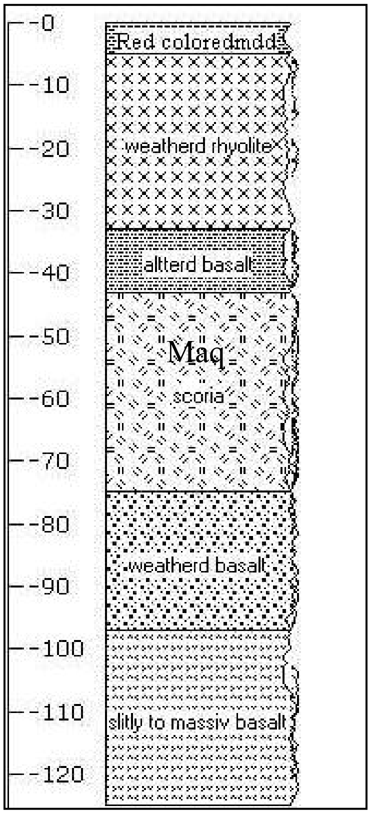


Figure 5.1 Dincha bore well lithologic log showing main aquifer (Maq) in the highly permeable formation

5.1. 2 Moderately permeable formation

The second type of aquifer is characterized by its Moderate permeability, with intermediate storage, porosity and transmissivity. This formation is situated by major within weathered and fractured basalt and rhyolite rock unit with associated peripheral extensions (Figure 5.1). Compositionally this formation is made up of jointed basalt with big boulders, intercalated with rhyolite. As newly developed deep bore well at Wushwush and shallow wells around Diri show that, volcanic ash material and basalt are the main aquifers for the described area which is north western and north eastern part of the basin. Springs of moderate yields are also common in this formation. From potential assessment, this formation is characterized as a site for ground water potential for the surrounding areas.

From the bore holes drilled in this rock, and field observation, it is possible to infer that permeability is moderate to low and wells have yields not greater than 3-4 l/s since the effect of weathering is moderate.

Compositionally, it is basalt intercalated with rhyolite which is exposed mainly on rugged and hill side of the topography. Their degree of weathering is decreased immediately with depth which plays a great role for the accumulation of ground water. In the plain area, the depth of such formation is not greater than 10 meter followed by slightly weathered basalt flow. From hydrogeological point of view, though the surface rock formation is highly weathered and permeable, unless it has a good depth, sufficient amount of groundwater may not be stored enormously. Boreholes in such formation are productive not anywhere in this area but on fault or fracture lines which might have deeply fractured formation favoring ground water circulation. This can be evidenced by the abounded and the newly developed Wushwush boreholes. Even though, it is out of the catchment, the newly drilled shallow deep wells around Diri in Shomba village, represents such formation. Because of the thin layer of the weathered basalt, the yield does not increase with depth of greater than100 meter. Hand dug wells and shallow drilled wells are more productive than bore holes from economical point of view.

5.1. 3 Low permeable formation

Slightly weathered to non weathered basalt and rhyolite formations have low permeability to impermeable formation. This formation is characterized by massive basalt and rhyolite non-fractured and exposed on the surface. Extreme surface runoff is favored on this formation by prohibiting rainwater entrance into the ground (infiltration). Hand dug wells are not productive in such formation unless perched aquifers (Localized alluvial deposits) are obtained. This type of rock is mainly found on the top of the resistive mountains and near the water divide of basin. This formation is very difficult and risky for groundwater resource and is exemplified by Gimbo well with well yield of less than 2 l/s. Therefore, it needs special attention in identifying fracture traces crossing this area (from aerial photograph, satellite image etc) and contribution of associated catchment aerial coverage. Hence the area covered by such unit is very poor zone of groundwater potential.

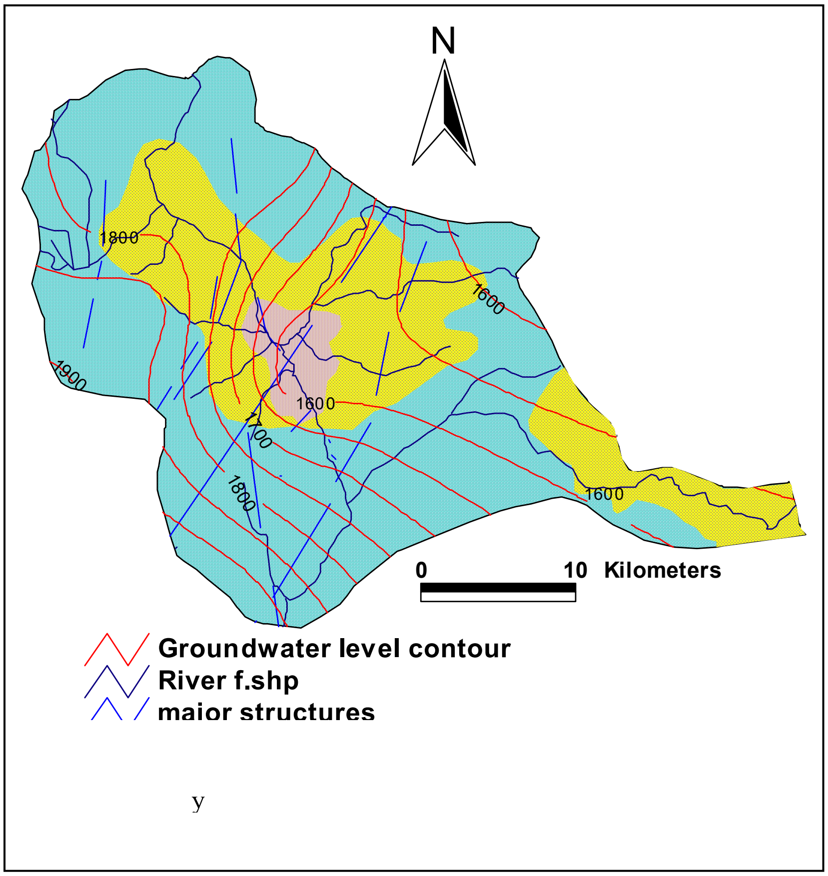


Figure 5.2 Hydrogeological map of Upper Guma Sub Catchment.

5.2 Recharge and discharge zone

Recharge of ground water depends on many factors, such as permeability of the formation, depth to water table, vegetation and slope. The major source of ground water recharge in the area is rainfall. The rainfall in the area is about 1686mm/year, which implies good potential for ground water recharge of the area.

Recharge area is usually in topographically high places where as discharge areas are located in topographic lows. In the recharge areas there is often a rather deep unsaturated zone between the water table and the land surface. Conversely, the water table is found either close to or at the land surface in discharge areas. There may be physical manifestation of the discharging ground water, which can take the form of springs, or stream and water indicator vegetations (Fetter, 1994).

Therefore, the main recharge areas for the study area are the high land areas of Wushwush, Sobra, areas and high lands in between Diri Gimbo and Bonga and its surrounding, connected ridges of northern part of the basin and eastern high lands along the Sobra - Mera ridge. Perennial rivers start from these topographically elevated areas and flows down to join the main Guma River.

The dense vegetation around the town area on the slopes, combined with the isolated patches of farmlands over the gentle slopes, helps to intercept surface runoff and favors ground water recharge. Around Bonga town area there are many springs and hand dug wells as manifestations of groundwater discharge from the shallow aquifers.

Discharge areas are those areas, which are mostly at the foot of mountainous area which are manifested by the presence of springs at the contact of the elevated and the low land areas. Therefore, alluvial deposit covered area is the main discharge zone of the basin. Therefore, in the study area highly weathered, friable and highly jointed with big boulder rock formation in elevated area is the recharge zone and the alluvial and colluvial deposits in the low land areas are the discharge area for the basin.

5.3 Productive well fields

Wells of high productivity are restricted in areas of the potential groundwater recourses around and with in the town of Bonga. There are three boreholes which are drilled for water supply, out of which Sheta well drilled in 1980 to a depth of 65m with a reported yield of 6.3 l/s with drawdown 5m, from the indicative observation made on the well, and attempts made to inspect the current condition of the well, with already installed pump positioned at a depth of 32m and over a period of pumping, the pumping rate has been noticed to have fluctuations between 2.5l/s during pumping to high pressure zone areas and about 6 l/s for low pressure zones. In general, it is noticed that the well has characteristics of low drawdown and fast recovery. The second borehole drilled in the compound of skill development center to depth of 120m in 1987(E.C), and the result was failure to gate water probably due to the existence of the geologic structure controlling the underground water movement in that particular area .

The third well in this area is in Dincha area drilled to a depth of 118m through clays and volcanic rocks in year 2000 and it has not been connected to the water supply system.

The maximum yield obtained is 7 l/s in this well field area. The above results indicate that the well field has an additional potential compared to its allowable drawdown. From the relationship that exists between the specific capacity of the well and its transmisivity, a pumping rate of about 8.5 l/s may be considered for design purpose for this well.

The overlying Quaternary sediments described as alluvium, and colluvium composed of gravel, sand, clay and silt mixtures in various proportions, underline by highly weathered and jointed part of the basalt formation with characteristics of moderate to high permeability and this unit exists being intercalated with the scoria revealed from drill logs clearly describing the hydrostratigraphic units of this well field. It can be generalized from ground water potential assessment point of view; the subsurface lithologies are promising to hold as well as to transmit water to the well and are grouped with in the high productive well field. The main recharge for this region is directly from precipitation and the surrounding elevated areas.

Water supply wells of Shomba, Gimbo and Wushwush areas are located closer at water divide and are moderately productive well fields so that wells get dried before their design periods. These well fields are mainly found in the areas of weathered and friable basaltic and rhyolite terrain with shallow depth. The degree of weathering as described in the previous section is shallow and is mainly dominates the undulating and rolling ridges with rugged topography. Boreholes in such formation are commonly sited on local fracture zone or depressional area where shallow ground water from the recharge area can be obtained easily. Due to the shallow nature of weathering, yields from bore holes are very small and are not promising for significant water to satisfy the need for highly populated area. As it is observed from the pump test analysis drilled for Wushwush and Gimbo towns.

5.4 Hand dug wells

Major part of the area is capable of exploiting hand dug wells due to recharges obtained from the available intense precipitation. From hydrogeological point of view, the presence of such productive hand dug wells in the basin gives a clue to the depth of ground water to be shallow.

5.5 Springs

There are many springs in the study area serving the community as a supplementary and main water supply sources. Most of them are capped. Spring is a concentrated discharge of ground water appearing at the ground surface as a current of flowing water (Todd, 1980). Springs can be classified in a number of ways based on magnitude of discharge, type of aquifer, chemical characteristics, water temperature, direction of water migration, relation to topography, and geologic structure. Bryan divvied springs into two categories.

1) Those resulting from non-gravitational forces and
2) Those resulting from gravitational forces.

Under the former category volcanic springs, associated with volcanic rocks and fissured springs, resulting from fractures extending to great depth in the earth's crust(thermal springs) where as gravity springs result from water flowing under hydrostatic pressure. Based on the above method of classification, the 3 types of springs are common in the study area. Depressional springs, contact springs and impervious rock fracture springs are the common types with various discharges according to the recharge area size and aquifer permeability. Depressional springs are the most common type in the basin (figure 5.3).

5.6 Ground water flow direction

As part of the hydrologic cycle, groundwater is in continuous movement from a recharge to a discharge area in accordance with laws governing water flow in lithosphere. The laws give the rate of energy loss against resistance from the flow medium(Sen, 1995). Therefore, the flow of water is governed by the known law called Darcy's law. The law states that 'the flow rate through porous media is proportional to the head loss and inversely proportional to the length of the flow path (Todd, 1980)

Local ground water flow is different from regional ground water flow in that, the local flow direction varies with in small areas according to the topographic effect at shallow depth and the regional ground water flow has general direction of flow at depth. The local ground water flow in this area supports the regional flow as evidenced by the ground water contour from hand dug wells and the presence of many springs following the topography. As can be observed in the water table contours, local flows have general directions of flow towards the low lands in the surroundings and finally the main (regional) flow is mainly towards central and south west part of the study area.

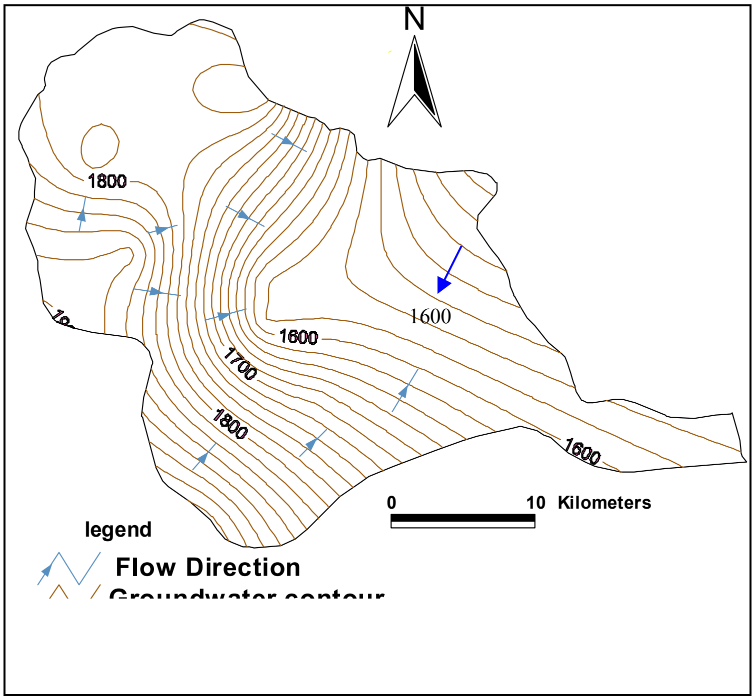


Figure 5.2 Groundwater flow direction contour map

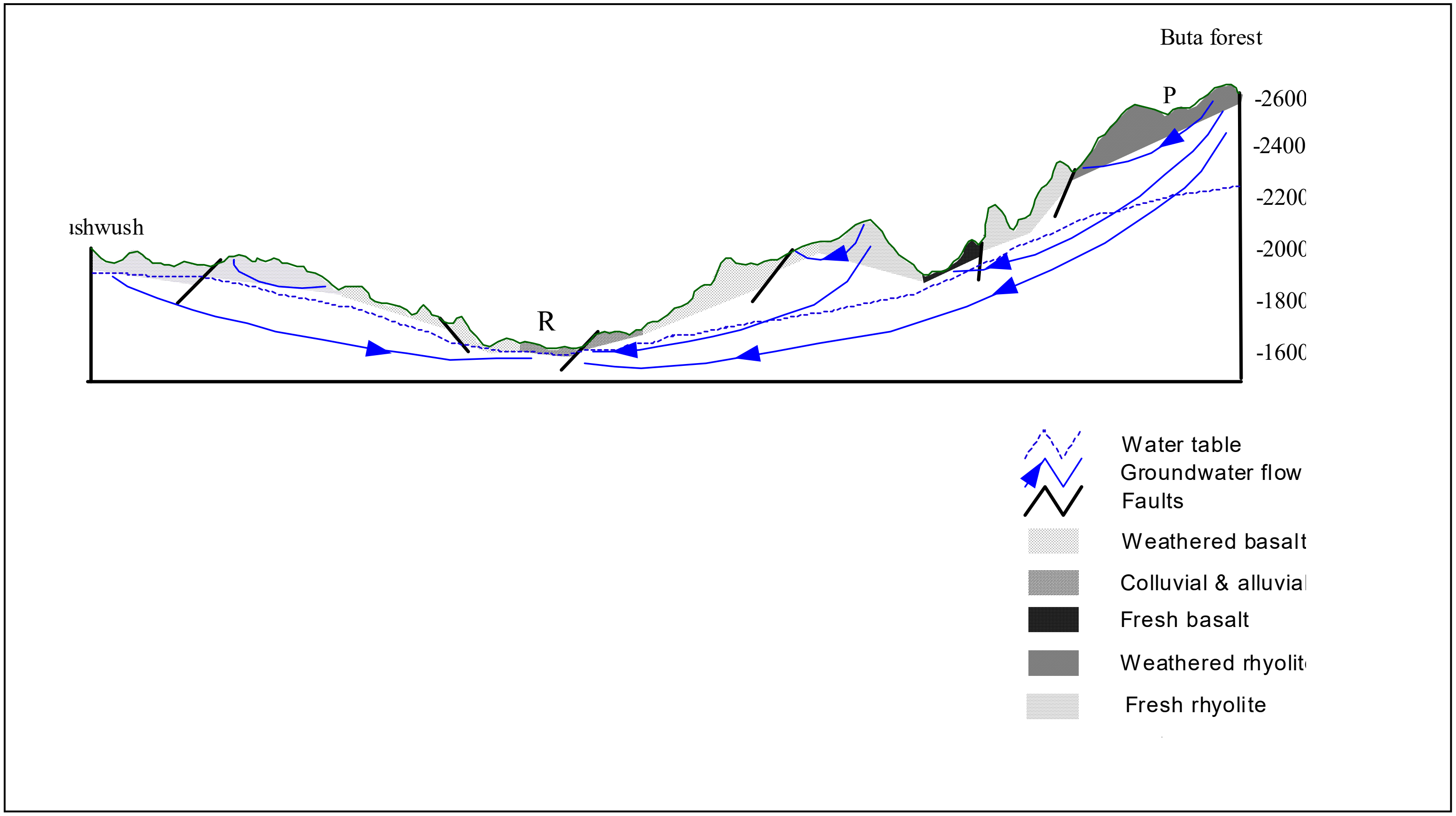


Figure 5.3 Coceptual model for regional and local groundwater flow system of the area (R-river, P-precipitation) along profile line AB on geological map(figure 4.2)

CHAPTER 6

HYDROCHEMISTRY

6.1 GENERAL

Investigation of the quality of water is the most important factor to be conducted depending on the purpose it is required. Thus, needs for establishing quality criteria for drinking water, industrial, and irrigation water varies widely. To establish these criteria measurements of chemical, physical, biological and radiological constituents must be specified, as well as standard methods for reporting and comparing results of water analyses must be adopted. Freeze and Cherry(1979) had described also the effect of geochemical processes on natural water in that, as groundwater moves along flow lines from recharge to discharge areas, its chemistry is altered by the effects of a variety of geochemical processes.

6.2 water sampling and analysis

For this study samples from rivers, springs, shallow and deep wells were collected and analyzed in the laboratory of Water resources of SNNPRS (Awassa). The extent to which small samples may be considered to be representative of a large volume of material depends on several factors such as the homogeneity of the material being sampled and the number of samples, the manner of collection and the size of the individual sample (Hem, 1992). During dry season a total number of 20 water samples were collected and their field parameters were measured. Na^+, and trace elements were not analyzed in these samples because of the lack of laboratory equipments and reagents in the water bureau. But Na^+ is calculated by ionic balance method and was confirmed by data from previous hydrochemical data of the area. From the above samples chemical analysis were done for 10 water samples (bore hole=5, spring=3, and river =2). Samples in the nearby area were also analyzed to see the variation in the basin and its surrounding having the same climate and geology. Important field parameters such as pH, Eh, Ec, and temperature were measured using pH and conductivity meters and taking their geographical location were performed using the GARMIN GPS. Complete chemical analyses for major ions of some of the samples have been done during water scheme drilling and construction in the area by Addis Ababa Water Supply and Sewerage Authority (AWSSA) and are used in this analysis.

6.3 Reaction error

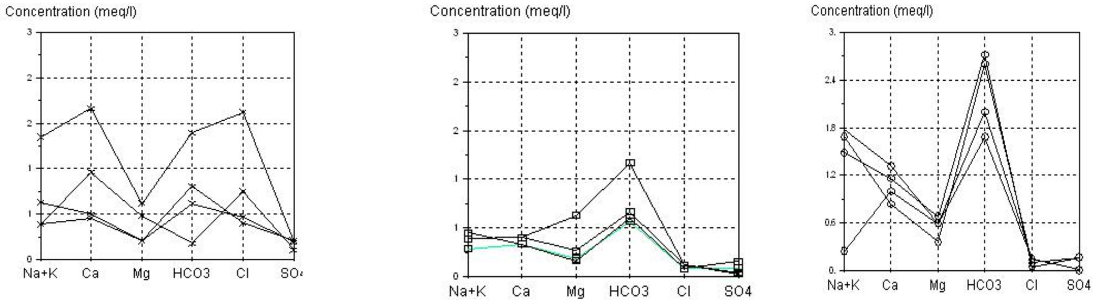
The techniques that the laboratory follows and the result must be checked for its accuracy before classification is done. Solutes present in concentration above 100mg/l generally can be determined with an accuracy of better than ±5 percent. For solutes present in concentration below 1mg/l, the accuracy is not generally better than±5 to 10 percent and can be poorer (Hem, 1992). Thus the reaction error can be determined as follows;

$$\text{Reaction error} = \frac{\sum cations - \sum anions}{\sum ions}$$

Therefore, the laboratory result has a range of reaction error from 0.2 to 3.6 % reaction error which is in the limit of accepted range, not greater than five percent.

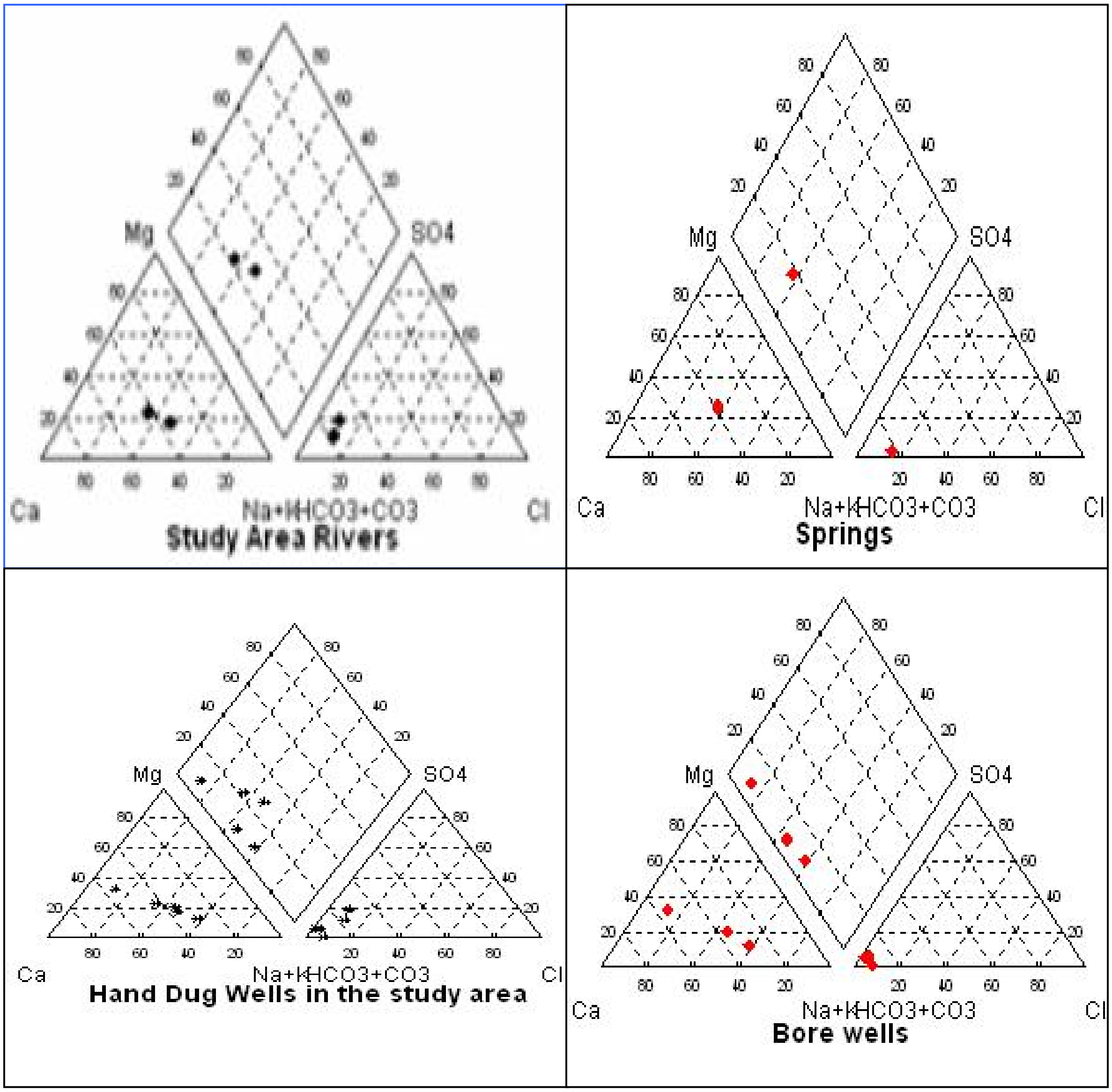
6.3.1 water type classification

Total dissolved solid include all solid materials in solution, in ionized or non ionized form. As it is related to the sum of the concentration of all ions, it is directly related to the electrical conductivity. TDS of natural water range from less than 10ppm of dissolved solids for rain and snow, to more than 300,000ppm for some brine (Tenalem and Tamiru, 2001). Thus, the water type obtained in the basin according to their TDS value fall in fresh water, with total dissolved values in the range of 0-1000 (Freeze and Cherry, 1979).Total dissolved solids vary spatially with a general trend of increasing from high land to low land. Water samples from the bore well, hand dug, springs and river sources have an average TDS of 140, 119.5, 67 and 52 mg/l respectively



HW rivers and springs BW

Figure 7.1 Schoeller diagram showing dominant species of ions in water samples taken from bore wells (BH), hand dug wells (H.W) and rivers and springs.



Study Area Rivers

Springs

Hand Dug Wells in the study area

Bore wells

Figure 7.1 piper tri-linear plots of different water sources

Classification of water types in the area according to the tri-linear piper diagram plots (figure 7.2) show that, most of the hand dug wells are Ca-Na-HCO_3 and Ca-Mg-Cl water type where as, springs are Ca-Na-HCO_3 and Ca-Mg-HCO_3 water type**.** The borehole results have a water type of Ca-Mg-HCO_3 and Na-Ca-HCO_3 which signifies the dominancy of volcanic terrain. Schoeller diagram in(Figure 6.1) depicts the dominant ion type in specified water sources here the principal ionic concentrations, expressed in milliequvallents per liter, are polted on six equally spaced logarithmic scales in the arrangement shown.

6.3.2 Classification based on total hardness

Hardness results from the presence of divalent metallic cations, of which calcium and magnesium are the most abundant in ground water these ions react with soap to form precipitates and with certain anions present in the water to form scale (Todd, 1980).

Total hardness (H_T) is customarily expressed as the equivalent of calcium carbonate.

Thus: $H_T = Ca \times \frac{CaCO_3}{Ca} + Mg \times \frac{CaCO3}{Mg}$

Where H_T, Ca and Mg are measured in mg/l. The ratios in equivalent weight are given by: $H_T = 2.5\ Ca + 4.1Mg$.

Hardness in mg/l as $CaCO_3$	Water classes	Total Hardness in mg/l as $CaCO_3$ of the study area
0__75	Soft	58-BH2,30-River and spring
75__150	Moderately hard	94 –BH1,
150__300	Hard	174 – Shomba shallow well
>300	Very hard	

Table6.1 Hardness classification of water (After Sawyer and McCarty), Todd (1980).

Based on the above, the water type in the study area is grouped as soft water, moderately hard water, and hard water.

6.4. Chemical behavior of water sources

6.4.1. Bore holes

Due to chemical and biochemical interaction between ground water and the geological materials through which it flows, and to a lesser extent because of contributions from the atmosphere and subsurface water bodies, ground water contains a wide variety of dissolved in organic chemical constituents in various concentrations (Freeze and Cherry,1979).

Major ions	Na	K	Ca	Mg	HCO3	Cl	SO4
Borehole (BH)1	30	7	30	8.16	151.3	3.48	6.4
BH 2	35	6	17	4.38	158	3.48	5.5
BH3	17	3	20	7.2	102.7	1.5	0.5
HD W 1	6	19.2	12	3	59	17	12
HD W 2	7	6.2	11	3	45	20	11
HD W 3	26	19	40	9	102	69	11
HD W4	5	5.2	9	2	35	9	9
HD W 5	9	3	23	7	13	32	6
Spring Sobra	6	4	8.5	5.4	66	3.8	0.82
River Dincha	6	3	6.8	2.43	38.3	2	0.8

BH1=Sheta well, BH2=Uniceff well, BH3= Wongi well; HD=hand dug well.

Table6.2 Major anions and cations in different water sources

Sodium is a major constituent of igneous rocks such as in plagioclase and it is liberated during the weathering these silicates and the distribution of these elements and the rate of its liberation are reflected in the quality of spring water. Potassium also occurs mostly in the potassium feldspars in igneous rocks. Calcium which is predominantly held in plagioclase feldspar again is released by weathering and incorporated in to ground water system, and in groundwater it is to be expected that with sufficient residence time underground, the calcium carbonate - carbon dioxide equilibrium in carbonate rich aquifer can be established (Weyl 1958). Because of the lower geochemical abundance of magnesium, its content in fresh water is generally below that of calcium. In the study area since the terrain is devoid of limestone the interaction of carbon dioxide and water in such area is responsible for the formation of various carbonate species and particularly for the bicarbonate ion dominancy in the water of wells, springs and rivers of the area.

6.4.2. Hand dug wells

Hand dug wells in the low land areas have higher TDS and Ec, than in the elevated area. Those hand dug wells cited on the pure basaltic terrain have high calcium and magnesium ions and those on the mixed tuff and weathered basalt have low calcium and magnesium ions. Generally, hand dug wells are dominated by calcium cation and bicarbonate anion followed by sodium cation and chloride and nitrate anion (Table 6.2). From the total ionic compositions, bicarbonate ions occupy the highest concentration proportion and followed by calcium (Table 6.2 and Fig.6.2).

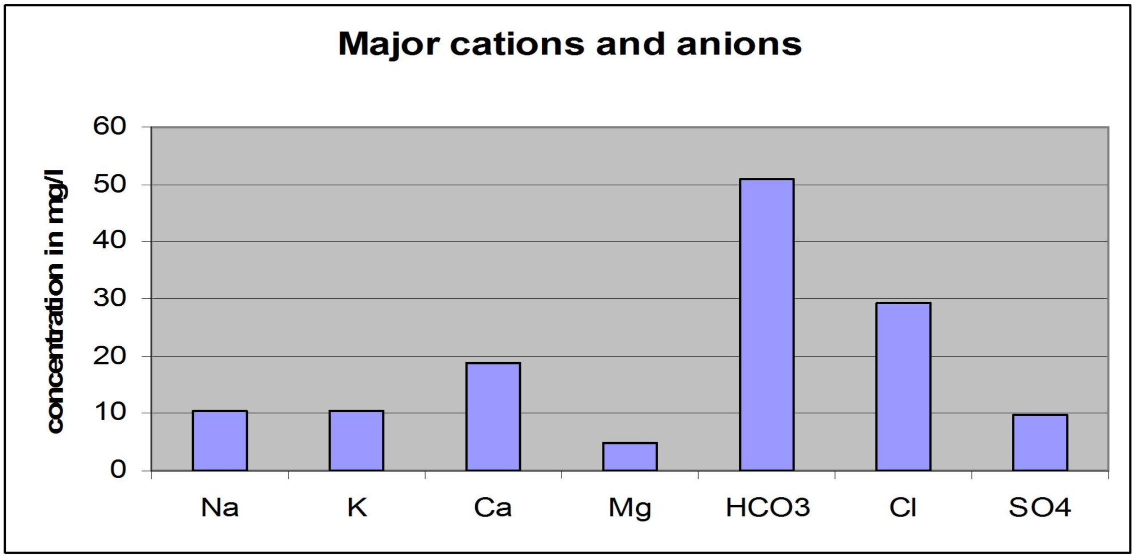


Figure 6.2 Major cation and anions from hand dug wells in the basin

6.4.3 Springs

Springs are dominant in the basin and have chemical analysis results which express the local geological and climate conditions in the basin. Their TDS value generally shows spatial variation of decreasing with increasing altitude. In all springs of the area dominant anion type is bicarbonate and cations, are dominated by calcium ion (Table 6.4).

6.4.4 Rivers

The flow of the tributaries of the main rivers starts from the high lands in the north eastern and western part and at the south east extreme of the basin. In some part of the basin they flow first on the mixed geological formations (intercalated tuff and basalt) which determine the geochemistry of the river. The major rivers in all over the flow paths, crosses pure basaltic formation and alluvial deposits.

The samples were taken at tow points (Barta water fall and at the immediate junction of Dincha and Guma rivers) along the main river. Total dissolved solids are increasing towards the low land. Chemical analysis is done for two of the samples. All major cations and anions increase with decreasing altitude along the river.

6.5. Water quality

The study of water chemistry gives important indication of the geologic history of the enclosing rocks, the velocity and direction of water movement, and the presence of hidden ore deposits (Davis, 1966). Accordingly, the subject of water analysis interpretation must often include some considerations of standards and tolerances that have been established for the intended use. To establish quality criteria, measures of chemical, physical, and biological, and radiological constituents must be specified, as well as standard methods for reporting and comparing results of water analysis (Todd, 1980). Based on major cations and anions, it is possible to show the general water quality for public supplies, irrigation and industry in the study area.

6.5.1. Quality of Water for public supply

The primary objective of water treatment and purification is to collect water from best available source and subject it to processing which will ensure water of good physical quality, free from unpleasant taste, or odor and containing nothing which might be detrimental to health (Punmia, etal, 1995).

The following important requirements of water quality for public supply are recommended by Punmia (1995).

- It should be colorless and sparkling clear. It must be free from solid insuspension and must not deposit sediment on standing.
- It should be of good test, free from odor, and it should be reasonably soft.
- It should be free from disease producing bacteria or organisms.
- It should be free from objectionable dissolved gasses, and
- It should be free from harmful salts.

- It should be free from objectionable minerals, such as iron, manganese, lead, arsenic, and other poisons metals.
- It should be free from radioactive substances such as radium, strontium etc.
- It should be reasonably free from phenolic compounds, chlorides, fluorides, and iodine.
- It should not lead to scale formation and should be non-corrosive.

Considering the evaluated chemistry of water the established goal of WHO and its member states is that “All people, whatever their stage of development and their social and economic conditions have the right to an adequate supply of safe drinking water.”

Ethiopia does not have national standards for drinking water, but recognizes the World Health Organization (WWO) standards as a target. Although, it is not easy to achieve these recommended standards. In general, the water quality of the sources investigated is good with only some hand dug wells and bore wells exceeding the WHO drinking water guidelines for some parameters measured.

The following standards are basically used as a guide line according to the WHO and commission of European communities (CEC) guidelines for drinking water (WHO, 1984; CEC, 1980) (Table6.3).

parameter	WHO Guidelines	CEC Standards		Result obtained			
		Guide	Max.Admis.Con.(MAC)	HDW	BH	SP	River
pH	6.5-8.5	6.5-8.5	Nm				
TDS (mg/l)	1000	Ng	1500	175	165	65	45
Calcium (mg/l)	Ns	100	Nm	14	30	8.5	6.8
Magnesium (mg/l)	Ns	30	50	5.6	8.16	5.4	2.4
Sodium (mg/l)	200	20	150	8.4	26	6	6
Potassium (mg/l)	Ns	10	12	7	6	4	3
Chloride(mg/l)	250	25	Nm	20	5	3.5	0.2
Sulphate(mg/l)	400	25	250	6	6	0.75	
Phosphate (mg/l)	ns	0.4	5	-	-	-	-
Ammonia (mg/l)	0.2	0.05	0.5	-	-	-	--
Nitrate (mg/l)	Ns	Ns	0.1				
Boron (mg/l)	Ns	1	Nm	-	-	-	-
Iron (mg/l)	0.3	0.05	0.2	-----	1.76	0.1	0.8
Manganese (mg/l)	0.1	0.02	0.5	-----	0.5	-----	0.7
Aluminum (mg/l)	0.2	0.05	0.5	---	-----	------	-----
Copper (mg/l)	1	0.1	Nm	-	-	-	-
Zinc (mg/l)	5	0.1	Nm	-	-	-	-
Fluoride(mg/l)	1.5	nm	Nm	-	-	-	-

MAC-maximum admissible concentration, NM-no maximum admissible concentration set, NS- no standard set

Table6.3 WHO and CEC standards for drinking water (WHO, 1984; CEC, 1980).

According to the above standards the water in the basin is suitable for drinking purpose since all the dissolved substances are in the limit of permissible range, except iron and Manganese which are beyond WHO standards. There are also other standards which are usefull for comparison and contain more comprehensive purpose of water for different applications such as industry, and irrigation. The bacteriological analysis of water for public supply should also be given due attention. Contaminated water may contain a host of microorganisms, due to which water born diseases may spread if water is not properly handled and treated before it is supplied for domestic use. Ground water may be contaminated due to improper disposal of liquid wastes, defective well construction and failure to seal the abandoned wells. Hence, the potablity of water from bacteriological activities is dependent on human being activities.

6.5.2. Water quality for irrigation

The suitability of ground water for irrigation is contingent on the effects of the mineral constituents of the water on both the plant and the soils. Salts may harm plant growth physically by limiting the up take of water through modification of osmotic processes, or chemically by metabolic reactions such as those caused by toxic constituents (Todd, 1980).

Irrigation –water criteria are dependent on the type of plants, amount of irrigation water used, soil and climate. In irrigation, in addition to salinity and boron, sodium hazard is the other problem most commonly encountered.

The two principal effects of sodium are a reduction in soil permeability and a hardening of the soil. Both effects are caused by the replacement of calcium and magnesium ions by sodium ions on the soil clay and colloids. The extent of this replacement can be estimated by the sodium adsorption ratio (SAR) which is expressed by the following formula.

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

Where the concentrations of the constituents are expressed in mill-equivalents per liter.

Most classification systems of irrigation water include limits on specific conductance (expressing total dissolved solids), sodium content, and boron concentration. Soils containing a large proportion of sodium with carbonate as the predominant anion are termed as alkali soils; and those with chloride or sulfate as the predominant anions are saline soils (Todd, 1980). Sodium content is usually expressed in terms of percent sodium (sodium percentage) defined by

$$\%\text{Na}=\frac{(Na+K)100}{Ca+Mg+Na+K}$$

Where all ionic concentrations are expressed in mill-equivalents per liter.

According to quality classification of water for irrigation (after Wilcox [53]), water quality of the study area is classified as good and permissible water for irrigation (table 6 .6).

WATER CLASS	% Na	Specific Conductance S/cm	Boron, mg/l			
			Sensitive crops	Semi tolerant crops	Tolerant crops	%Na of the study area
Excellent	<20	<250	<0.33	<o.67	<2.00	
Good	20-40	250-750	0.33-0.67	0.67-1.33	1.00-2.00	40.9
Permissible	40-60	750-2000	0.67-1.00	1.33-2.00	2.00-3.00	47.8,54.7, 55.9
Doubtful	60-80	2000-3000	1.00-1.25	2.00-2.50	3.00-3.75	
Unsuitable	>80	>3000	>1.25	>2.50	>3.75	

Table 6.6 Quality classification of water for irrigation (after Wilcox [35]).

The figure blow is useful and summarizes way of classifying irrigation water based on their SAR and Salinity hazard, (Figure 6.3). In the graph, C1, C2,C3 and C4 represents the degree of salinity hazard expressed by the specific conductance and are grouped as low, medium, high, and very high. Similarly, S1, S2, S3 and S4 represents the degree of sodium hazard which is grouped as low, medium, high and very high respectively based on their value(After Richard, as indicated in Todd 1980).

Generally, the basin has suitable water quality for irrigation or is free from sodium hazard from natural condition and can be used for irrigation activity using both surface and ground water with proper drainage management system in the area given due attention to the technologies that have to do with the surface physiographic conditions .

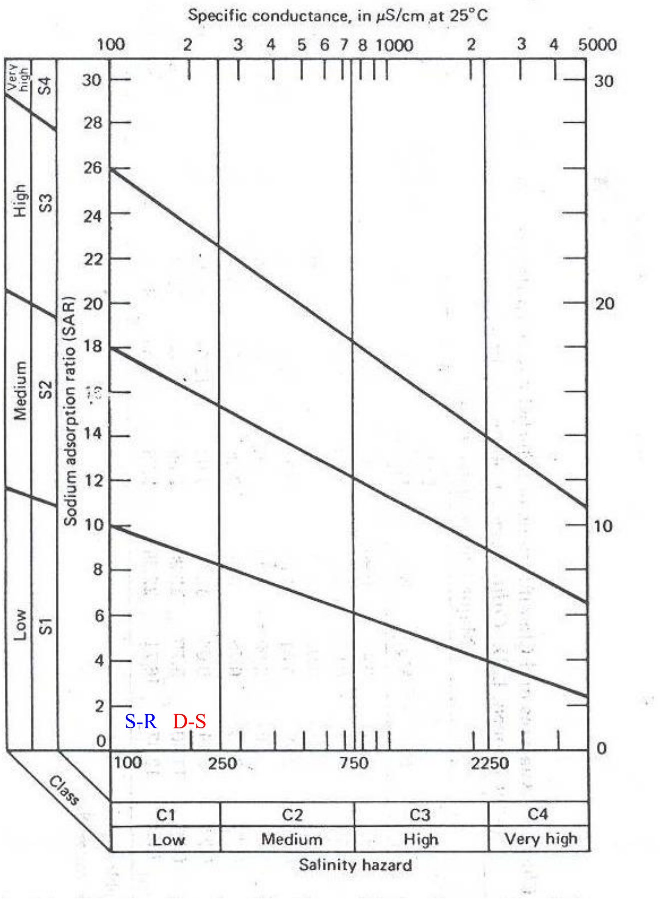


Figure 6.3 Diagram for classification of irrigation water (afterRichard[35]).(S-R=springs and rivers, D-S= deep and shallowells)

6.5.3 Industrial Water quality Assessment

An adequate ground and surface water supply of suitable quality often becomes a primary consideration in selecting new industrial plant locations. It should be apparent that the quality requirements of water used in different industrial processes vary widely. Even with in each industry, criteria can not be established; instead only recommended limiting values or ranges can be used. Salinity, hardness, and silica are the three parameters that usually are important for industrial water (Todd, 1980).

In the study area there are tea and coffee processing plants and for future industrial developments in the area, based on the general trend of major ions together with hydrogeological conditions it is possible to say that quality of water for industry is promising for many of industries as it is confirmed from water chemical analyses results.

Industrial water for food and drink, and medical drug industries, so far as it comes in to direct contact with the products, must have the quality of potable water. Water for cooling purposes should not be corrosive, nor should it become corrosive during the cooling process though the temperature dependant break down of the calcium-carbon dioxide equilibrium. The requirement of water for steam generation as in the case of tea processing plant in the study area depends first of all on the type of boiler construction and the working pressure, with low dissolved solids and gasses and no acid reactions.

Water can be treated for every purpose; however there is a practical limit, especially when large amount is needed. As a matter of economy it may be necessary to site water consuming industries in areas where there is an abundant supply of suitable water.

6.6 Water pollution

The possible pollutants in the water are virtually limitless. All solutes introduced in to the hydrologic environment as a result of man's activities are referred to as contaminants, regardless of whether or not the contaminations reach levels that cause significant degradation of water quality. The term pollution is reserved for situations where contaminant concentrations attain levels that are considered to be objectionable (Freeze and Cherry, 1979). Most pollution originates from the disposal of waste water following the use of water for any of a wide variety of purposes. Thus a large number of sources and causes can modify ground water quality, ranging from septic tanks to irrigated agriculture. The principal sources and causes of ground water pollution are categorized into four categories-municipal, industrial, agricultural and miscellaneous.

In the study area, the common possible sources of pollution are agricultural activities and municipal wastes. Agricultural sources and causes include fertilizer and soil amendments, and pesticides. Particular attention should be given not to use sites for fuel depot in well head areas as is common in the study area.

Nitrogen dissolved to form nitrate (NO^-_3) is gating increasingly wide spread because of agricultural activities and disposal of sewage on or beneath the land surface. Its presence in undesirable concentration is threatening large aquifer systems in many parts of the world (Freeze and Cherry, 1979). Although NO^-_3 is the main form in which nitrogen occurs in ground water, dissolved nitrogen also occurs in the form of ammonium (NH^+_4), ammonia (NH_3), nitrite (NO^-_2), nitrogen(N_2), nitrous oxide (N_2O) and organic nitrogen.

From the result of the water samples, there are hand dug wells with indication of down ward migrating Nitrate pollution in Bonga area along Chiri road due to down ward migration from municipal sources.

145 l/s and 65 l/s which are well in excess of the water supply requirements in the projected period.

The rivers in the study area were once decided to be assessed for their potential for the installation of micro or small hydro power schemes aimed to supply electricity to the surrounding towns and preliminary socioeconomic studies conducted and for financial reasons further investigation was not conducted. Therefore the general picture of the surface water potential from the inter relation of precipitation surface runoff and base flow components is promising to conduct those activities dependable on the available water resources.

The river basin of the study area has a defined boundary and also has relationship with groundwater resources in most of the cases. The development of balanced plan for water resources utilization requires full knowledge of the quantity, quality and distribution of land use in the entire watershed and its influence on the river flows. In addition to the above uses, the available water resources can be used for major irrigation activities using suitable techniques and minor water needs for river side cultivations (Table7.1).

Study area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Ann.
P(mcm)	43.2	44.6	97.1	151.5	176.7	186.2	183.9	222.9	164.03	112.7	52.17	51.43	1476.6
TRO(mcm)	1.8	1.36	3.5	10.5	36.1	47.8	96.8	104.2	73.93	47.4	9.47	2.87	435.7

Table 7.1 surface water resource of the study area.

7. 2 Assessment of groundwater resources

For reliable assessment of groundwater resources, detailed and authentic information relating to hydrogeological formations and the water balance of the entire catchment is required. Under this research collection of hydrological inventory data, hydrological evaluation of the formation characteristics of the water bearing strata and the hydrogeological mapping were undertaken. The rainfall contribution to the groundwater recharge is estimated by calculating the fraction of rainfall infiltrating into the ground over the catchment area. Progressive development of groundwater resources can be initiated through shallow tube wells and deep tube wells for the projected periods accordingly to satisfy the per capita water demand for domestic and non domestic water consumption such as industrial water use in Wushwush tea processing. Water production for Bonga town for the target year 2030 public supply is projected to be 1.008426 X 10 ^{6}m^{3} production according to feasibility study of Bonga town by Ministry of Water Resources water demand estimation. Therefore, from the result of estimated annual recharge it is possible to see that the identified groundwater potential is significantly greater for the industrial and irrigation activities to be launched. There are numerous low-yielding springs in the study area situated on the slopes serving as water sources for local population; however the main sources of water supply in the towns are tube wells and shallow wells. Planning for maximum development of our water resources for the long time benefit of the people should take into account the trends in population growth, the resulting agricultural production requirement, the growing needs for industry and other needs. Conjunctive use of surface and groundwater can take the form of full utilization of surface water supplies supplemented by groundwater or the direct use of ground water during periods of low canal supplies or canal closures. The possibility of using this method of exploiting the resources in the study area is justifiable due to the prevailing water resources and physiographic conditions.

7. 3 SYNTHESIS

This study attempts to analyze and put appropriate discussions concerning water resource potentials in Guma-Sub Catchment based on meteorological, hydrogeological, and hydrochemical descriptions in the previous chapters. In this chapter, results of the study will be explained more briefly in order to show how the result is obtained using different evidences from the existing data and newly measured data.

7.3.1 Results from analysis of hydrometeorology and the water balance

The difference in precipitation in the basin is not that much great between low and high land areas. This is due to the source of the precipitation in the area is not dominantly affected by the topographic variations within the area. According to the data records, perception in the basin shows temporal variation of eight-month rainy season and four months of low rain season. Maximum and minimum rainfall from spatial point of view is in Wushwush and in Gojeb station respectively. August is a month that registers maximum rainfall and minimum rainfall in the basin is in January.

Significant elevation difference in the basin and limitations of meteorological stations in the southwestern part has led to use, averaging the Theissen polygon method and Isoheytal methods to determine annual precipitation in the basin.

In determining evapotranspiration in general, class A-meteorological stations are very essential with full capacity to measure all parameters. Data quality limitations are solved by applying appropriate methods of adjustments and estimation of evapotranspiration is performed based on the available methods.

Temperature, relative humidity, Wind speed and sun shine hour data are taken from stations and were used in hydrometeorological characterization of the area. Evapotranspiration is also subdivided into potential and actual evapotranspiration. To determine actual evapotranspiration, determination of potential evapotranspiration primarily is necessary. Again Penman and Thornthwaite methods are averaged to over come limitations of accuracy and is applied for the determination of potential evapotranspiration. Therefore, the maximum possible amount of evapotranspiration when there is excess amount of water in a soil is computed and tabulated in table 3.10 with a maximum value of 85.2 mm/ month in the month of February which is the windy month in the basin. Annual value of evapotranspiration is calculated as 849.4 mm for the basin.

Actual evapotranspiration is the real amount of water that evaporates and transpires depending on the available water and climatic conditions and Thornthwaite water balance model is used for the calculation. Three major soil categories are grouped with different vegetation cover for computing actual evapotranspiration. Clay loam, sandy loam and clay are the main soil categories. For this computation, a soil-water balance model was used based on crop coefficient for the above soils. For this model, surface runoff, precipitation, potential evapotranspiration and crop coefficients are the input data. According to the model result, actual evapotranspiration values are 816.2 mm, 722.9 mm and 796.9mm per year for clay loam, sandy loam and clay respectively. Annually the basin loses 800.7 mm in the form of actual evapotranspiration (Tabl3.14).

Measured values of Guma Sub-Catchment river discharges are the main data in providing information about the catchment characteristics and nature of rivers. The rivers show variation in rate of discharge as it flows from high land area to the low land area.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annl.
P(mcm)	43.14	44.6	97.1	151.5	176.7	186.2	183.9	222.9	164.	112.8	52.2	51.4	1476.6
ET(mcm)	52.12	53.9	73.3	63.6	57.7	52.9	51.5	51.6	61.7	60	61.4	60.9	700.6
TRO(mcm)	1.79	1.36	3.5	10.5	36.1	47.8	96.8	104.2	73.9	47.4	9.5	2.87	435.8
GOF(mcm)	10.16	8.02	9.8	12.8	17.0	21.0	26.1	34.6	41.1	30.3	17.3	11.5	239.6

Table 8.1 Base flow and surface runoff relation

The annual total discharge of the river from long term mean monthly averaged flow is recorded as 435.8 MCM in the study area. The records were taken from the gauges on both Dincha and lower Guma rivers. Its base flow is greater than the surface run off as it can be seen from table 8.1 and the separation was done using hydrograph method. Therefore, accordingly the basin has a total volume of 240 MCM and 196 MCM annually as a base flow and direct run off respectively.

7.3.2 Results from analysis of hydrogeology.

Pump test results from a borehole in the delineated well field shows great variation in transmisivity and well yield as compared to other areas in the study area which is dependent on aquifer characteristics of the formation. According to the analysis of the wells in highly productive well fields, transmisivity is high in the alluvial deposit with an average value of 1.69 X 10^{-3} m^2/d from two wells and the yield of these wells are averaged to be 6-7 l/s with unconfined aquifer type. High land area around Wushwush has the intermediate to low values of transmisivity. Shallow wells are representative of aquifer with moderate transmisivity and well yield from such aquifer is 1.5-2 l/s.

7.3.3 Distribution of lithologies and structures: Lowland areas are characterized by alluvial deposits, which can serve as a big reservoir for the basin at shallow depth and intercalation of tuff at depth. Northern central part of the basin is basalt with shallower depth of weathering and the southeastern part is dominantly covered with fresh basalt. In high lands and between the high land and lowland, rhyolite and tuff formations are situated. From structural point of view, the central, northern and southeastern part is more affected by different structures, which can play great role in ground water exploration for locating specific well cites in the area.

Groundwater circulation is shallow as it is reflected by the presence of many springs in the southwestern part with low total dissolved solids. Most of springs are dipration and some are contact springs and their concentrations are high around southwester where jointed basalt which allows percolation of water exists. Groundwater flow is mostly influenced by topography and orientation of bedded or layered rocks away from the basin or to ward the basin. In this case there is no such layered rock formation dipping away from the basin. This is evidenced by the presence of successive springs from high land area to the low land.

7.3.4 Results from the analysis of hydrochemistry of water

Laboratory analysis supplemented by field measurements provides the information necessary to characterize water sources according to their chemistry. Due to the volcanic terrain of the basin and shallow ground water circulation, almost all of the water sources are fresh water according to their TDS classification ranging from 52 mg/l to 140 mg/l in the catchment. Concentration of ions is maximum in the low land area with a general trend of increase from high land to lowland because of high residence time indicating hydrogeochemical evolution and high rock-water interaction. The minimum Ec value is 50 µs/cm in Sobra spring and the maximum E.C value is 507 µs/cm in the low land hand dug well around Bonga town. Chemistry of all other water sources (springs, rivers, and boreholes) reflect the local geology of the basin but chemistry of hand dug wells reflects the influence of pollution from the surrounding towns.

The bore wells in the highly productive well field have an iron content which increases with depth and is beyond the WHO guide line for consumption requiring some sort of treatment. Iron is one of the most important element in igneous rocks occurring in the ferromagnesian minerals as pyroxenes, amphiboles, biotite, and solid solution serious of end members fayalite ($FeSio_4$) and foresterite (Mg_2SiO_4).The liberation of iron by weathering and its content in natural waters results from chemical equilibra ,comprising oxidation and reduction solution and precipitation of hydroxides, carbonates and sulfates etc. with the combined effect of pH, Eh and dissolved CO2 and sulfur specious can be best made clear by stability field diagrams.(Hem 1960a,1960b). Soils develop as a result of physical, chemical and biological transformation of rock constituent, depending mainly on the type of temperature and amount of precipitation. In hummed climates and during wet seasons in other climates the downward movement and leaching is predominant for the soil moisture containing the dissolved constituents transporting them to the groundwater. Leaching of iron is low in alkaline and weakly acid soil horizons because under these conditions they form only slightly soluble oxides and hydroxides with decreasing pH the solubility raises and with it the degree of leaching. Fe and Mn are preferentially removed under reducing conditions as divalent ions (Schaffer and schahtscheble 1976). The occurrence or absence of iron and manganese in groundwater depends on their oxidation state and the pH conditions. in most oxygenated Groundwater dissolved iron often is measured between 1 to 10 mg/l. therefore, iron content of groundwater in the study area is enriched as described and should be given attention to modify it for the required purpose.

CHAPTER 8

CONCLUSION AND RECCOMMENDATION

CONCLUSION

♣ Upper Guma Sub-Catchment located in Omo-Gibe basin has a total area of 876 km^2 and is characterized by gently sloping to highly rugged topography that results in dense dendretic drainage patterns.

The basin is within temperate (Weynadega) climatic zone. From long term mean monthly precipitation the basin gets 1668mm annual rainfall. The actual and potential evapotranspiration is computed as 800.7 mm and 849.4 mm per annum respectively.

Evaluation of water resource potential of the catchment is done by conventional geological and hydrogeological description and mapping of different lithologic units, analysis of hydrometeorological data, river discharge and hydrochemistry of different water sources were done.

Accordingly, from geological map of newly produced with a scale of 1:50,000, three main litho logic units have been identified with sub-divisions. The weathered and fractured basalt and fresh basalt; Weathered and unweathered rhyolite units; and recent alluvial formation.

♣ In terms of chronology, those volcanic products of both acidic and basic rocks are Miocene to Pliocene and the alluvial deposit is the quaternary deposit. River beds are the recent results of alluvial materials from the highland eroded materials by its tributaries. From structural point of view north eastern edge of the boundary are affected by the NW-SE dominant faults.

Based on aquifer characteristics comparison from hydrogeological point of view, three hydrostratigraphic units are mapped. Highly permeable with well yield of above 6-7 l/s, moderately permeable with well yields of 3-4 l/s and low permeability with less than 2 l/s . The highly permeable unit is the alluvial deposits intercalated with tuff, weathered and fractured basalt at depth is the potential zone for groundwater exploitation. The moderately permeable unit consists of fractured and weathered basalt and part of rhyolite. The low permeable formation consists of all fresh basaltic and rhyolitic rock units.

Recharge areas for the basin are those areas starting from the surrounding highlands while discharge areas are those low lands and other areas where more springs concentrate. From

1476.6 mcm annual precipitation 700.6mcm is lost as actual evapotranspiration and base flow separation is calculated to be 239.6mcm from 435.8mcm total annual runoff that leaves the catchment area. The annual ground water recharge is estimated to be 110.7 mcm and is about ten percent of the total precipitation. Based on the successive location of springs and borehole yields, groundwater flow is generally following the topography.

♣ Analysis of the hydrochemistry of different water sources show that two types of water are identified based on their TDS value. All water sources range in the classification of fresh water. Dominant water type is Ca-Mg-HCO_3 followed by Ca-Na- HCO_3 with special case of the hand dug wells with water type of Ca-Mg-NO_3 which are manifestations of contaminants from the surrounding. Concerning chemical water quality, surface and shallow groundwater sources are with in the limit of acceptable value of WHO water quality standards for water supply except iron content of deep bore wells which has to be removed by aeration treatment system, irrigation, and industries excluding trace elements which are not analyzed in this study.

Recommendations

► Mechanism to treat excess iron content in bore wells should be designed considering an aeration tank for treating the water and a reservoir as part of storage in the distribution system.

► Surface runoff in the basin is not only pure water but eroded soils from elevated and rugged areas are moving together due to encroachments of natural forest for different purposes. This condition reduces water infiltration to the ground. Hence soil and water conservation program should be promoted specially in the high topographic areas.

► In order to evaluate the basin fully, distribution of bore holes are not uniform and even the drilled ones have no proper drilling and pump test data. Therefore, additional boreholes are recommended specially in the northern and southern part of the area and data should be properly stored.

► River discharge measuring stations should be checked for its proper functioning by the responsible parties as it was cross checked from unreliable discharge reading above the available precipitation.

- ► There should be at least one meteorological station that can measure class A measurements and therefore, the dismantled station in Chiri town has to be reestablished.
- ► It is important to start irrigation practice using the river waters. To bring sustainable agriculture, utilization of groundwater for irrigation will be the final alternative. Trace element analysis is not done due to lack of budget and it needs analysis before implementation of any industry and for extensive irrigation of fruits.
- ► Bacteriological analysis should be accompanied with chemical water quality investigation. Therefore, proper well design and sanitation with regular disinfections is recommended.
- ► Further investigation on the lower Guma catchment and interrelation with upper Guma sub-catchment together with river basin ground water modeling is recommended for the practical utilization of the rivers for assessing the combined potential of the basin for hydropower and water resource for irrigation.
- ► Disposal of gaseous, liquid, and solid wastes can poison surface and ground water and infect by pathogens and impaired the intended use. Effect of sewage and wastewater disposal should be given attention by the municipality to avoid the direct discharge to the surface runoff and not harm groundwater resources.
- ► Planning and zoning of an area should take in to consideration to protect the recharging area from pollution
- ► Consequences of solid waste disposal on groundwater quality should be handled by properly identified sanitary landfills.

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for irrigation or not. Almost all parts of this study area are dependant on rain water; because of this the people are not utilizing the available resource properly and contributing to the development in this regard. But within the basin there is large possibility to integrate both the surface and ground water and make use of it for irrigation and other utilities if traditional farming system (rain fed agriculture) is supported by irrigation. And therefore, to use this technology, there is a basic need of ground water and surface water potential evaluation.

The hydrology, hydrogeology, and geology of this study area, Guma sub catchment, as a whole is not studied separately and in detail except the regional study of the Omo Gibe River basin master plan for different developmental activities at a scale of 1:250,000 published in 1996. Generally, the project area lacks a detailed hydrological, hydro chemical and hydrogeological study in order to launch developmental activities using integrated groundwater and surface water in the sub catchment, and therefore, this research will have important role towards the sustainable use of water resources in the area.

1.2 OBJECTIVE

The main objectives of the research are:

- To produce hydrogeological map of the area at the scale of 1:50,000.
- To analyze spatial variation of hydrochemistry in the basin.
- To establish physical parameters of the aquifer.
- To determine groundwater flow directions in the basin.
- To assess and evaluate possible sources of water pollution (if there is any).
- To delineate potential sites for immediate development.
- To suggest possible future sustainable integrated utilization of the surface and groundwater resources.

1.3 METODOLOGY

As it is common for the most part of the country, the scarcity of available data for the intended research was a problem to use certain methods of calculating basic parameters for the evaluation of water resources, and even hydro meteorological data are not continuous for different purposes. However, by using long term meteorological data and applying different techniques of supplementing and adjusting missing data the research has been accomplished. For this study different materials and equipments have been used.

- Aerial photographs obtained from Ethiopian Mapping Authority.
- 1:50,000 topographic maps of Bonga , Chiri, Felegeselam and Gojeb were used
- Satellite image of thematic mapper of land sat TM 5 and others.
- Geological and hydrogeological map of Ethiopia at the scale of 1:2,000,000
- GPS for locating water samples and water points (spring, hand dug well , borehole and river samples)
- Measuring instruments for (EC, Eh, Temperature, pH meter dissolved oxygen(Do)
- Plastic bottles for water samples and compass ,pocket lens and hammer

While trying to select a project area for this study, basin area delineation and most of the inventory work of water point identification field work has been done and the main fieldwork was accomplished from 2 February to 30 March (2005) covering most of the inventory work of water points, collection of water samples from springs, hand dug wells, boreholes and rivers. The remaining data collection and works in field are accomplished and during this stay, the following activities had been done.

- Detail geological and hydrogeological map at a scale of 1:50,000.
- Water point locations and level measurements in hand dug wells and bore holes.
- Prior knowledge of the area by the researcher was used for data collection. And refining boundary conditions.

Hydro meteorological data were collected from the metrological office for the analysis of hydrological parameters of the study area. With in the basin there are many hand dug, drilled shallow wells, springs and deep bore wells of which several of them are not giving proper function at the prevailing conditions.

CHAPTER 2

GENERAL OVERVIEW OF THE STUDY AREA

2.1 Location and accessibility

The Omo Gibe basin covers an area of some 78 000 Km^2 with a length of 550km and an average width of 240 km, varying between 100-245 km. The basin extends from 9^0 22’ N in the north to 4 ^{0} 27’ N in the south and from 35^0 00 E in the west to 38^0 24’ E at its eastern most extent. Figure 2.1 shows the location of the basin. It is an enclosed river basin that flows into Lake Turkana in Kenya which forms its southern boundary. The western water shade of this basin is the range of hills and mountains that separate the Omo Gibe from Baro- Akobo Basin. It is in this part of the basin that the study area (Guma Sub Catchment) is located and is bounded within$7^0 10^{'}$ N- 7^0 $25^{'}$ N latitude and 36^0 05’ E - 36^0 $30^{'}$ E longitude and is totally in the kafa zonal administrative region of the SNNNRS (Figure 2.1).

The study area is 440km south west of Addis Ababa and it has a temperate (Weynadega) climate. The total aerial coverage of the study area is about 876 km^2.

The elevation in the basin ranges from 1880 meter above sea level (m.a.s.l) at the Buta forest in the south west of the basin and 1580 m.a.s.l at the convergence part of the Dincha and Guma rivers. The area is accessible by all weather roads and dry weather roads. Bonga is the zonal town in the study area and is 440 km far from Addis Ababa in the south west direction.

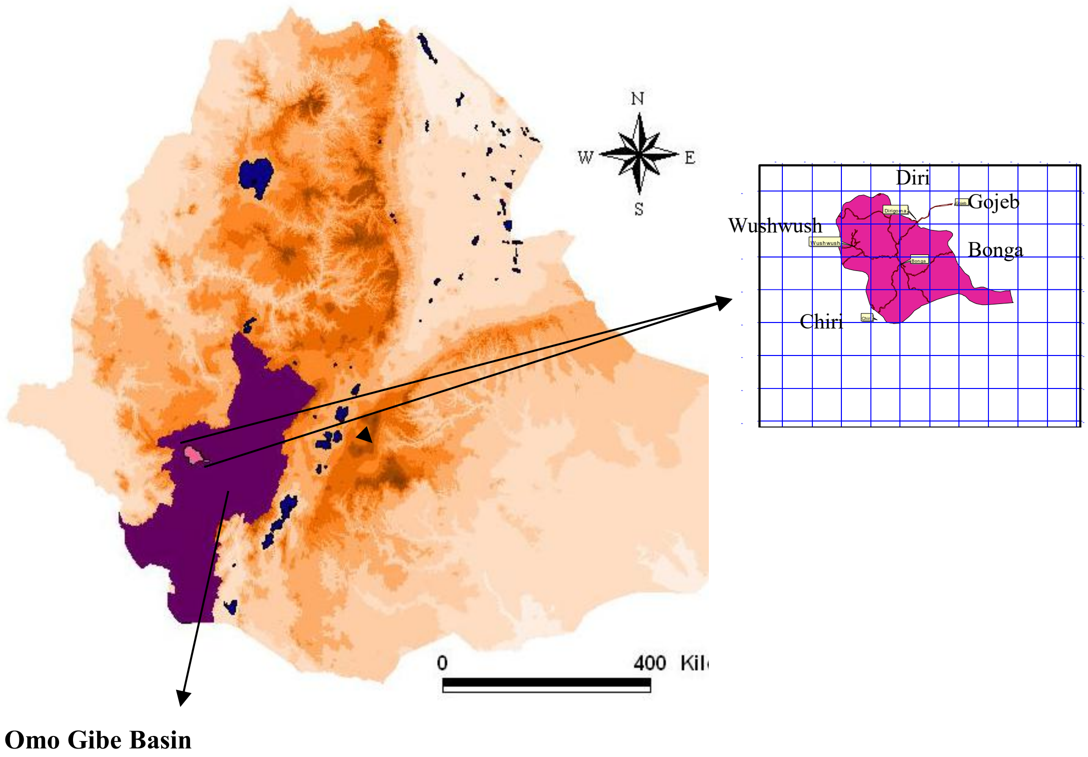

Figure 2.1 Location map of Upper Guma Sub-Catchment

2.2 Climate

The climate of Guma catchment is classified as temperate (weynadega) climatic zone. Monthly mean maximum temperature in the study area is 28.2 ^{o}c in the month of March where as the monthly mean minimum temperature is 11.8^{o}c in the month of January. The area attains its mean minimum and maximum monthly temperature as most of the stations (the five stations) confirmed within the study area. This condition related to the rainy season as temperature falls with the entrance of rain season and increases with the dry season. Temperature with in the study area shows altitudinal variations with a general trend of increasing rainfall with increasing altitude, which is directly the inverse of temperature.

The average monthly rainfall ranges from about 253.51 mm in the highlands in the northeastern part of the study area and 48.86 mm in the northwestern part of the area.

Rainfall distribution with in the area is unimodal (Figure 3.3), which has only one peak period of rainfall and one lowest period. The lowest period of rainfall covers the months of November to February where as the rainy season covers the months of March to October.

2.3 Topography and Drainage

Tertiary volcanism and the subsequent faulting, weathering and denudational processes are responsible for the present landscape of the study area. The high to low relief, dissected hills and mountains are the result of volcanisms. Erosion and deposition by the major rivers are forming relatively wide to flat and marshy flood plains. Faulting and fracturing in eastern and southeastern part are forming vertical scarp zones and steep hill slops. The basin characteristics such as the area, land surface topography and other morphological properties vary only with respect to geological time and this may be treated as constant. Topography of an area plays an important role for subsurface groundwater percolation and soil erosion rate. The sloppy the area is more susceptible for erosion and surface run off rather than infiltration and deposition.

Topography of the area ranges from flat to mountains and gorges. The flat area covers the lowland areas that are surrounded locally in several locations and ruggedness characterize the basin. Southern and Eastern part of the basin is dominantly rugged and hilly with deeply cut gullies where as the Northern part is more gentle except the cliff or ridge of the extreme part along the water divide of Woshi river catchments.

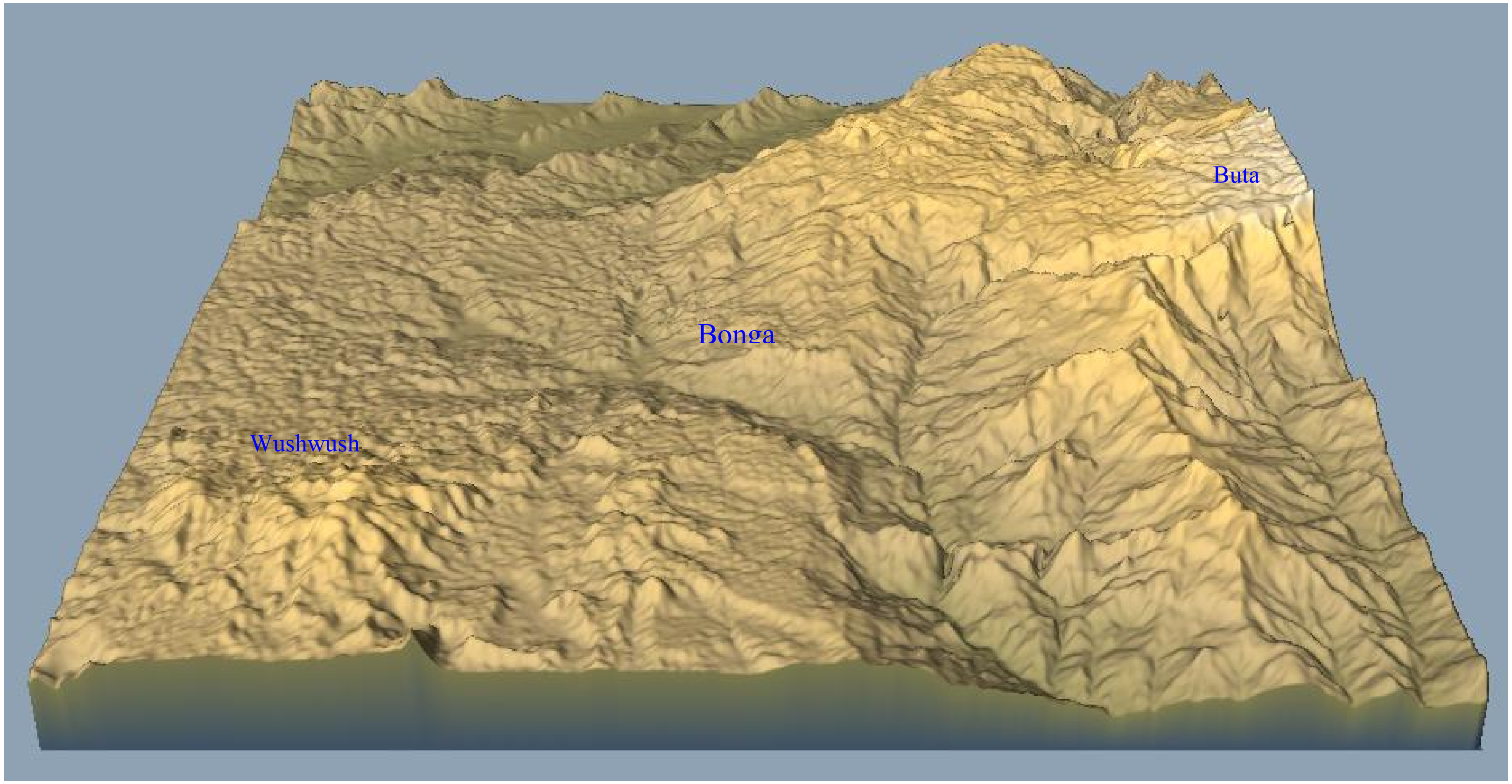

Figure 2.2 Digital Elevation Model of the study area.

The combined effects of climate and geology on the catchment topography yield an erosion pattern which is characterized by a net work of channels or streams. The drainage pattern and density in the study area is dominantly represented and characterized by dense drainage with dendrtic pattern. This is governed by shallow weathering layer and uniform geology of the area. Most of the precipitation in this category is not allowed to infiltrate and then to percolate in enormous amount (Figure 2.3).

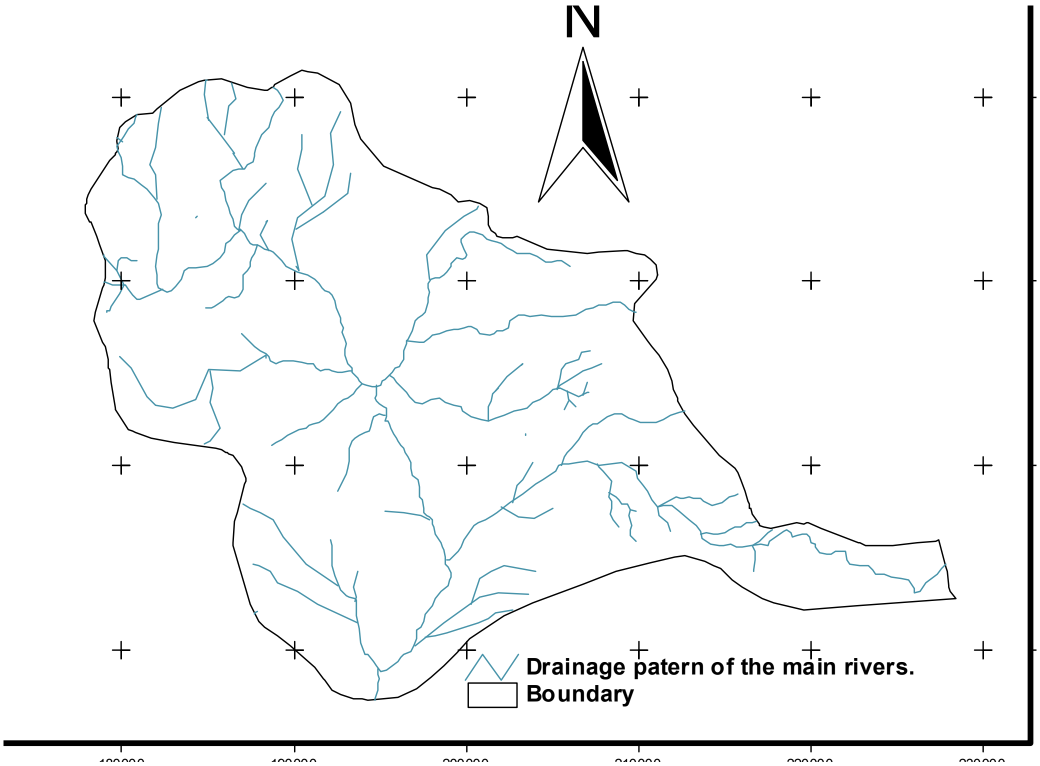

Figure 2.3 Drainage map of the study area

2.4 Soil and Land use

2.4.1 Soil classification

Previous soil studies of the basin range from the general to the specific. More specific soil studies in the Basin have concentrated on the irrigation potential evaluations. For Wushwush Tea Plantation a report and map at 1:50000 scale exists for the plantation of about some 2000ha and above. The genesis of all soils is governed by the soil forming factors of climate, organisms, relief/topography, parent material and time .The inter play of these various factors within the study area has determined the nature of its soils. Parent materials such as basalt and other basic igneous rocks are rich in ferromagnesian minerals which break down to clay minerals resulting in clay textured soils. In the study area almost all of the parent materials are volcanic rocks which under the influence of a pluvial regime and relatively warm temperature, have weathered to form deep, well drained clay soils over almost all of the highland areas. Soil morphology relates to the appearance of the soil in the field in terms of depth, color, texture, structure, consistency, drainage and the presence or absence of stones and carbonates. These, together with chemistry, are the criteria to categories the soils into soil units by earlier studies. The dominant soil units of the study area fall into three main soil groups. These classifications are taken from the study of Omo Gibe basin land resource development master plan (1996) and supplemented by field visit.

Well drained red and brown clays

This type of soil is a larger unit that describes the mountainous wet forested areas of the basin covering some 60% of the study area .Topographically the area is hilly to mountainous with most slopes 15-30%.The soils are a complex to deep well drained red and brown clays with some shallower areas corresponding to steeper slops and locally poorly drained bottom lands. The land use is still primary high forest but is rapidly being encroached by rain feed agriculture, Tea, and coffee plantation.

Sandy loam- These soils are developed in fluvial red and brown soils found only on almost flat surface on which during high rainy season, water will stay for certain days as a stagnant water. It is situated on the central and north eastern parts and by sides of stream banks with 10% aerial coverage of the study area. These soils represents poorly drained alluvial of low lying areas in high rain fall areas around Bonga that are water logged and do not dry out.

Clay loam- These soils are developed on slightly to moderately dissected undulating to rolling low relief hill side slopes and plantation areas. The soils are moderately deep to deep, well drained, dark yellowish brown or dark grayish brown in colors. Southeast of the basin is dominantly covered with this soil unit.

No	Soil type	Area coverage (km2)	Weighted area (%)
1	Drained red and brow clay	542.81	60.2
2	Sandy loam	90.62	10.35
3	Clay loam	257.834	29.45

Table2.1 Soil type and their actual coverage in the basin

2.4.2 Land use/ Land cover

Based on the type of covering material of the area with their present services, major land cover/land use units of the study area are described as three units.

1. Moderately cultivated areas with shrub lands
2. Dense natural and man made protected forest coverage.
3. Plantation with cultivation, grasses, bush and significant shrubs.

Moderately cultivated areas cover the area with moderately steepy slopes. Shrubby grass land with scatter cultivation and open wooded land with bush covers northern peripheral part of the study area which is not suitable for cultivation due to its rugged and dissected terrain. Plantation together with other bushes according to land cover classification is categorized in Afro alpine occupied zone of high land area. In general the basin is occupied more by relatively dense natural and man made forest followed by moderately cultivated with shrubby grass land, bush, open shrubby grass land. Plantation and Alpine vegetation takes the least coverage.

No	Land use/Land cover	Coverage (km^2)	Weighted area (%)
1	Moderately cultivated with open shrubby grass land, and afro alpine	214.2	29.45
2	Dense natural broad leaved forest coverage	543.12	60.2
3	Plantation with cultivation and open wooded land	90.7	10.35

Table 2.2. Aerial coverage of land use/land cover.

Major crops growing in the basin are Teff, Maize, Bean, Barley, Wheat and other highland areas are dominated by highland broad leaved trees, Junipers and other bushes. Moderately sloping areas are covered dominantly with:

- Acacia species,
- Lowland eucalyptus
- Ficus species (Shola, Warka and others)

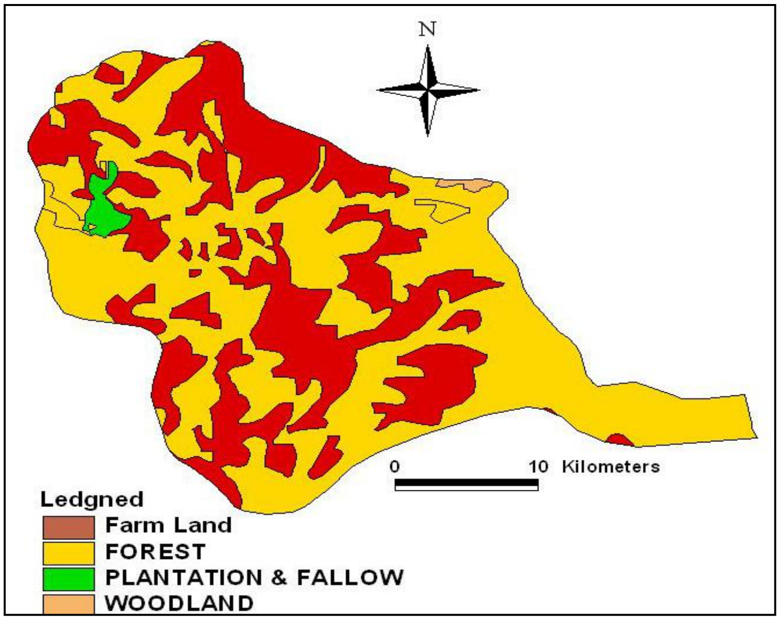

Figure 2.4 Land use/land cover map of the study area

CHAPTER 3

HYDROMETEOROLOGY

A description of the properties of the atmosphere and of the main features of solar radiation will provide the bases for considering the physics of evaporation and the formation of precipitation. And hence, It is the study of precipitation and evaporation, the two fundamental phases in the hydrological cycle which involve processes in the atmosphere and at the earth's surface /atmosphere interface (Shaw, 1988).There fore, hydrometheorological data play a great role in determining or solving different problems, such as determination of probable maximum precipitation used in the spill way design, forecasting of precipitation for reservoir operation, determination of probable maximum winds over water surfaces for evaluating the resulting waves in connection with the design of dams and other structures, determination of maximum and minimum temperature for evaluating evaporation and evapotranspiration, or for evaluating water resource potential etc (Jayarami, 1992).

3.1 Hydro meteorological data

Meteorological parameters such as atmospheric pressure, wind velocity, temperature, humidity, radiation, sunshine, precipitation and evaporation are essential for the understanding of the atmospheric phenomena. In Ethiopia, collecting meteorological data systematically and continuously is the responsibility of the National Meteorology Service Agency (NMSA). For the analysis of various hydrologic cycle components, long-term meteorological data have been taken from NMSA for the stations distributed in the study area and in the vicinity (Table3.1).

No	Stations	Location UTM		Altitude m.a.s.l	Recording period(year)
		Latitude	Longitude		
1	Bonga	195602	803396	1650	since1953 ˚2
2	Wushwush	183930	808454	1950	since1954 ˚1
3	Chiri	189766	787833	2000	1987------2000 ˚1
4	Dirigoma	199882	816624	1760	since1988 ˚2
5	G0jeb	210386	820515	1250	1972------1990 ˚1

Table3.1 Meteorological stations in and around Upper Guma Sub Catchment

˚1 Records temperature, wind speed, relative humidity, sunshine hours and rainfall

˚2 Records temperature and rainfall

Metrological stations are located in such a way that, in the periphery of the basin there are three stations and with in the basin there are two stations. Of these stations, class-A meteorological station which can measure all parameters currently is that of Wushwush only and the other one which was established to serve as class-A in Chiri is abounded since 2000.

The other stations measure only temperature and rainfall. Two of the stations within the basin are Bonga and Wushwush, where as, the peripheral ones are Chiri, Gojeb and Dirigoma. Wushwush is class A- station and the data are used in the calculation of long term average wind speed and sun shine hours from stations. Meteorological Stations are not evenly distributed in the basin, but are sufficient. Except in the south - eastern part of the basin, the study area is bounded by meteorological stations. This distribution makes the result of rain fall (precipitation) calculation or analysis to apply appropriate method to obtain reasonable value for the basin. Similarly other parameters are the result of these stations at different altitudes. The only problem here is that for different reasons, the stations do not have continuous records and there are gaps for different years. However, the mean values of the days or months, which are recorded in the five stations, are reasonably adjusted using different techniques for the purpose of the study.

Mean monthly minimum and maximum temperature of the five stations, Bonga, Wushwush, Chiri, Dirigoma and Gojeb are 52,51,13,18 and 17, years of recorded data respectively. Other basic parameters in addition to the above once such as wind speed, relative humidity and sunshine hours are recorded at Wushwush station. Though not currently functional, Chiri and Gojeb stations have recorded several of these parameters.

Monthly mean wind speed at Wushwush, Chiri and Gojeb stations have records of seven years each and sunshine hours at Wushwush and Chiri stations has been recorded for seven years. Relative humidity is recorded at Wushwush and Gojeb with a total recording data of seven and ten years respectively. The Chiri station has also records of Pan Evaporation for eight years .The data obtained from these stations are used to represent the study area.

River discharge measurements are made in four gauging stations distributed along the river course at different location (at Gicha near Bonga with coordinates 7^0 17' N and 36^0 13'E covering drainage area of 175 km^2, Sheta near Bonga located at 7^0 17' N and 36^0 14'E with a drainage area of 190.6 km^2, Dincha near Bonga with coordinates at 8^0 11' N and 37^0 28'E with a drainage area of 286 km^2, and Guma near Anderacha with coordinates 7^0 9' N and 36^0 15'E draining an area of 231.25 km^2) to know its annual discharge. Gicha and Sheta records just the upper extreme catchments draining from north western and north eastern part where as Dincha accounts middle part while Guma gauging is for lower and south eastern part of the study area. Four of the gauges have maximum and minimum discharge in M^3 /s and monthly mean river discharge records of 20 years data taken in to account for this study.

3.2 Precipitation analysis

Precipitation is the out put or result of hydrologic process through a combination of circumstances when water vapor changes back to the liquid state through the process of condensation to form clouds. Of all the components of the hydrological cycle, precipitation is the most commonly measured. It would appear to be a straight forward procedure to catch rain fall as it falls. The rainfall obtained from a single rain gauge station is known as the point rain fall or station rainfall. Precipitation for a given duration over a particular area rarely produces uniform rainfall depth over the entire area. Maximum rainfall at certain gauge could not represent the whole area for different reasons.

3.2.1 Determination of aerial depth of precipitation

Based on the available rainfall data taken from different stations analyses should be done to obtain representative aerial depth over the whole study area. Since most hydrological problems require knowledge of the average depth of rainfall over a significant area, such as river basin some procedures must be used to connect the rainfall measured at the individual rain gauges to the aerial averages. The average depth of rainfall is also termed as equivalent uniform depth of rainfall (Jayarami, 1996). The three methods to arrive at an approximate average depth of rainfall are

1. Arithmetic mean method
2. Thiessen polygon method
3. Isoheytal method

Arithmetic mean method is the simplest of the three methods and the result is obtained by dividing the sum of the rain fall amounts recorded at all the rain gauge stations which are located with in the area under consideration by the number of stations (Wilson1983).

That is:

$$P = \frac{P1 + P2 + - - Pn}{n}$$

Where P is the average depth of rain fall and p1, P2--Pn are the rain falls recorded at stations 1, 2, --- etc. and n is the number of rain gauge stations with in the area. There fore, P = 1663.6mm is the average depth of rain fall using arithmetic method. This method is accurate as other methods if the area is flat and the Gauges are distributed uniformly over the area and the variation of individual gauge records from the mean is not too large (Shaw, 1988 and Jayerami, 1996). But these conditions are not fulfilled in the study area for the reason that the area is not flat (with altitudinal variation of 2300m.a.s.l) and the gauges are only two in addition to their non uniformly distribution. Hence the result obtained using arithmetic could not represent the average areal depth of the whole area.

The second method (Thiessen polygon method) attempts to make allowance for irregularities in gauge locations by weighing the record of each gauge in proportion to the area which is closer to that gauge than to any other gauge (Figure3.1).

The method is given by $P=\frac{A1P1+A2P2+---AnPn}{\sum Ai}$

Where P=average aerial depth rain fall.

P1, P2---Pn=mean annual rain falls recorded at each rain gauge stations.

A1, A2 ---An=Polygonal areas around each stations with in the basin

Using this method, the result obtained is 1701.765mm (Table3.2)

Station	Mean annual rainfall(mm)	Area of influence(km^2)	Weighted area (%)	Weighted rainfall(mm)
Bonga	1623.8	413.262	0.472	766.434
Wushwush	1928.13	227.88	0.260	501.314
Chiri	1647.67	8.847	0.101	166.415
Dirigoma	1628.7	137.343	0.157	255.706
Gojeb	1489.63	8.865	0.010	14.896
Total	8317.93	875.8820	1	
Thiessen				1701.765

Table3.2 Theissen polygon method to calculate annual rainfall in Upper Guma Sub Catchment

The third method is called Isoheytal method which is perhaps the most accurate method of computing the average depth of rainfall. Isohyets may be defined as lines joining points of equal rainfall (Figure 3.2). In other words all the places along an isohyets experience the same amount of rain fall. The basin areas along with the rain gauge station locations in and around the areas are drawn to a suitable scale. According to this method the annual precipitation in the Sub catchment is equal to 1692.213mm (Table3.3)

Isohyetal range mm	Average isohyetal value (mm)	Enclosed area km^2	Weighted area (%)	Weighted rainfall mm
<1600	1575	10.6	1.21	19.06
1600-1650	1625	374.93	42.8	695.5
1650-1700	1675	223.8	25.55	427.96
1700-1750	1725	69	7.88	135.93
1750-1800	1775	57	6.51	115.55
1800-1850	1825	55.6	6.35	115.89
1850-1900	1875	59.7	6.81	127.69
>1900	1925	25.4	2.89	55.63
Total		875.93	100	1693.213

Table 3.3 Isohyetal method of calculating annual rain falls in Upper Guma Sub Catchment.

Among the above methods the arithmetic mean method is fur less than the Theissen polygon and Isohyetal methods. Isohyetal method gives intermediate value owing to the topographic effect in calculating the monthly weighted rainfall and therefore the arithmetic, Theissen, and Isoheytal methods are averaged to fit best for the study area and hence, the annual precipitation in the basin is found to be 1686.mm.

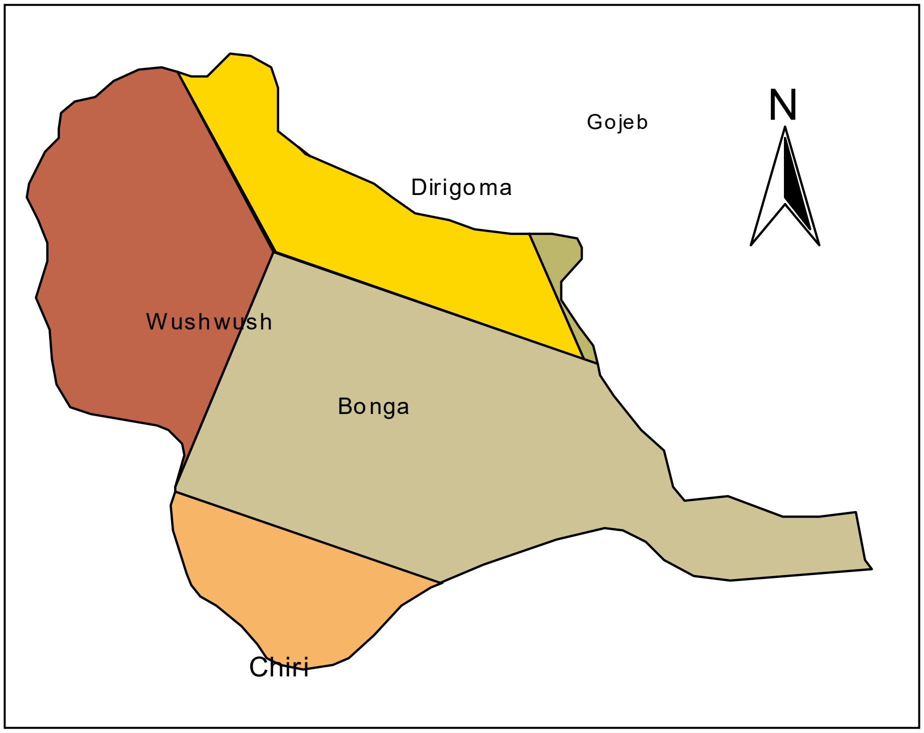

Figure 3.1 Theissen polygon method

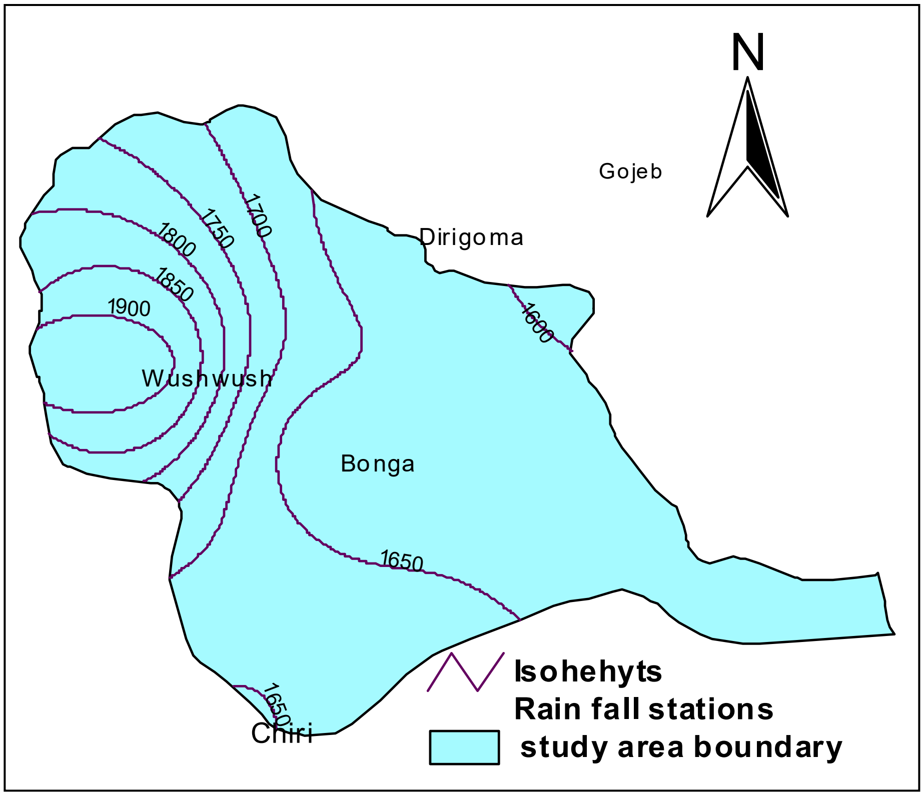

Figure 3.2 Isoheytal map of the study area

3.2.2. Rainfall characteristics

Precipitation process in nature is subjected to spatial and temporal variation. We can not predict with certainty what would be the rainfall for any given period in future. The rain fall magnitude can be estimated only with some probability attached to them. Therefore the analysis of the rainfall data obtained over a long period in the past would help to make reasonable estimates of rainfall to be used in various developmental activities.

The rainfall distribution in the study area is not uniform which ranges from 1489.63mm to 1928.13mm.The highest rainfall is recorded in Wushwush and the lowest rainfall record is from the north eastern part closer to Gojeb area. As it is displayed in the precipitation bar graph, the maximum rainfall is recorded in the month of July and the minimum rainfall is recorded in the month of January. Then majority of the rainfall in the basin is obtained during the summer time (Kiremt) May, Jun, July, and August which covers 71% of the total annual rainfall (Table 3.4). The minimum records are in the months of December, January, and February with unimodal rain fall characteristics (Figure.3.1).

Station	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
Bonga	50.1	50.9	105.5	177.2	187.1	192.	204.5	204.2	186	144.3	62.9	59.3	1623.8
Wushwush	42.8	45.4	126.9	189.1	207.9	218	211.0	413.6	208.	141.5	55.7	65.6	1928.1
Chiri	56.8	59.29	121.1	194.6	174.	175	193.1	201.6	166	150.7	67.1	64.2	1647.7
Dirigoma	59.1	37.9	98.0	166.2	210.0	233	218.3	213.5	186	112.3	40.66	53.7	1628.7
Gojeb	32.4	55.8	91.3	120.2	194.29	222	200.	170.8	81.7	66.5	66.54	41.8	1489.6
Arithmetic mean.	48.2	49.8	108.6	169.5	194.8	208	205.3	240.7	165.	123.06	58.58	56.9	1663.6
Theison polygon.	49.7	51.4	111.4	173.7	200.2	214	210.9	255.6	188.	129.39	60.32	56.6	1701.6
Isoheytal mean	48.8	50.5	110.3	172.3	203.2	211	209.1	253.5	186	128.13	58.78	60.7	1693.2
average	48.9	50.5	110.1	171.8	199.4	211	208.4	249.	179	126.8	59.2	58.6	1686

Table 3.4 long terms mean monthly rainfall (mm) of the five stations in and around the basin

The monthly Rainfall intensity of the area is clearly depicted in the graph shown below

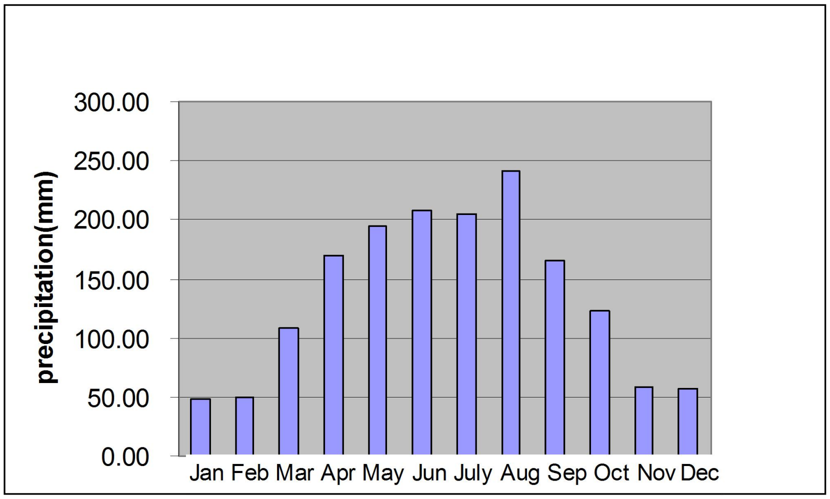

Figure 3.3 Monthly rainfall distribution in upper Guma Sub Catchment

3.3. Temperature

Temperature is measured at five stations and the mean monthly temperature is computed as the arithmetic average of the mean daily temperature of all the days in the month. The minimum temperature of all the five stations is recorded in the month of December where as the maximum temperature recorded is during the months of March and April.

Station	Month	Jan	Feb	March	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Bonga	Maximum	27.7	28.3	28.2	27.6	27	26.2	25.5	25.5	26.2	27.2	27.7	27.8
	Minimum	10.2	11	12	12.7	13	12.5	12.3	12.6	12.6	12	11.4	10.7
	Average	19.1	19.7	20.2	20.1	20	19.3	18.9	19.1	19.4	19.6	19.6	19.2
Wushwush	Maximum	26.2	25.9	26.4	25.5	25	23.2	21.4	21.9	23.2	24.7	25.5	25.5
	Minimum	10.4	10.9	11.8	12.6	12.5	12.1	12.0	11.9	11.6	11.1	10.7	10.4
	Average	18.2	18.4	19.1	19.1	18.7	17.6	16.7	16.9	17.4	17.9	18.1	17.9
Chiri	Maximum	26.2	26.4	26.6	25.6	25.3	24.3	23	23.1	23.3	24.4	24.9	25.2
	Minimum	12.4	13.2	12.6	12	11.6	11.4	10.5	10.6	11.1	10.9	11.9	12.4
	Average	18.3	19.8	19.6	18.8	18.4	17.9	16.7	16.9	17.2	17.7	18.4	18.8
Dirigoma	Maximum	25.8	27.2	27.3	26.7	25.7	25.1	24	24	24.5	25.3	25.3	26.3
	Minimum	13.8	14.2	14.5	14.5	14.1	13.6	13.9	13.3	14.1	13.9	13.7	13.2
	Average	19.8	20.7	20.9	20.6	19.9	19.4	18.9	18.9	19.3	19.6	19.5	19.75
Gojeb	Maximum	32.3	32.2	32.1	31.3	30.5	28.8	28.1	28.1	28.7	29.7	30.8	31.41
	Minimum	12.5	14.1	15.5	15.8	16.5	16.1	15.6	15.5	15.4	14.6	13.1	12.9
	Average	22.4	23.1	23.8	23.5	23.5	22.4	21.9	21.7	22.1	22..2	22	22.1

Table 3.5 Monthly mean max. and mean min. temperature variability of the five stations

Temperature varies spatially with altitude with a general trend of decreasing with altitude, although there are some variations in some stations at certain months (Table3.6).

Station	Jan	Feb	March	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Bonga	19.1	19.7	20.2	20.1	20	19.3	18.9	19.1	19.4	19.6	19.6	19.2
Wushwush	18.2	18.4	19.1	19.1	18.7	17.6	16.7	16.9	17.4	17.9	18.1	17.9
Chiri	19.6	19.8	19.6	18.8	18.4	17.9	16.7	16.9	17.2	17.7	18.4	18.8
Dirigoma	19.8	20.7	20.9	20.6	19.9	19.4	18.9	18.9	19.3	19.6	19.5	19.75
Gojeb	22.4	23.1	23.8	23.5	23.5	22.4	21.9	21.7	22.1	22..2	22	22.1
Average	19.7	20.34	20.72	20.42	20.1	19.32	18.62	18.7	19.08	18.7	19.52	19.55

Table3.6.Monthly mean of max. and minimum temperature of the five stations.

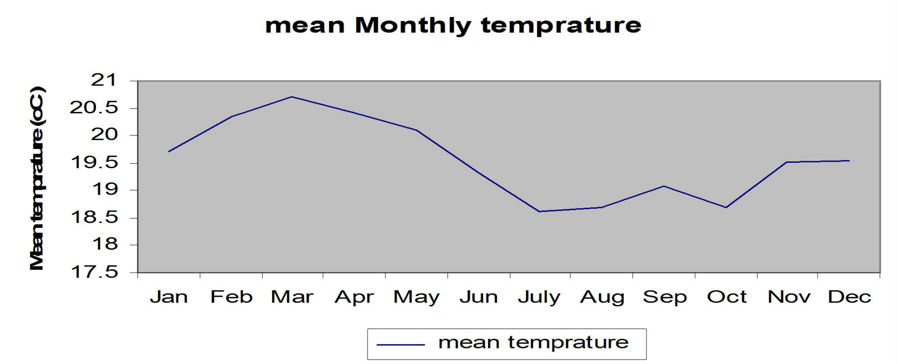

Figure 3.4 Monthly mean temperature variability of the Upper Guma Sub-Catchment.

3.4 Relative Humidity

Relative humidity is the relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature (Shaw, 1988). Available data of relative humidity is from two stations one in Gojeb which has a total of 11 years data and the other in Wushwush with 7 years of data and the average is used for the calculation. It attains its maximum and minimum values in the months of July and February respectively. This is related to the rainy season and dry season in the study area during summer its value raises and during winter its value lowers (Table3.7).

Stations	Mean	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
GOjeb	mean at 600	93.9	90.9	90.3	91.5	91.2	95.4	90.8	92.3	92.8	93.4	91.7	93.7
	mean at 1200	78	74.5	76.8	77.1	80	79.5	80.7	79	78.9	80.2	74	74.8
	mean at 1800	77.7	75	78	80	79.2	81.1	80.9	81.5	81.9	84.2	78.6	78.3
	average	83.2	80.1	81.7	82.7	83.5	85.3	84.1	84.6	84.6	86	84.4	82.3
	mean at 600	80.1	81.7	82.8	83.5	85.4	84.2	84.3	84.6	85.9	82.2	82.3	83.2
	mean at 1200	78.4	80.5	81.8	82.1	84	82.1	83.5	83.7	85.4	81.8	81	81.4
	mean at 1800	79.6	81.3	82.5	83	84.9	83.8	84.1	84.3	85.8	82.7	83	82.6
	average	79.4	81.2	82.4	82.9	84.8	83.7	84	84.2	85.7	82.3	82.1	82.4
Average Total		79.8	81.2	82.6	82.9	85.1	83.7	84	84.2	85.9	83.4	82.1	82.3

Table3.7 Monthly mean relative humidity at the study area

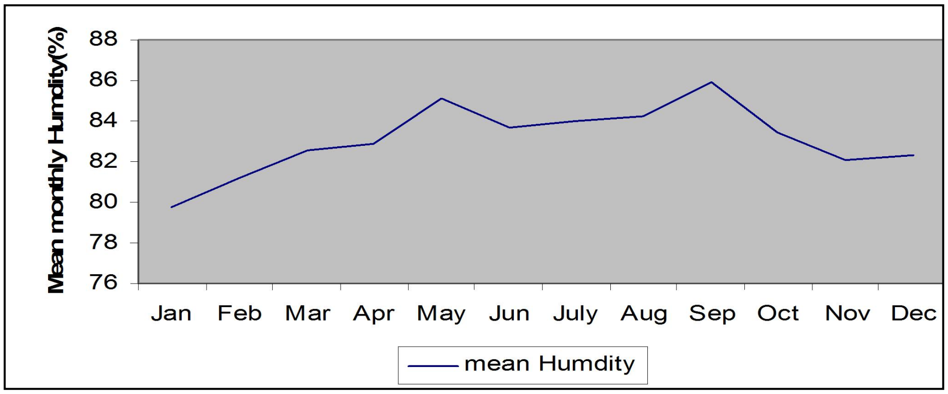

Figure 3.5 Monthly mean relative humidity at the study area

3.5. Wind speed

Data on wind velocity is required in the evaporation studies. Wind speed varies with the height above the ground. However, the wind speed at any height can be approximately obtained from the known wind speed at the known height of observation. Wind speed in the study area and near by station is measured at 2m above the surface of ground.

Available data sources are from three stations (Wushwush, Chiri, and Gojeb) which are averaged and used for the calculation of evaporation. Wind speed shows decreasing spatial variation with altitude and gets its maximum and minimum value in the months of January and September respectively (Table3.8).

Station	Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Wushwush	82.7	79.3	81.1	82.3	82.8	84.7	83.3	84	84.1	85.7	82.6	82.1	82.7
Chiri	82.4	79.4	81.1	82.4	82.9	84.8	83.5	84	84.2	85.7	82.5	82.1	82.4
Gojeb	82.5	79.5	81.1	82.4	82.8	84.9	83.5	84	84.2	85.8	82.8	82.1	82.5
average	82.5	79.4	81.1	82.4	82.8	84.8	83.4	84	84.2	85.7	82.6	82.1	82.5

Table3.8 Average means wind speed of the study area (in m/s)

Wind speed has a great effect on the rate of evaporation in that the higher the wind speed takes away the moisture in the air which facilitate or favors evaporation when its movement is turbulent. Laminar movements have not significant effect.

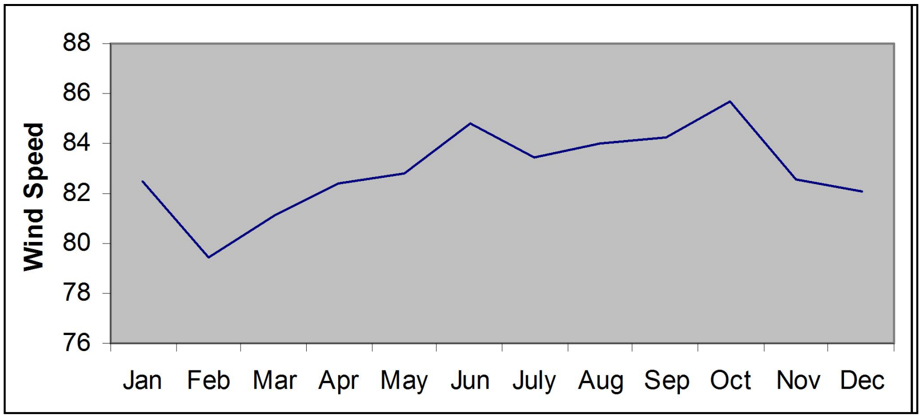

Figure 3.6 Average mean wind speed of the study area

3.6. Sunshine hours

It is the duration of sunshine in a day. It plays the main role as evaporation factor and it has a direct relationship with evaporation. This data is available only from Wushwush, Chiri and Bonga.

stations	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	total
Wushwush	6.7	5.1	6.5	5.7	6.1	3.8	2.7	3.3	4.4	6.8	7.5	7.2	6.7
Chiri	6.3	5.6	6.6	5.4	4.3	3.2	2.5	2.2	4.5	6.1	7.5	7.1	6.3
Bonga	7.6	6.6	6.4	6.6	6.0	4.9	3.1	3.6	4.9	6.8	7.6	8.0	6.0
average	6.9	5.8	6.5	5.9	5.5	3.4	2.8	3	4.5	6.6	7.5	7.4	6.9

Table3.9 Mean monthly sunshine hours of the three stations

The area attains its maximum and minimum sunshine hours during January and July respectively (Table3.9). It's maximum and minimum is the reflection or result of cloud cover during summer and winter.

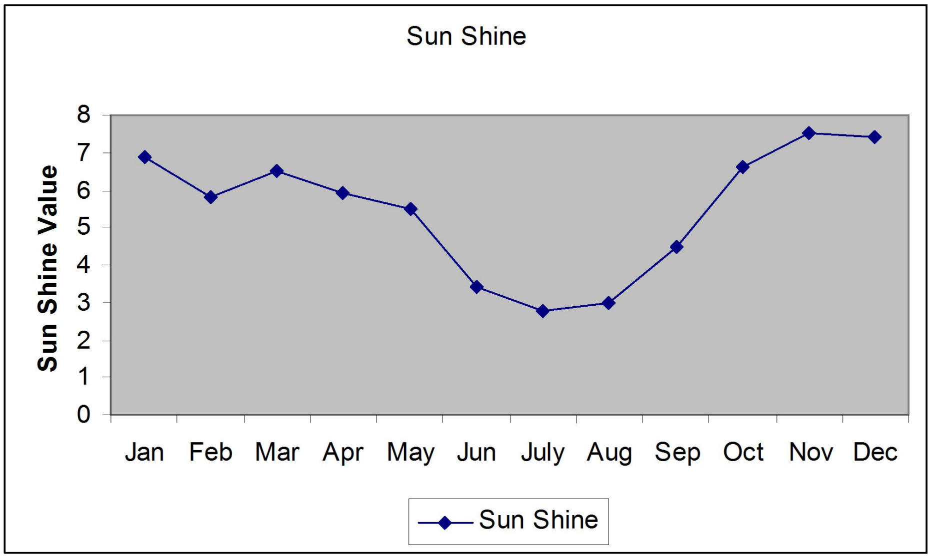

Figure 3.7 Mean monthly sunshine hours of the Study area.

3.7. Estimation of Evapotranspiration

Evaporation is the process by which water from land and water bodies escapes in to atmosphere. It is one of the most complicated hydrologic processes and deserves more elaborate treatment. The nature of evaporating surface affects evaporation by modifying the wind pattern. Over a rough, irregular surface, friction reduces wind speed but has a tendency to cause turbulence, so with an induced vertical component in the wind, evaporation is enhanced. Over an open water surface, strong winds cause waves which provide an increased surface for evaporation in addition to causing turbulence. As wind passes over smooth, even surfaces there is little friction and turbulence and the evaporation is affected predominately by the horizontal velocity (Shaw, 1988).

Direct measurement of evaporation from open water body or pan evaporation in the study area is of no interest for the reason that natural or man made large open water body in the form of lake or reservoir does not exist therefore, the roll of evaporation will not be treated separately rather, it will be dealt in the combined effect of evapotranspiration. Calculation of evaporation from open water body combines the two approaches to evaporation calculation, the mass transfer method and the energy budget method. The basic equations are modified and rearranged to use meteorological constants and measurements of variables made regularly at climatological stations

$H=Eo + Q$--3.1 (Simplified energy balance equation)

$Eo=f(u)(e_s-e_d)$ --3.2 (Mass transfer method)

Where H= the available heat

Eo= Energy for evaporation=rate of evaporation

Q=energy for heating the air

f(u)= a function of wind speed

e_s-e_d=Saturation deficit

e_s=saturated vapor pressure of air at water surface

e_d=saturated vapor pressure of air above the water surface

After rearranging of different parameters based on the above two methods (eq.3.1 and 3.2), penman arrived at his final equation for open water evaporation. The corresponding formula is

$Eo= (\Delta/\gamma H + Ea)/ (\Delta/\gamma + 1)$ --------------------------------3.3

Where Eo=evaporation rate (mm/day)

Δ= Slope of the curve of saturated vaprer pressure plotted against temprature.

γ= hygrometry constant (0.27 mm of mercury)

$H= R_I (1-r) - Ro$---3.4

Where R_I = incoming solar radiation

Ro=out goring solar radiation

r= the Aledo equals 0.05 for water

But $R_I (1-r) = 0.95\ Ra\ fa\ (n/N)$ ---3.5

$fa\ (n/N) = 0.18+0.55\ n/N$-- 3.6

Where Ra = solar radiation arriving at the atmosphere (fixed by latitude and season)

n= bright sun shine hours per day

N= maximum possible sunshine ours obtained from standard meteorological tables.

And $Ro= \sigma T^4_a(0.56-0.09\sqrt{e_d})\ (0.10+0.9n/N)$----------------------------------3.7

Were: σT_a is theoretical black body radiation at temperature Ta of air

σ = Stefan-Boltzman constant $5.67X10^{-8}wm^{-2}\ k^{-4}$

(T must be converted to ^{o}k)

e_d= mean vapor pressure for the same period.

Next, Ea in equation 3.5 is found using the coefficients derived by experiment for open water. $Ea=0.35\ (0.5+U_2/100)(e_a-e_d)$--------------------------------3.8

Where: U_2 =mean wind speed at 2m above the surface in miles per day

e_a=saturated vapor pressure at air temperature.

e_d = saturated vapor pressure at dew point t_d = actual vapor pressure

Saturated vapor pressure (e_a)**:** This value can be obtained from the standard curve drawn for the relation between temperature and saturated vapor pressure or from the standard table. But empirically it can be calculated as:

$$e_a = 6.11\exp\left(\frac{17.3T}{T+237.3}\right) \text{ -------------------------------------3.9}$$

Where T is temperature in ^{o}c and e_a in mill bar.

Actual vapor pressure (e_d)**:** This value is calculated from the relation of relative humidity and temperature given by:

$$RH\% = e_d/e_a \text{--} 3.10$$

Δ (Slope of the saturated vapor pressure curve corresponding to the air temperature) can be obtained from the approximate equation 3.11. (Jayarami, 1996

$$\Delta = \frac{4098ea}{(237.3+T)^{2}} \text{----------------------------------} 3.11$$

Where e_a in mm and T in ^{0}c. Hygrometer constant (γ) has a typical value of 0.4859 mmHg / ^{0}c (Maidment, 1993).

Where e_a =saturation vapor pressure (mmHg)

e_d =actual vapor pressure (mmHg)

RH =relative humidity (%)

U_2 =wind speed (mile/day)

n =daily mean bright sunshine hour (hr/day)

N =maximum possible sunshine hours determined by latitude and season (12^{o} N Latitude is for the study) from standard tables.

fa =a function of sun shine hour

Ra =solar radiation which depends on latitude and season (mm of water /day)

R_1 =incoming solar radiation (mm/day)

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

σ =Stephan-Boltzman constant (5.67 x 10^{-8} x Wm^{-2} T^{-4})

T =temperature (^{o}c)

TK=temperature in Kelvin

Ro =out going solar radiation (mm/day)

H =available heat (mm/day)

Ea =energy for evaporation (mm/day)

σT^4 =theoretical black body radiation (mm/day)

Δ =slop of saturation vapor pressure plotted against temperature

γ =hygrometric constant (0.27mmHg/^{o}c)

Eo =open water evaporation (mm/month)

The overall explanations of all the above mathematical derivations of Penman method of calculations is important for the understanding of the interrelated meteorological entity to be described. Evapotranspiration, denoted by ET, which is the sum of the water used by plants in a given area in transpiration and the water evaporated from the adjacent soil in the area in any specified time. In an area covered with vegetation, it is difficult from practical point of view to separately evaluate evaporation and transpiration. Transpiration is the process by which water vapor escapes from the living plant and represents the most important aspect of water loss in the hydrologic cycle.

3.7.1.2 Estimation of potential evapotranspiration (PET)

Potential evapotranspiration is that which would occur if there was always adequate water supply available to a fully vegetated surface. It is the upper limit of ET for a crop in a given climate. Potential evapotranspiration tends to increase as the temperature, sunshine, and wind speed increase and as the humidity decreases. Calculations of potential evapotranspiration can be done by using different formula and for this research, Penman modified method, Thornthwaite, and Turk are considered and to minimize the contribution of error from each single method the average of the Penman and Thornthwaite values are used in the study area.

Penman modified method is used based on the available data. Resulting from later experience, the evaporation rate formula was modified (MAFF, 1967) to allow the condition under which evaporation plus transpiration takes place from a vegetated surface (Shaw, 1988) and it is given by:

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

Where the extra subscript t signifies inclusion of transpiration effects from equation 3.3.

$$H_t= R_I(1\text{-}r) - Ro\text{-------------------------------------}3.13$$

Where: r = the reflective coefficient for incident radiations the Albedo, from the basin depending on the nature of the surface. There fore the value of r for Guma Sub Catchment case is averaged as 0.185

$$Eat = 0.35\ (1+U_2/100)\ (e_a-e_d)\ \text{----------------------}3.14$$

This is similar to that of equation 3.10 except the coefficient 0.5 being replaced by 1 to allow for extra roughness in the wind speed function.

$$R_l\ (1-r) = (1-r)\ Ra.\ fa\ (n/N)\ \text{------------------------------}3.15$$

In addition to the Albedo modification in equation 3.5 to equation 3.16, equation 3.6 takes the form $fa\ (n/N) = (0.16+0.62n/N)$--------------------- - ---------------3.16

For latitudes south of 54 .5 ^{0}N, the empirical equation for the out going radiation in the calculation takes the form:

$$Ro = \sigma\ Ta^4\ (0.47-0.\ 075\ \sqrt{e_d})\ (0.17+0.83n/N)\text{--------------}3.17$$

Albedo (short wave-reflection coefficient) of any basin can vary widely with time of day, season, latitude and cloud cover. In the absence of knowledge on crop the value of r (reflection coefficient), is recommended to be 0.23 (Maidment, 1993)

In the study area however , the average and dominant crops, forests, soil and grass are cereals, plantations, clay soil, deciduous broad leaved and coniferous tree, and grasses with their Albedo, 0.24, 0.13, 0.3, 0.2 , 0.23and 0.22,0.1 respectively (Dunn and Leopold (1978) and Maidment (1993)). Therefore by averaging the above Albedo the value of r is taken as 0.185. Using this Albedo, the value of R_l (1-r) will be

$$R_l\ (1-r)=0.783\ Ra\ fa(n/N)\text{-----------------------------------}3.19$$

According to penman equation the study area has a lower potential evapotranspiration during summer time in the month of Jun (PET=50.5mm/m) because of the cloudy weather while the maximum evapotranspiration on the contrary occurs during winter time in the month of March (PET= 90 mm/month) (Table3.10).

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Ave.temp.	20.34	20.72	20.42	20.1	19.32	18.62	18.7	19.08	18.7	19.52	19.55	19.7
R.H%	81.2	82.6	82.9	85.1	83.7	84	84.2	85.9	83.4	82.1	82.3	79.8
Sun(hrs)	5.8	6.5	5.9	5.5	3.4	2.8	3	4.5	6.6	7.5	7.4	6.9
Wind(m/s)	70.4	81.1	82.4	82.8	84.8	83.43	84	84.2	85.7	82.6	82.1	82.5
PET(mm)P	83	99.5	90	83	62	50.5	54.5	63.5	83	76	78	84
Thornthwaite	71.6	70.9	76.7	76.5	50.6	65.8	60.9	61.9	71	60.6	65	60.3
Aver PET	77.3	85.2	83.35	79.75	56.3	58.15	57.7	62.7	77	68.3	71.5	72.15

Table 3.10 Potential evapotranspiration of the study area.

In addition to the above well known method there are several empirical formulas for a general estimate of evapotranspiration for the catchment.

Turc method: - this method uses a formula to estimate annual values of evapotranspiration for catchment taking mean annual precipitation in mm and mean temperature in degree centigrade data and the potential evapotranspiration is found to be 970.3mm annually.

Thornthwaite method:- this also uses an empirical formula for evapotranspiration calculation and accordingly the annual value for the study area is calculated to be 885.9mm. Potential evapotranspiration of the area is calculated by taking the average of these methods and the result is indicated as shown in table (3.10) above.

3.7.2 Actual evapotranspiration

Actual evapotranspiration(AET) over a catchment is often obtained by first calculating the potential evaporation plus transpiration (PET),that is assuming an unrestricted availability of water, and then modifying the result by accounting for the actual soil moisture content (Shaw,1988). The term actual evapotranspiration is used to describe the amount of evapotranspiration that occurs under field conditions. The majority of the water loss due to evapotranspiration takes place during the winter months while little loss is during the summer. Always actual evapotranspiration is less or equal to potential evapotranspiration. When the vegetation is unable to abstract water from the soil, then the actual evapotranspiration becomes less than potential.

If a soil is saturated then, it will hold no more water. In this conditions, actual evapotranspiration is equal to potential evapotranspiration (AET=PET) (Shaw, 1988). If there is no rain to replenish the water supply, the soil moisture gradually becomes depleted by the demand of vegetation to produce a soil moisture deficit (SMD). As soil moisture deficits increases, actual evapotranspiration becomes increasingly less than potential evapotranspiration. The values of soil moisture deficit and actual evapotranspiration vary with soil type and vegetation.

Penman (1950) introduced the concept of ‘root constant’ that defines the amount of soil moisture (mm depth) that can be extracted from a soil without difficulty by given vegetation. A soil moisture budget can be made on a monthly basis for various types of vegetation classified according to their root constants. There fore to evaluate actual evapotranspiration over a basin area, the proportions of different types of vegetation covering the basin must be known.

Accordingly, the study area has been classified in to three major groups of soil type with their vegetation cover. Based on these categories and meteorological data the actual evapotranspiration of the basin is calculated using Thornthwaite and Mather soil water balance model. This model considers that soil is always saturated and that vegetations can take the amount of water they require for growth.

Month	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Au	Sep	Oct	No	Dec	Annul
P	48.9	50.5	110	172	199	211	208	249	180	127	59.2	58.67	1686
PET	77.3	85.2	83.5	79.8	56.3	58.2	57.7	62.7	77	68.3	71.5	72.15	849.4
P-PET	-27.4	-34.7	26.6	92.2	143	153	150	186	103	59	-12.3	-13.48	
AcPwL	-86.5	-129									-12.3	-25.8	
Sm	307	258	259	331	441	481	500	500	500	500	487	461	
ΔSM	-18	-20	0.2	12.8	+11	+14	+19	0	0	0	-10	-8.6	
AET	66.9	70.5	83.5	79.8	56.3	58.2	57.7	62.7	77	68.3	69.2	67	816. 2
D	1.3	4.7	0	0	0	0	0	0	0	0	2.3	5.15	13.45
S	0	0	26.4	79.4	123	119	130	106	103	59	0	0	745.8
Taf RO	1.3	12..2	18.2	73.5	47	110	123	99	95	51	0	1.5	
RO	.7	6.1	9.1	39	24	55	62	50	43	26	0	.8	314.3
Detn.	.6	6.1	9.1	36	23	55	61	49	42	25	0	.7	

Table 3.11 Calculated actual evapotranspiration using water balance model for the clay loam soil covered with, matured forest. The maximum water capacity of the root depth is 500mm.

Where, p=precipitation
AET=Actual evapotranspiration
D=Soil moisture deficit
S=Moisture deficit
Ac PWL=accumulated potential loss

ΔSM=change in soil moisture during the month indicated
RO=direct runoff
PET=Potential evapotranspiration
Sm=maximum soil moisture

Taf RO =total available for run off Detn.= detention

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Au	Sep	Oct	No	Dec	Annu
P	48.9	50.5	110.1	172	199	211	208	249	179.7	127	59.2	58.67	1686
PET	77.3	85.2	83.5	79.8	56.3	58.2	57.7	62.7	77	68.3	71.5	72.15	849.4
P-PET	-27.4	-34.7	26.6	92.2	143	153	150	186	103	59	-12.3	-13.48	
AcPwL	-86.5	-129									-12.3	-25.8	
Sm	4.4	1.1	11.4	90.7	97,5	97.5	97.5	97.5	97.5	97.5	51.1	23.6	
ΔSM	-20.4	-3.3	10.1	79.3	0	0	0	0	0	0	046	-12.7	
AET	68..9	53.5	83.5	79.8	56.3	58.2	57.7	62.7	77	68.3	60	71	796.9
D	11.8	39.3	0	0	0	0	0	0	0	0	3	2.5	
S	0	0	26.6	92.2	103	103	120	106	103	59	0	0	712.8
Taf RO	21	10	9.7	11	115	97	197	162	154	170	85	42	
RO	11	5	5	6	58	49	99	82	77	85	43	21	541
Detn.	10	5	4.7	5	57	48	98	80	77	85	42	21	

Table3.12 Calculated actual evapotranspiration (AET) using water balance model for the clay soil covered with moderately deep rooted cereal crops having water holding capacity of 150mm.

Month	Jan	Feb	Ma	Ap	Ma	Jun	Jul	Au	Se	Oct	Nov	Dec	Annu
P	48.9	50.5	110.	172	199	211	208	249	180	127	59.2	58.67	1686
PET	77.3	85.2	77.3	85	84	80	56	58	58	63	71.5	72.15	849.4
P-PET	-27.4	-34.7	26.6	92.2	143	153	150	186	103	59	-12.3	-13.48	
AcPwl	-86.5	-129									-12.3	-25.8	
Sm	0.16	0	0.3	43	43	43	43	43	43	43 1	31.3	5.5	
ΔSM	0.1	0.02	0.3	42. 7	0	0	0	0	0	0	10.1	-9.6	
AET	49	50.6	77.3	85	84	80	56	58	58	63	71	68	722.9
D	30.8	42.6	0	0	0	0	0	0	0	3	8	11.5	96
S	0	0	26.6	92.2	103	123	150	136	103	51	0	0	784
Taf	30.8	42.6	19	43	12	14	14	17	95	51	8	11.5	
RO	16	22	10	22	62	72	71	89	43	26	4	8	445
Detn.	14.8	20.6	8.7	21	61	72	71	90	42	25	4	7.5	

Table3.13 Calculated actual evapotranspiration using water balance model. The soil is fine sand loam with shallow rooted crops and plantation, open grass, shrubs and cultivated which has a maximum water capacity of root zone 75 mm.

The above tables are the results of different parameters considered to play a great role in the system of evapotranspiration of a given basin. As a summary the relations of soil type, land use/land cover and actual evapotranspiration is described below.

No	Soil type	land use/land cover	Aerial(%) proportion	AET (mm)	Weighted AET(mm)	S(mm)	Weighted S (mm)
1	Clay	moderately cultivated for cereals with open grass land	29.45	796.9	234.68	712.8	209.9
2	Sandy loam	plantation with cultivation ,grass and significant shrubs	10.35	722.9	74.8	784	81.14
3	Clay loam	Matured forest cover with cultivation, shrubby and open wooded grass	60.2	816.2	491.3	745.8	448.9
Tota					800.7		739.3

Table3.14 Relation between soil type, land use/land cover and actual evapotranspiration.

Finally, the calculated amount of evapotranspiration and surplus water in the basin gives that the basin losses water in the form of actual evapotranspiration having an amount of 800.7 mm. (Tabl3.14).

3.8 Runoff Rainfall Relationship

For hydrological analysis and design, it is often necessary to develop relations between precipitation and runoff. Such relations are use full for extrapolation or interpolation of run off records, which are generally available for long periods (Jayarami, 1996). In addition to its usefulness for analysis it is also possible to understand the geological and hydrogeological characteristics of the basin as runoff depends on soil infiltration capacity, intensity and duration of precipitation and topography and shape of the basin.

The rivers in the study area are gauged at four stations ,but two of the four stations covering the northern and north eastern, western and north western part of the drainage area with 512 km^2 area is gauged by Dincha gauging station and southern and south western part with 231.25km^2 area by Guma gauging stations.

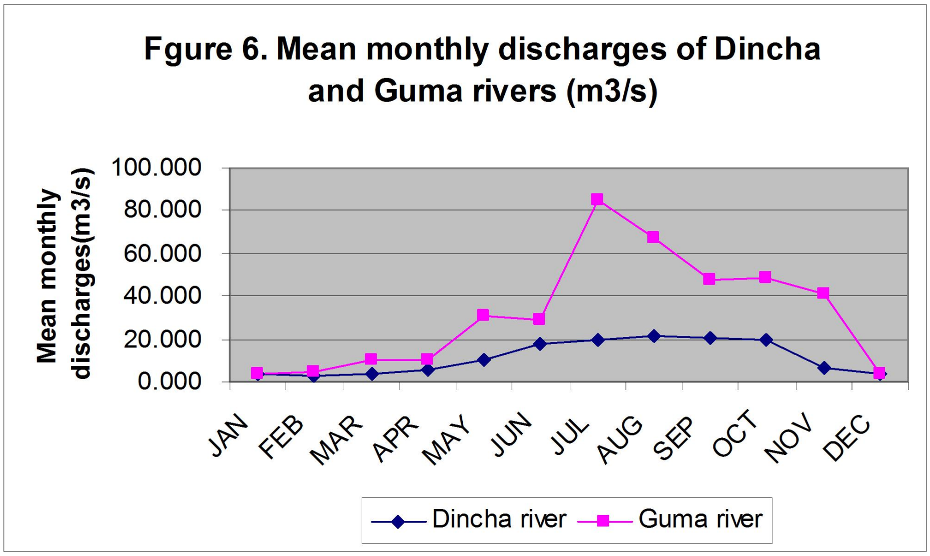

Fig 3.8 Flow nature of Dincha river as it flows down stream during dry season

From the above figure it is possible to conclude that the gauging station with minimum areal coverage, the Guma Station, has greater discharge as compared to the Dincha gauge owing to its fun shape and greater percent of steeply slope.

In the study area the highest precipitation is mostly recorded in the months of June, July and August. As a result of this highest rain fall, the maximum river discharge or runoff is recorded in the month of August (Table3.15). Here the month of maximum precipitation and month of maximum runoff fall in the same month. From hydrogeological point of view, this condition has its own meaning that, the area or the basin is not by major permeable which allows the initial rain fall up to the maximum amount to infiltrate till saturation and the runoff will start immediately. The relationships of the two parameters are shown below from the hydrograph (figure 3.8).

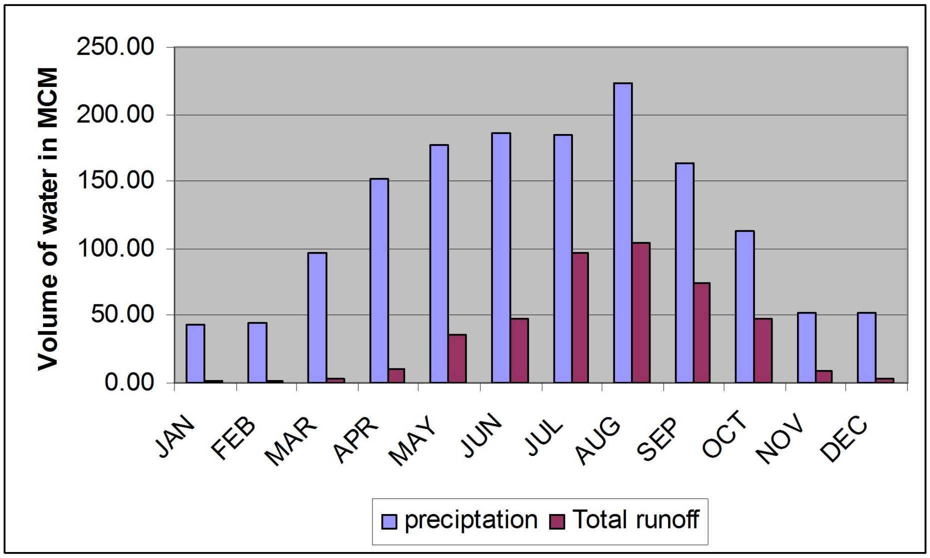

Figure 3.9 Relation ship between surface runoff and precipitation.

Generally, of the total precipitation (1486.6 mcm) in the basin, the river flow (435.7 mcm) annually covers 29.3 % (Table 3.15).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
P(mcm)	43.1	44.6	97.10	151.55	176.69	186.15	183.96	222.99	164.	112.79	52.2	51.4	1476.6
TRO(mcm	1.79	1.36	3.48	10.47	36.10	47.83	96.83	104.23	73.9	47.43	9.47	2.87	435.8
GOF(mcm	10.2	8.02	9.80	12.80	17.00	21.00	26.10	34.60	41.1	30.32	17.3	11.5	239.7

Table 3.15 Runoff and base flow components from precipitation in MCM.

Depth of ground water in a basin is a reflection of hydrogeological, geological and hydrological characteristics of the area. Shallow ground water indicates that the area is permeable with enough Precipitation to saturate or raise the water table in the permeable hydrogeologic unit in the study area. On the contrary if the ground water is deep, the area might be either suffering from precipitation shortage or the area is impermeable at the surface and is recharged not from local recharge but from regional. Depth to ground water has its own manifestations such as depth of hand dug wells, shallow wells, deep wells, and springs, in the area.

3.9 Surface water and Groundwater interaction

Groundwater and surface water are not isolated components of hydrologic system and hence, understanding their interrelation is needed for effective management of water resources. In recent years, as winter (1995) points out, studies of surface and groundwater interactions have expanded in scope to include studies of head water streams, lakes, wetlands and estuaries. As Hubbert (1940) shows, given an aerially uniform precipitation and infiltration over undulating surface, a groundwater flow system will develop driven by a water table surface that is a subdued replica of the land surface. In any basin, surface water (River or stream) is either gaining stream or losing stream. The readings from the river (see run off section) show that the region is generally characterized by humid climates and have shallow water tables and gaining steams. Aquifers are often saturated and groundwater is usually discharged through evapotranspiration and base flow to streams. Recharge rates in these regions are often limited by ability of aquifer to store and transmit water, processes that are strongly affected by sub surface geology. During summer, there is high amount of rain fall that can saturate the subsurface formation and that leads to the flow of river without losing its initial volume rather gaining down stream.

3.10 Groundwater Recharge estimation

In regions where water supplies rely heavily on groundwater, knowledge of natural recharge is important for quantifying safe yields of aquifers to avoid unacceptable decline in water tables (Bouwer 1989; sophocleous 1991). Groundwater recharge can be defined as the entry of water into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table with in the saturated zone (Freeze and cherry, 1979).Estimating amount of groundwater recharge in the basin is important for efficient ground water resources management. The availability of the background information on climate; geomorphology, including topography; vegetation, soil type, and permeability; physiographic setting; geology; and hydrology (water table depth, gaining vs. loosing streams) are important to come out with reasonable estimation and have been described in their respective chapters. To estimate ground water recharge of the area different techniques of estimation have been used

3.11 Base flow separation method

In water shades with gaining streams, ground water recharge can be estimated from stream hydrograph separation (Halford and Mayer 2000).This method is possible to do either by hydrograph method or using software.

Using hydrograph separation methods of straight line method, constant slope method and concave base flow separation method, it is possible to estimate amount of recharge with various result (McCueb, 1989). But to be logical and reasonable for this study, the constant slope method is selected. In this method, it is only necessary to select the point on the recession where direct run off ends. This point can be obtained by either using the concept of inflection point on the hydrograph recession which is the point where the hydrograph goes from being concave to convex or using an empirical formula proposed for large water shed (McCuen, 1989).

$N=A^{0.2}$ where, N=number of days from peak flood to the end of surface run off A=area of the basin in square miles.

But the draw back of this formula for this study is that since the empirical formula needs large water shed or basin it over estimate the base flow .There fore to be more reasonable inflection point method is used to separate the base flow from the runoff.

In the study area the catchment is divided in to three areas as 512 km^2 gauged by Dincha river gauging station; the 231 km^2 area gauged by Guma river gauging station and the rest 133 km^2 area being out of the gauging station for which the runoff part is calculated by considering the runoff coefficient of 0.2 and the long term mean monthly precipitation (Table 3.16).The annual ungauged runoff accordingly is found to be 45.14 mcm.

Ungaued RO	JAN	FEB	MA	APR	MAY	JUN	JUL	AU	SEP	OCT	NO	DEC	Ann.
Ppn mm	48.9	50.5	110	171.8	199.4	211	208.4	249.	179.7	126.8	59.2	58.6	1686
RO coef.	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
area	133	133	133	133	133	133	133	133	133	133	133	133	
URO mcm	1.31	1.3	2.9	4.6	5.3	5.65	5.6	6.77	4.98	3.42	1.6	1.5	45.14

Table 3.16 Calculated runoff for the ungauged part of the study area.

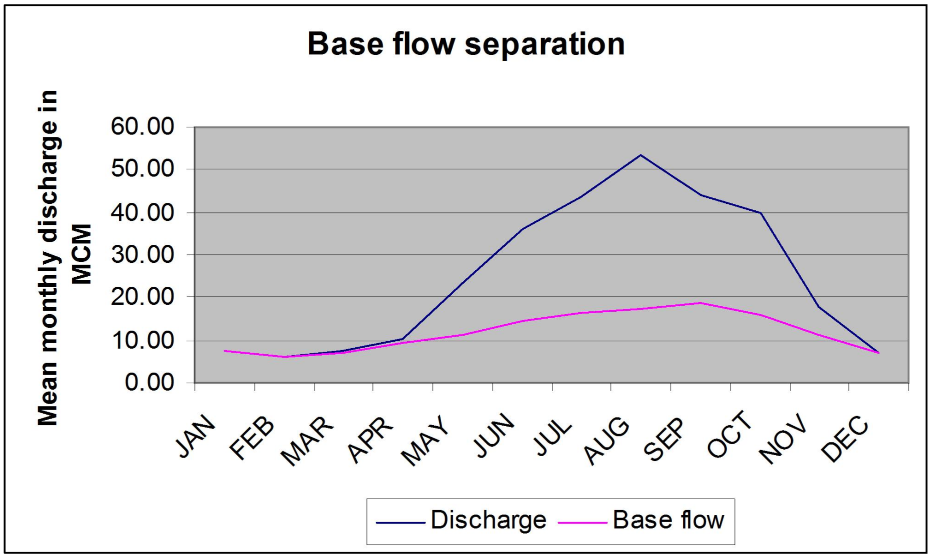

Figure 3.10 Base flow separation of Dincha River from hydrograph.

One of the methods of separating base flow from the total flow of Guma Catchment River is manually from the hydrograph. Therefore, base flow of the study area is obtained to be 104.3 MCM of the total flow 165.7 MCM and the annual runoff is 61.4 MCM per year.

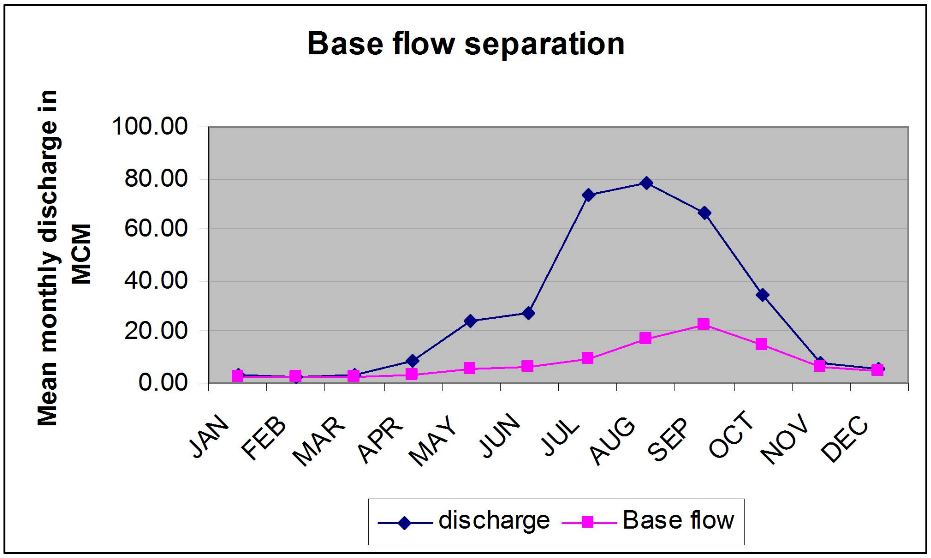

Figure 3.11 Base flow separation of Guma River from hydrograph.

Dincha river	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Ann.
discharge MCM	7.72	6.03	7.36	10.39	23.20	36.1	43.5	53.56	43.97	40.07	17.6	7.15	296.8
base flow MCM	7.60	6.03	7.20	9.40	11.20	14.4	16.5	17.30	18.70	15.80	11.2	7.15	142.5
SRO MCM	0.12	0	0.16	0.99	12.00	21.7	27.1	36.26	25.27	24.27	6.5	0.0	154.4

Table 3.17 Amount of base flow (MCM) of Dincha River from the hydrograph separation method.

Base flow from the total flow of Dincha River is manually from the hydrograph. Therefore, base flow of the study area is obtained to be 142.5 MCM of the total flow 296.8 MCM and the annual runoff is 154.4 MCM per year.

Guma river	JAN	FEB	MA	APR	MA	JUN	JUL	AUG	SEP	OCT	NO	DEC	Ann.
discharge MCM	2.92	1.99	2.9	8.3	24.5	27.0	73.7	78.51	66.1	34.3	7.5	5.6	333.4
base flow MCM	2.56	1.99	2.6	3.4	5.8	6.6	9.6	17.30	22.4	14.5	6.1	4.3	97.17
SRO MCM	0.36	0.00	0.4	4.8	18.7	20.4	64.2	61.21	43.7	19.7	1.4	1.3	236.3

Table 3.18 Amount of base flow (MCM) of Guma River from the hydrograph separation method.

Accordingly the result shows that 239.65 MCM is the total base flow and 435.79 MCM is the total runoff of the study area obtained from the above three components (Table3.19).

3.11 Water balance method

The range of recharge rates that can be estimated by different techniques varies and determines, in part, which technique to apply. The reliability of the recharge estimates is also quite variable The water balance represents the hydrological gains and losses of a given system (reservoir, column of soil, aquifer, river basin, etc) over a specific period (Tenalem and Tamiru, 2001).

For this study the use of water-budget approach is selected because it is applicable in areas of humid climate. For natural catchment, measurement of the precipitation and river discharge may be made satisfactorily with some degree of precision. But the measurement of ground water movements into or out of the drainage area cannot be made easily .In this study of water balance, the catchment’s ground water inflow is assumed to be zero based on the detailed field observation around the water divide of the basin from Gojeb basin and Woshi river sub catchment. This condition made the evaluation relatively simple in avoiding the subsurface and surface movement of water across the defined watershed boundary. There fore, water balance of the basin is represented by the general equation.

Inflow=Out flow + change in storage

Here, the inflow includes precipitation and ground water inflow where as the out flow includes surface runoff, ground water out flow, Evapotranspiration and change in storage. The general water balance equation is;

$$P + Gi = AET + TRO + GOF \pm \Delta s$$

Then finally, the study area will have a water balance equation of:

$$\Delta S = P - AET - TRO - GOF \quad \text{in mcm}$$

Where; P=Precipitation, Gi =ground water inflow = 0, AET= actual Evapotranspiration, TRO=Total surface run off, GOF=Groundwater out flow from the catchment and ΔS = Change in storage, the values of all of these components are clearly indicated in (table3.19)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annl.
P(mcm)	43.14	44.63	97.10	151.55	176.69	186.15	183.96	222.99	164.03	112.79	52.17	51.43	1476.63
ET(mcm)	52.12	53.96	73.3	63.6	57.7	52.9	51.5	51.6	61.7	60	61.4	60.9	700.68
TRO(mcm)	1.79	1.36	3.48	10.47	36.10	47.83	96.83	104.23	73.93	47.43	9.47	2.87	435.79
GOF(mcm)	10.16	8.02	9.80	12.80	17.00	21.00	26.10	34.60	41.10	30.32	17.30	11.45	239.65
ΔS=P-ET-TRO-GOF	-20.93	-18.71	10.52	64.68	65.89	64.43	9.26	32.56	-12.2	-24.96	-36	-23.79	110.751

Table 3.19 Long terms mean monthly water balance result of Upper Guma sub-Catchment (MCM)

There fore, the amount of recharge in Upper Guma Sub-Catchment basin is calculated not to be greater than 10 percent of the total precipitation in the area indicating that the over all groundwater potential except the identified well field is not of potential groundwater availability. The results of this set of calculations are portrayed in table 4.5 which summarizes a great deal of information on the hydrology of the area. Besides showing the seasonal pattern of precipitation, evapotranspiration, and runoff, it indicates the time of moisture recharge, and moisture surplus. The water balance is therefore valuable for understanding the ecology, agronomy, and economics of growing crops.

CHAPTER 4

GEOLOGY

4.1 Regional Geology

Broadly speaking the geology of the Omo Gibe Basin is characterized by Tertiary and quaternary age rhyolite and basalt volcanics in the North and middle part of the Basin with quaternary alluvial overlying pre-Cambrian basement gneisses and granites in the south.

The pre-Cambrian rocks crop out only in the southern part oft the Omo-Gibe Basin; where as Tertiary Volcanics extend throughout the basin.

The Omo- Gibe Basin area was a continental land mass during Paleozoic and Mesozoic times and major part of the basin is underline by Tertiary volcanic rocks which have been sub-divided in to four groups

1-Early Flood Basalt

2-Lower Felsic volcanics and sediments comprising basaltic, andesitic and more felsic lavas. This formation contains a sequence of coal, lignite, and oil shell deposits interbeded with volcanics, which is up to 300m thick, and is found scattered in several parts of the central basin.

3-Upper Felsic Volcanics-includes thick rhyolites, trachytes, and felsic ignimbrites, up to 2000m thick.

Where these volcanics have been eroded, the central intrusive core often remains as a prominent conical hill or plug.

4 – Nazareth Group-comprises a series of rhyolite trachyte plugs, flows, ignimbrites and other payroclsts, as well as some lacustrine sediments containg coal and lignite deposits.

According to Dereje Ayalew, Gezahegn Yirgu, and RaphaelPik, Journal of African Earth Science Volume 381,on characteristics of volcanic rocks from south western Ethiopia ,

The Ethiopian Continental Flood Basalt (CFB) province is one of the youngest (30 MYS) large igneous province (LIP), covering an area of at least 600,000km^2(Mohr and Zanettin, 1988), associated with continental break- up and ocean basin formation. The mantle plume contribution to the magmatism was already registered in the pri-rift basalts from Northern Ethiopia plateau.

According to Mohr (1964) the volcanic succession of south-western part of the country is divided in to Ashangi group, being of Eocene to Miocene age, forming the trap series and younger Megdela group being of Miocene to Pleistocene age. Jima volcanics was named by Merla etal.(1973) to trachybasalts and rhyolites which cover most part of southwestern Ethiopia. Davdsen (1983) has reported K/Ar Age of 42.7 to 30 Ma for the Jima volcanics.Two units (Jima Basalt- pjb and Jima Rhyolite- pjr) which shows conformable relashinship were identfide.The Jima Rhyolite being the younger of the two units in south west Ethiopia are equvallent to the Megdela group.The basalt flows form unbroken succession several hundred meters thick in some places,and in others felsic rocks are interculated with basalt flow closer to the base or form a thick succession just above the basal basalts.

4.2 Geology of the study area

The steep escarpment of the volcanic landscape characterizing the area is the result of structural/faulting effects while gentle to steep slopes and the flat alluvial/marshy plains at the bottom of the valleys are due to denudational and depositional process. The geology of the study area consists of volcanics constituting acidic and basic rocks such as rhyolite, tuffs, agglomerates and basalts. The gentle to steep sloping parts of the region are covered by in-situ derived compact clayey soils. Alluvial deposits exist along the channels of the rivers particularly adjacent to the town of Bonga. The alluvial and colluvial deposits are the derivation of local geology through weathering and transportation by erosion.

4.2.1 Lithologic description

In general the geology of the area can be categorized in to 3 main rock units (Fig.4.1). These units are

1. Basalt
2. Rhyolite and trachyte
3. River bed deposits

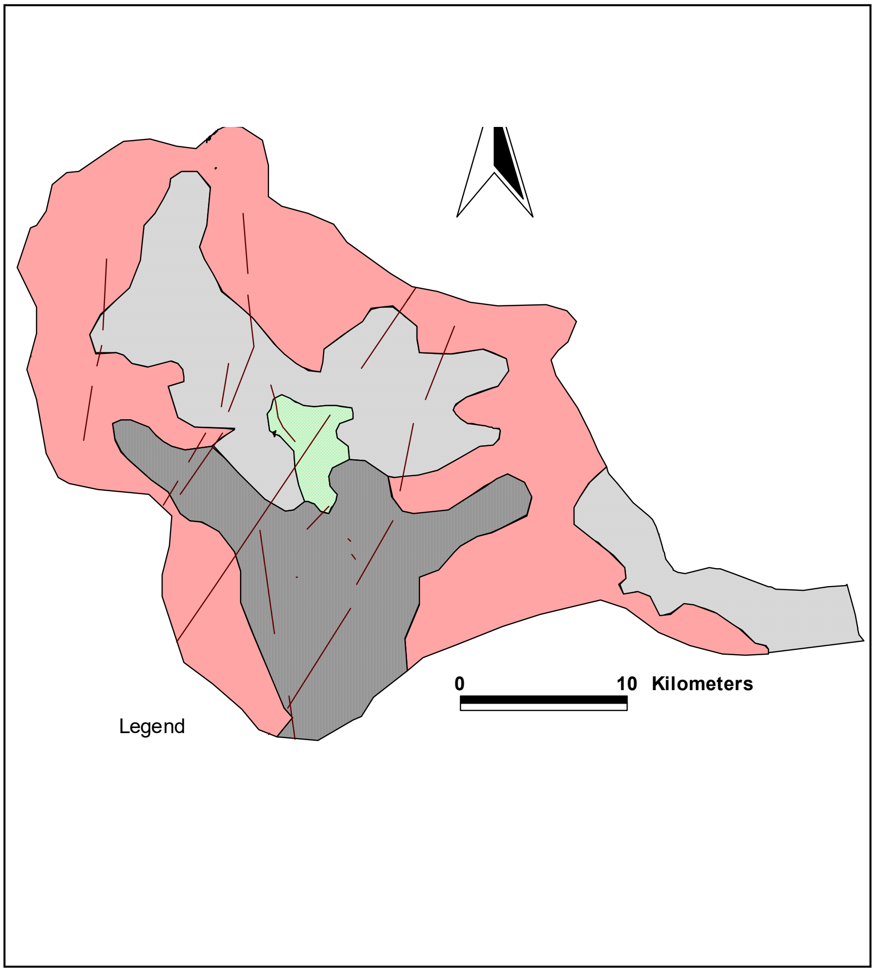

Figure 4.1 Geological map of Upper Guma Sub- Catchment

4.2.2 The Basalt unit

The Basalt rock units are the second dominant formation in the basin with different degree of weathering that has been resulted due to the prevailing wet climate which has no significant variation from place to place with in the study area. The high land area around south east of Wushwush town and the northeastern parts have weathered and fractured basalts including those from the western parts of the study area, and the second sub type of basalt outcrops in the southern part of Bonga with very thick fine grained basalt of an average thickness of about 50m can be observed in Gedam and its surrounding and sometimes with columnar structure and in places covered by highly jointed basalts. It is highly jointed and boulder type which is serving as a good building stone source for Bonga and the surrounding towns. It is there exposed in almost all of the lower elevations where stream banks crosses and immediately below or at the foot of high land areas. (Plate.4.1). Highly weathered and friable basalt of the same group of basalt is common in the basin especially northern and north eastern part of it. This formation covers relatively smaller area of the basin as compared to the former one. This rock unit is sensitive to erosion due to its topographic situation and its degree of weathering (Plate 4.2).

4.2.3 Fresh to slightly weathered rhyolite and fine and course grained tuff

All these formations are the result of acidic volcanic rocks which almost in all cases rests over the basalt in the study area with the thickest exposure immediately by sides of the road at quarry sites. Fresh rhyolite formation occurs in most of the area after some excavation to remove weathered and altered materials at the elevated surroundings of the area. The degree of compaction of this unit varies from place to place with highly compacted being just above the basaltic unit. Volcanic tuff is common in Bonga area as exposed formations are with high degree of weathering. The aerial coverage of this geologic unit is extensive as compared to the other units. This rock unit is also sub- divided in to tow as weathered and fresh/un weathered rhyolitic units.

4.2.4. River bed deposits

River courses in any basin are filled with different size alluvial materials, which shows or express the nature of the basin along which they travel and degree of erosion. All the river which starts from the tope of Wushwush, Diri, and Mera areas flows with high sediment load. Along the course of the river there are three types of river beds (the silty sand, the sandy gravel, and gravel and pebbles with boulders).In the study area it is the middle part of the rivers coarse around Bonga town which covers most of the flat area occupied with silt and sand soils. Next to this formation as one goes up stream the sandy gravel soil type will take the dominancy and then followed by gravel, pebble and boulders as the river course starts to elevate. An extensive clay soil up on which marsh areas developed cover in the northeastern part of the study area.

Plate.4.1 Flow of Dincha River in its lower course and deposition along river course (alluvial deposit).

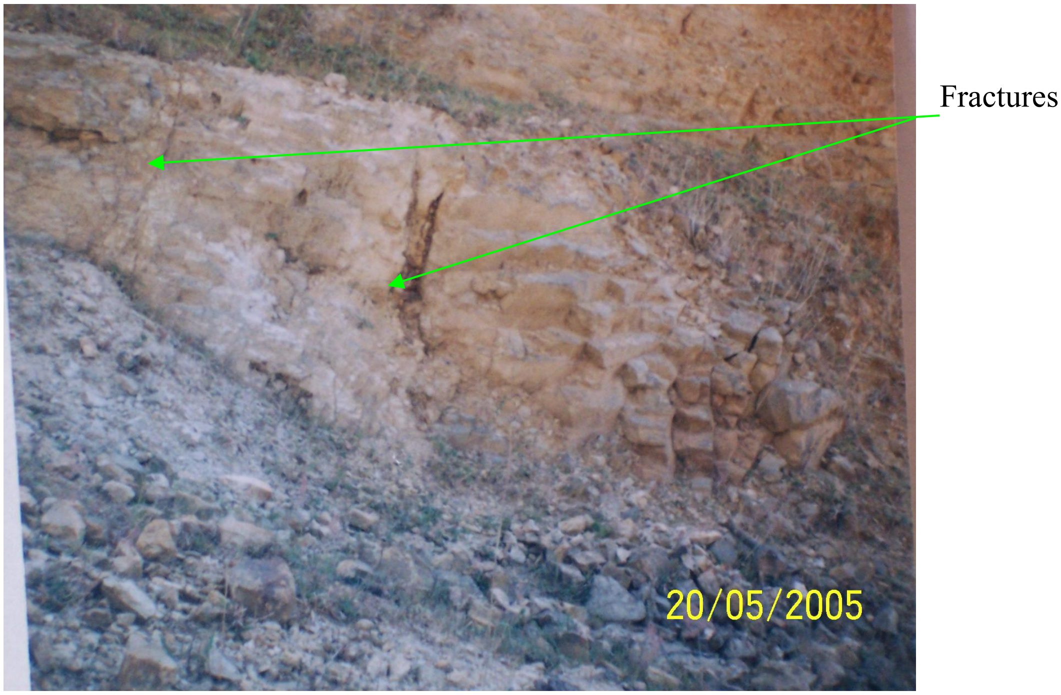

Plate.4.2 fractured and weathered rhyolite

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Plate 4.4 Unweathered rhyolite unit being exposed at the quarry site

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Plate 4.4 weathered rhyolite and columnar basalt exposed at the water fall cliff.

Plate 4 .5 contact between over-ling rhyolite and under-lying fresh basalt

Plate 4.6 Dry season flow of Dincha River at its gauging station.

4.2.5 Geologic structures

Identification of geologic structures is useful for any structure controlled phenomenon along which mineralization, ground water accumulation and emanating hydrothermal springs etc are prominently determined. However, unless it is studied in detail or detected properly, it may cause negative impact on the developmental activities such as construction of buildings, dams, etc.

The cause for geological structures are deep tectonic activities either regionally or locally which can change the morphology of the earth through time .In the study area different structures cross the basin with different orientations.

Aerial photographs studies and filed observations have revealed that faults, fractures and joints characterize the area. The general trend of the fault in the area is NE-SW and NW-SE direction. The vertical fault escarpment forming the water fall on the upstream stretches of the Barta river at about three km from the town is prominent fault structure. The continuation of this fault system has been observed to have reached the area of Sobra spring site and is inferred to further extend to the valley of Dincha river .There are also other minor fault/fracture systems in the area. The drainage system of the area is structurally controlled (Figure 4.1).

CHAPTER 5

HYDROGEOLOGY

General

The study of water in the earth which deals with the occurrence, distribution, and movement of water in addition to physical as well as chemical relation-ships with the surrounding environments defines hydrogeology (Sen., 1995).

The most important advances in hydrogeology to day have been stimulated by studies designed to solve problems of great economic importance. This trend will probably continue as the demand for water will undoubtedly increases with growing population and industrialization, so that the subject matter will be helping for water resource estimation, to assess water pollution risk for safe land use allocation and understanding of surface and ground water interaction conditions. Therefore, in this chapter the hydrogeologic condition affecting surface and ground water interaction in the study area will be discussed by starting with descriptions of the hydrogeological units.

5.1 Aquifer Characterization

Characterization of hydrogeological units of the area needs to describe and evaluate the contribution of many physical parameters such as soil cover, morphology, geology and rainfall, runoff, and evapotranspiration relationships. The geologic zones important to groundwater must be identified as well as their structure in terms of water holding and water yielding capabilities (Todd, 1980).

In the study area data from springs, hand dug wells, boreholes, and geological features and associated structures in combination with the above parameters are used for the description of different hydrogeologic units in the area. Different geological settings of the area which ranges from recent quaternary deposits comprise of alluvial, colluvial and residual deposits to Tertiary volcanics comprise of acidic and basic rocks (tuff and basalt). Many hand-dug wells, several springs, shallow boreholes and seven deep boreholes are inventoried from different formations and accordingly the following water bearing characteristics of rocks are identified.

Ground water occurrence in the area is governed by several factors such as rainfall, geology/thickness of aquifer material, topography, rate of evapotranspiration and possibility of ground water recharge etc. As can be noticed from the geological and hydrogeological descriptions of the major formations in the area the alluvial, colluvial deposits which have limited thickness, form only high to moderate productive shallow aquifer systems .These are being utilized through hand dug wells and low yielding springs at the slope breaks and in some localities combined with the top, highly weathered basalt/tuff formation. Significant quantities of groundwater exists at depth within the scoria and fractured rhyolite and basalt formations. These can be tapped for town water supply through deep wells. Therefore, the study area is characterized by three hydrogeologic units (Figure 5.1)

5.1.1 Highly permeable formation

This hydrogeologic unit of the area consists of the Quaternary sediments which are composed of gravel, sand, clay and silt mixture in various proportions and this type of formation is found at the lower elevation of the basin along Dincha and Sheta rivers. This is totally alluvial and colluvial deposits characterized by high permeability, porosity, and Transmisivity. In this part of the study area springs are observed emerging out of quaternary sediments at hill breaks, contacts between alluvial deposits and underlining weathered basalt and old landslide deposit. The discharge of the springs ranges from 0.1to 0.5 l/s do not dry through out the year. As different borehole logs show and alluvial deposit is the result of weathering of basalt which starts with moderately weathered and then decreases with depth.

This area is in the surroundings of Bonga town where the area is topographically controlled with a feature of incised narrow stretches of valleys between the adjacent hills. These geomorphological conditions combined with other hydrogeological factors govern the occurrence of deep groundwater in these valleys. Adjacent to the town significant groundwater in the locality is anticipated to be stored mainly within the scoria formation as well as weathered and fractured volcanic rocks (rhyolite and basalt) as has been revealed by wells drilled in the area. The area occupied by this formation is hydraulically interconnected with the surrounding rock formation in that the scoria revealed to exist underground has important properties from a hydrogeological point of view, due to its high porosity and permeability which make it a promising formation for groundwater occurrence. Groundwater recharge from the surrounding recharge areas could be stored and transmitted within this formation with the capacity to release significant water to wells. This condition is clearly evidenced by the presence of productive wells with a yield of greater than 6 l/s and a total draw-down of only 2.5 m, from the saturated thickness of 22m. Pump test from Dincha bore hole (in the same formation) after through development a continuous pump test at a rate of 7 l/s for a period of 68 hrs and the well has a dynamic water level of 6.36m with a total drawdown of only 3.86m below ground level. The tranmissivity of the well is determined to be about 1.69 X 10^{-3} m^2/s and has a specific capacity of 8.31 X 10^{-2} l/s/m. From ground water storage and releasing capability or in general ground water potential assessment point of view the area is the best zone with in the basin. Within this hydrogeologic unit the roll of geologic structures is significant that, care should be taken to minimize the probability of losing a well drilled in this area.

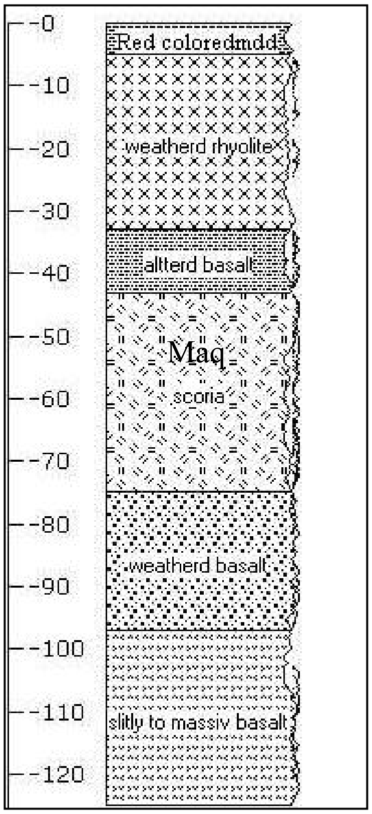


Figure 5.1 Dincha bore well lithologic log showing main aquifer (Maq) in the highly permeable formation

5.1.2- Moderately permeable formation

The second type of aquifer is characterized by its Moderate permeability, with intermediate storage, porosity and transmissivity. This formation is situated by major within weathered and fractured basalt and rhyolite rock unit with associated peripheral extensions (Figure 5.1).

Compositionally this formation is made up of jointed basalt with big boulders, intercalated with rhyolite. As newly developed deep bore well at Wushwush and shallow wells around Diri show that, volcanic ash material and basalt are the main aquifers for the described area which is north western and north eastern part of the basin. Springs of moderate yields are also common in this formation. From potential assessment, this formation is characterized as a site for ground water potential for the surrounding areas.

From the bore holes drilled in this rock, and field observation, it is possible to infer that permeability is moderate to low and wells have yields not greater than 3-4 l/s since the effect of weathering is moderate.

Compositionally, it is basalt intercalated with rhyolite which is exposed mainly on rugged and hill side of the topography. Their degree of weathering is decreased immediately with depth which plays a great role for the accumulation of ground water. In the plain area, the depth of such formation is not greater than 10 meter followed by slightly weathered basalt flow. From hydrogeological point of view, though the surface rock formation is highly weathered and permeable, unless it has a good depth, sufficient amount of groundwater may not be stored enormously. Boreholes in such formation are productive not anywhere in this area but on fault or fracture lines which might have deeply fractured formation favoring ground water circulation. This can be evidenced by the abounded and the newly developed Wushwush boreholes. Even though, it is out of the catchment, the newly drilled shallow deep wells around Diri in Shomba village, represents such formation. Because of the thin layer of the weathered basalt, the yield does not increase with depth of greater than100 meter. Hand dug wells and shallow drilled wells are more productive than bore holes from economical point of view.

5.1.3 Low permeable formation

Slightly weathered to non weathered basalt and rhyolite formations have low permeability to impermeable formation. This formation is characterized by massive basalt and rhyolite non-fractured and exposed on the surface. Extreme surface runoff is favored on this formation by prohibiting rainwater entrance into the ground (infiltration). Hand dug wells are not productive in such formation unless perched aquifers (Localized alluvial deposits) are obtained. This type of rock is mainly found on the top of the resistive mountains and near the water divide of basin. This formation is very difficult and risky for groundwater resource and is exemplified by Gimbo well with well yield of less than 2 l/s. Therefore, it needs special attention in identifying fracture traces crossing this area (from aerial photograph, satellite image etc) and contribution of associated catchment aerial coverage. Hence the area covered by such unit is very poor zone of groundwater potential.

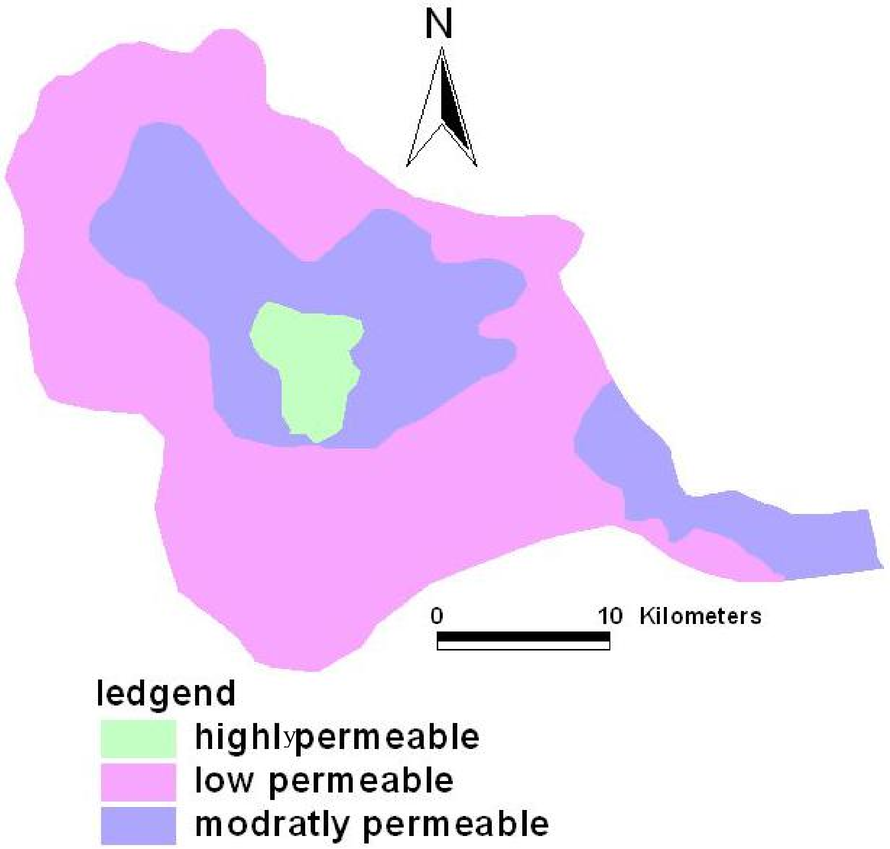


Figure 5.2 Hydrogeological map of Upper Guma Sub Catchment.

5.2 Recharge and discharge zone

Recharge of ground water depends on many factors, such as permeability of the formation, depth to water table, vegetation and slope. The major source of ground water recharge in the area is rainfall. The rainfall in the area is about 1686mm/year, which implies good potential for ground water recharge of the area.

Recharge area is usually in topographically high places where as discharge areas are located in topographic lows. In the recharge areas there is often a rather deep unsaturated zone between the water table and the land surface. Conversely, the water table is found either close to or at the land surface in discharge areas. There may be physical manifestation of the discharging ground water, which can take the form of springs, or stream and water indicator vegetations (Fetter, 1994).

Therefore, the main recharge areas for the study area are the high land areas of Wushwush, Sobra, areas and high lands in between Diri Gimbo and Bonga and its surrounding, connected ridges of northern part of the basin and eastern high lands along the Sobra - Mera ridge. Perennial rivers start from these topographically elevated areas and flows down to join the main Guma River.

The dense vegetation around the town area on the slopes, combined with the isolated patches of farmlands over the gentle slopes, helps to intercept surface runoff and favors ground water recharge. Around Bonga town area there are many springs and hand dug wells as manifestations of groundwater discharge from the shallow aquifers.

Discharge areas are those areas, which are mostly at the foot of mountainous area which are manifested by the presence of springs at the contact of the elevated and the low land areas. Therefore, alluvial deposit covered area is the main discharge zone of the basin. Therefore, in the study area highly weathered, friable and highly jointed with big boulder rock formation in elevated area is the recharge zone and the alluvial and colluvial deposits in the low land areas are the discharge area for the basin.

5.3 Productive well fields

Wells of high productivity are restricted in areas of the potential groundwater recourses around and with in the town of Bonga. There are three boreholes which are drilled for water supply, out of which Sheta well drilled in 1980 to a depth of 65m with a reported yield of 6.3 l/s with drawdown 5m, from the indicative observation made on the well, and attempts made to inspect the current condition of the well, with already installed pump positioned at a depth of 32m and over a period of pumping, the pumping rate has been noticed to have fluctuations between 2.5l/s during pumping to high pressure zone areas and about 6 l/s for low pressure zones. In general, it is noticed that the well has characteristics of low drawdown and fast recovery. The second borehole drilled in the compound of skill development center to depth of 120m in 1987(E.C), and the result was failure to gate water probably due to the existence of the geologic structure controlling the underground water movement in that particular area .

The third well in this area is in Dincha area drilled to a depth of 118m through clays and volcanic rocks in year 2000 and it has not been connected to the water supply system.

The maximum yield obtained is 7 l/s in this well field area. The above results indicate that the well field has an additional potential compared to its allowable drawdown. From the relationship that exists between the specific capacity of the well and its transmisivity, a pumping rate of about 8.5 l/s may be considered for design purpose for this well.

The overlying Quaternary sediments described as alluvium, and colluvium composed of gravel, sand, clay and silt mixtures in various proportions, underline by highly weathered and jointed part of the basalt formation with characteristics of moderate to high permeability and this unit exists being intercalated with the scoria revealed from drill logs clearly describing the hydrostratigraphic units of this well field. It can be generalized from ground water potential assessment point of view; the subsurface lithologies are promising to hold as well as to transmit water to the well and are grouped with in the high productive well field. The main recharge for this region is directly from precipitation and the surrounding elevated areas.

Water supply wells of Shomba, Gimbo and Wushwush areas are located closer at water divide and are moderately productive well fields so that wells get dried before their design periods. These well fields are mainly found in the areas of weathered and friable basaltic and rhyolite terrain with shallow depth. The degree of weathering as described in the previous section is shallow and is mainly dominates the undulating and rolling ridges with rugged topography. Boreholes in such formation are commonly sited on local fracture zone or depressional area where shallow ground water from the recharge area can be obtained easily. Due to the shallow nature of weathering, yields from bore holes are very small and are not promising for significant water to satisfy the need for highly populated area. As it is observed from the pump test analysis drilled for Wushwush and Gimbo towns.

5.4 Hand dug wells

Major part of the area is capable of exploiting hand dug wells due to recharges obtained from the available intense precipitation. From hydrogeological point of view, the presence of such productive hand dug wells in the basin gives a clue to the depth of ground water to be shallow.

5.5 Springs

There are many springs in the study area serving the community as a supplementary and main water supply sources. Most of them are capped. Spring is a concentrated discharge of ground water appearing at the ground surface as a current of flowing water (Todd, 1980). Springs can be classified in a number of ways based on magnitude of discharge, type of aquifer, chemical characteristics, water temperature, direction of water migration, relation to topography, and geologic structure. Bryan divvied springs into two categories.

1) Those resulting from non-gravitational forces and
2) Those resulting from gravitational forces.

Under the former category volcanic springs, associated with volcanic rocks and fissured springs, resulting from fractures extending to great depth in the earth's crust(thermal springs) where as gravity springs result from water flowing under hydrostatic pressure. Based on the above method of classification, the 3 types of springs are common in the study area. Depressional springs, contact springs and impervious rock fracture springs are the common types with various discharges according to the recharge area size and aquifer permeability. Depressional springs are the most common type in the basin (figure 5.3).

5.6 Ground water flow direction

As part of the hydrologic cycle, groundwater is in continuous movement from a recharge to a discharge area in accordance with laws governing water flow in lithosphere. The laws give the rate of energy loss against resistance from the flow medium(Sen, 1995). Therefore, the flow of water is governed by the known law called Darcy's law. The law states that 'the flow rate through porous media is proportional to the head loss and inversely proportional to the length of the flow path (Todd, 1980)

Local ground water flow is different from regional ground water flow in that, the local flow direction varies with in small areas according to the topographic effect at shallow depth and the regional ground water flow has general direction of flow at depth. The local ground water flow in this area supports the regional flow as evidenced by the ground water contour from hand dug wells and the presence of many springs following the topography. As can be observed in the water table contours, local flows have general directions of flow towards the low lands in the surroundings and finally the main (regional) flow is mainly towards central and south west part of the study area.

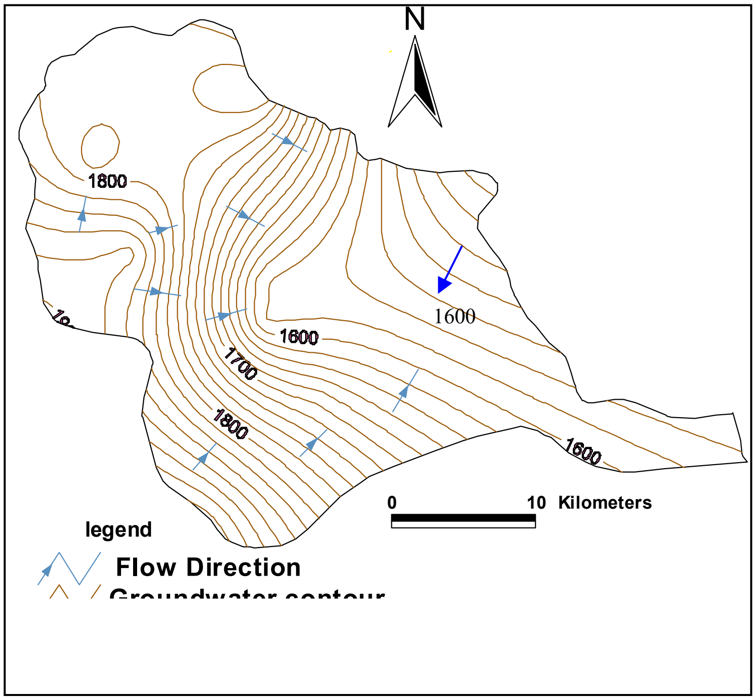


Figure 5.2 Groundwater flow direction contour map

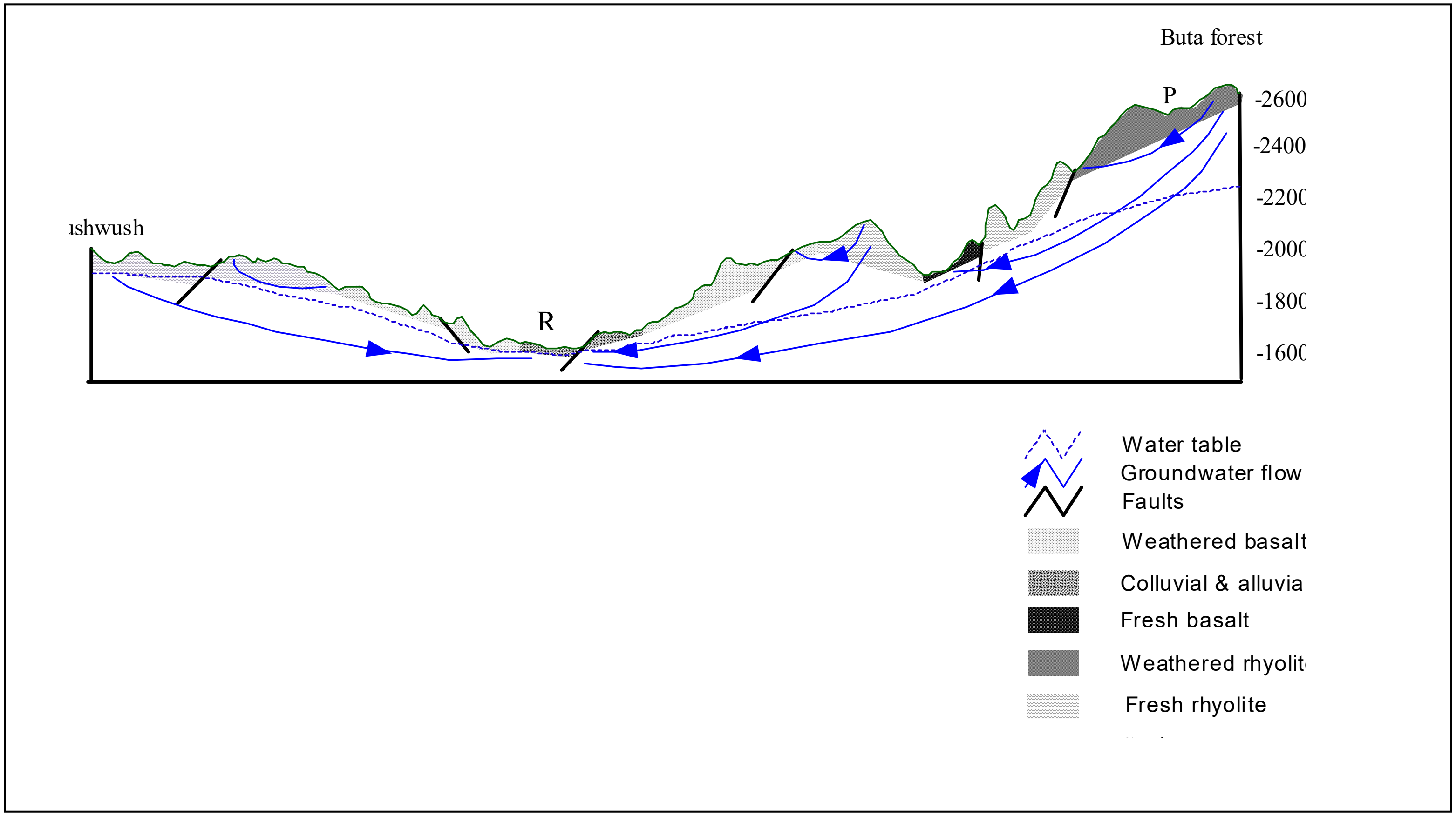


Figure 5.3 Coceptual model for regional and local groundwater flow system of the area (R-river, P-precipitation)

CHAPTER 6

HYDROCHEMISTRY

6.1 GENERAL

Investigation of the quality of water is the most important factor to be conducted depending on the purpose it is required. Thus, needs for establishing quality criteria for drinking water, industrial, and irrigation water varies widely. To establish these criteria measurements of chemical, physical, biological and radiological constituents must be specified, as well as standard methods for reporting and comparing results of water analyses must be adopted. Freeze and Cherry(1979) had described also the effect of geochemical processes on natural water in that, as groundwater moves along flow lines from recharge to discharge areas, its chemistry is altered by the effects of a variety of geochemical processes.

6.2 water sampling and analysis

For this study samples from rivers, springs, shallow and deep wells were collected and analyzed in the laboratory of Water resources of SNNPRS (Awassa). The extent to which small samples may be considered to be representative of a large volume of material depends on several factors such as the homogeneity of the material being sampled and the number of samples, the manner of collection and the size of the individual sample (Hem, 1992). During dry season a total number of 20 water samples were collected and their field parameters were measured. Na^+, and trace elements were not analyzed in these samples because of the lack of laboratory equipments and reagents in the water bureau. But Na^+ is calculated by ionic balance method and was confirmed by data from previous hydrochemical data of the area. From the above samples chemical analysis were done for 10 water samples (bore hole=5, spring=3, and river =2). Samples in the nearby area were also analyzed to see the variation in the basin and its surrounding having the same climate and geology. Important field parameters such as pH, Eh, Ec, and temperature were measured using pH and conductivity meters and taking their geographical location were performed using the GARMIN GPS. Complete chemical analyses for major ions of some of the samples have been done during water scheme drilling and construction in the area by

Addis Ababa Water Supply and Sewerage Authority (AWSSA) and are used in this analysis.

6.3 Reaction error

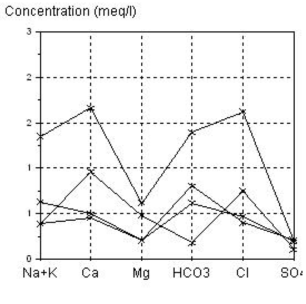
The techniques that the laboratory follows and the result must be checked for its accuracy before classification is done. Solutes present in concentration above 100mg/l generally can be determined with an accuracy of better than ±5 percent. For solutes present in concentration below 1mg/l, the accuracy is not generally better than±5 to 10 percent and can be poorer (Hem, 1992). Thus the reaction error can be determined as follows;

$$\text{Reaction error} = \frac{\sum cations - \sum anions}{\sum ions}$$

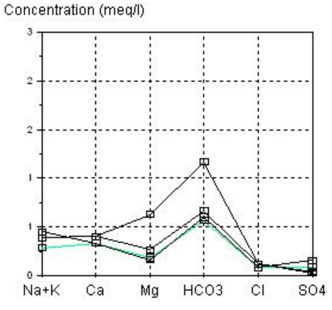
Therefore, the laboratory result has a range of reaction error from 0.2 to 3.6 % reaction error which is in the limit of accepted range, not greater than five percent.

6.3.1 water type classification

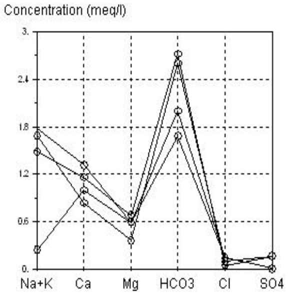
Total dissolved solid include all solid materials in solution, in ionized or non ionized form. As it is related to the sum of the concentration of all ions, it is directly related to the electrical conductivity. TDS of natural water range from less than 10ppm of dissolved solids for rain and snow, to more than 300,000ppm for some brine (Tenalem and Tamiru, 2001). Thus, the water type obtained in the basin according to their TDS value fall in fresh water, with total dissolved values in the range of 0-1000 (Freeze and Cherry, 1979).Total dissolved solids vary spatially with a general trend of increasing from high land to low land. Water samples from the bore well, hand dug, springs and river sources have an average TDS of 140, 119.5, 67 and 52 mg/l respectively



HW



rivers and springs



BW

Figure 7.1 Schoeller diagram showing dominant species of ions in water samples taken from bore wells (BH), hand dug wells (H.W) and rivers and springs.

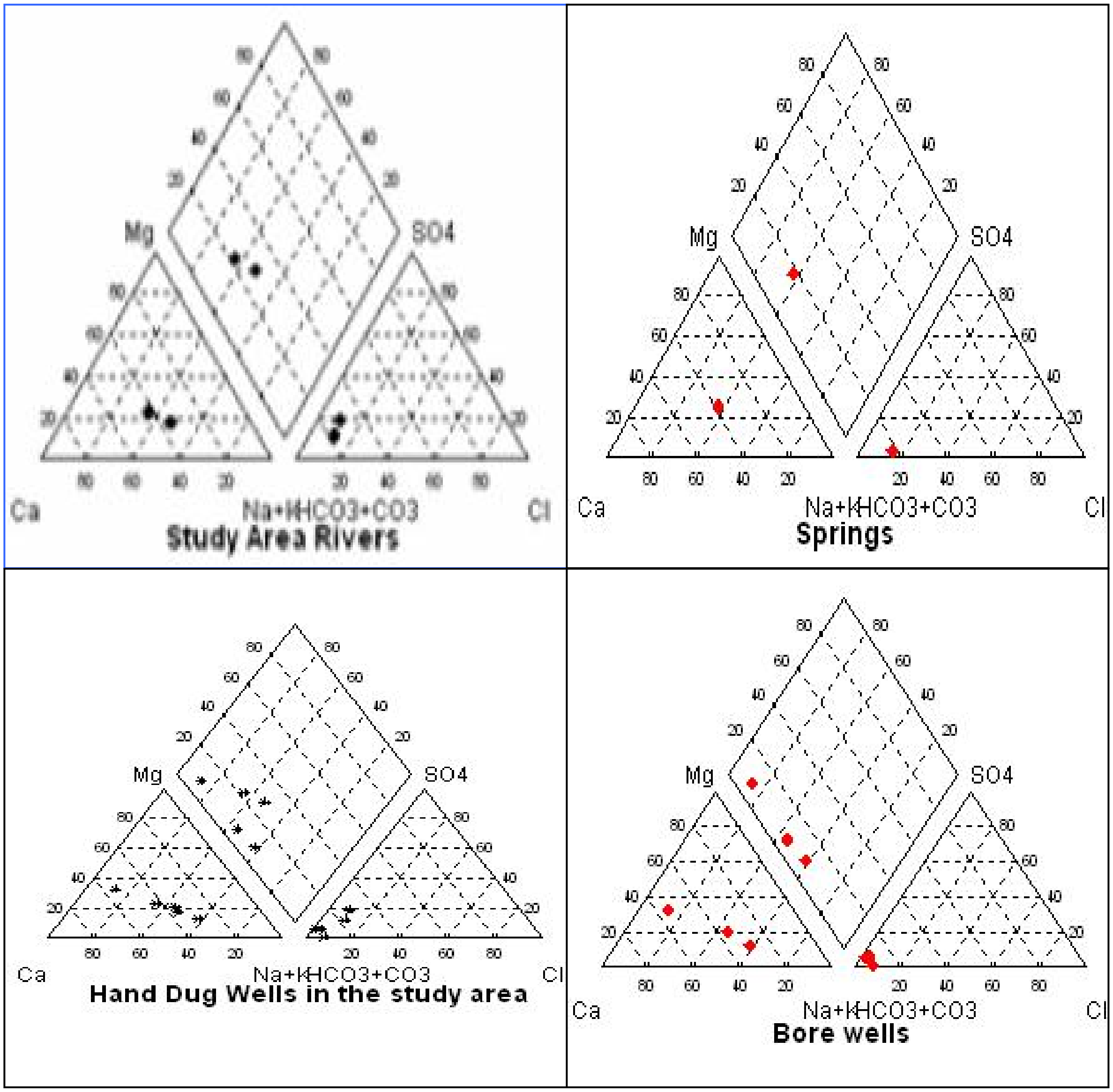


Figure 7.1 piper tri-linear plots of different water sources

Classification of water types in the area according to the tri-linear piper diagram plots (figure 7.2) show that, most of the hand dug wells are Ca-Na-HCO_3 and Ca-Mg-Cl water type where as, springs are Ca-Na-HCO_3 and Ca-Mg-HCO_3 water type**.** The borehole results have a water type of Ca-Mg-HCO_3 and Na-Ca-HCO_3 which signifies the dominancy of volcanic terrain. Schoeller diagram in(Figure 6.1) depicts the dominant ion type in specified water sources here the principal ionic concentrations, expressed in milliequvallents per liter, are polted on six equally spaced logarithmic scales in the arrangement shown.

6.3.2 Classification based on total hardness

Hardness results from the presence of divalent metallic cations, of which calcium and magnesium are the most abundant in ground water these ions react with soap to form precipitates and with certain anions present in the water to form scale (Todd, 1980).

Total hardness (H_T) is customarily expressed as the equivalent of calcium carbonate.

Thus: $$H_T = Ca \text{ X } \frac{CaCO_3}{Ca} + Mg \text{ X } \frac{CaCO3}{Mg}$$

Where H_T, Ca and Mg are measured in mg/l. The ratios in equivalent weight are given by: $H_T = 2.5\ Ca + 4.1 Mg$.

Hardness in mg/l as $CaCO_3$	Water classes	Total Hardness in mg/l as $CaCO_3$ of the study area
0__75	Soft	58-BH2,30-River and spring
75__150	Moderately hard	94 –BH1,
150__300	Hard	174 – Shomba shallow well
>300	Very hard	

Table6.1 Hardness classification of water (After Sawyer and McCarty), Todd (1980).

Based on the above, the water type in the study area is grouped as soft water, moderately hard water, and hard water.

6.4. Chemical behavior of water sources

6.4.1. Bore holes

Due to chemical and biochemical interaction between ground water and the geological materials through which it flows, and to a lesser extent because of contributions from the atmosphere and subsurface water bodies, ground water contains a wide variety of dissolved in organic chemical constituents in various concentrations (Freeze and Cherry,1979).

Major ions	Na	K	Ca	Mg	HCO3	Cl	SO4
Borehole (BH) 1	30	7	30	8.16	151.3	3.48	6.4
BH 2	35	6	17	4.38	158	3.48	5.5
BH3	17	3	20	7.2	102.7	1.5	0.5
HD W 1	6	19.2	12	3	59	17	12
HD W 2	7	6.2	11	3	45	20	11
HD W 3	26	19	40	9	102	69	11
HD W4	5	5.2	9	2	35	9	9
HD W 5	9	3	23	7	13	32	6
Spring Sobra	6	4	8.5	5.4	66	3.8	0.82
River Dincha	6	3	6.8	2.43	38.3	2	0.8

BH1=Sheta well, BH2=Uniceff well, BH3= Wongi well; HD=hand dug well.

Table6.2 Major anions and cations in different water sources

Sodium is a major constituent of igneous rocks such as in plagioclase and it is liberated during the weathering these silicates and the distribution of these elements and the rate of its liberation are reflected in the quality of spring water. Potassium also occurs mostly in the potassium feldspars in igneous rocks. Calcium which is predominantly held in plagioclase feldspar again is released by weathering and incorporated in to ground water system, and in groundwater it is to be expected that with sufficient residence time underground, the calcium carbonate - carbon dioxide equilibrium in carbonate rich aquifer can be established (Weyl 1958). Because of the lower geochemical abundance of magnesium, its content in fresh water is generally below that of calcium. In the study area since the terrain is devoid of limestone the interaction of carbon dioxide and water in such area is responsible for the formation of various carbonate species and particularly for the bicarbonate ion dominancy in the water of wells, springs and rivers of the area.

6.4.2. Hand dug wells

Hand dug wells in the low land areas have higher TDS and Ec, than in the elevated area. Those hand dug wells cited on the pure basaltic terrain have high calcium and magnesium ions and those on the mixed tuff and weathered basalt have low calcium and magnesium ions. Generally, hand dug wells are dominated by calcium cation and bicarbonate anion followed by sodium cation and chloride and nitrate anion (Table 6.2). From the total ionic compositions, bicarbonate ions occupy the highest concentration proportion and followed by calcium (Table 6.2 and Fig.6.2).

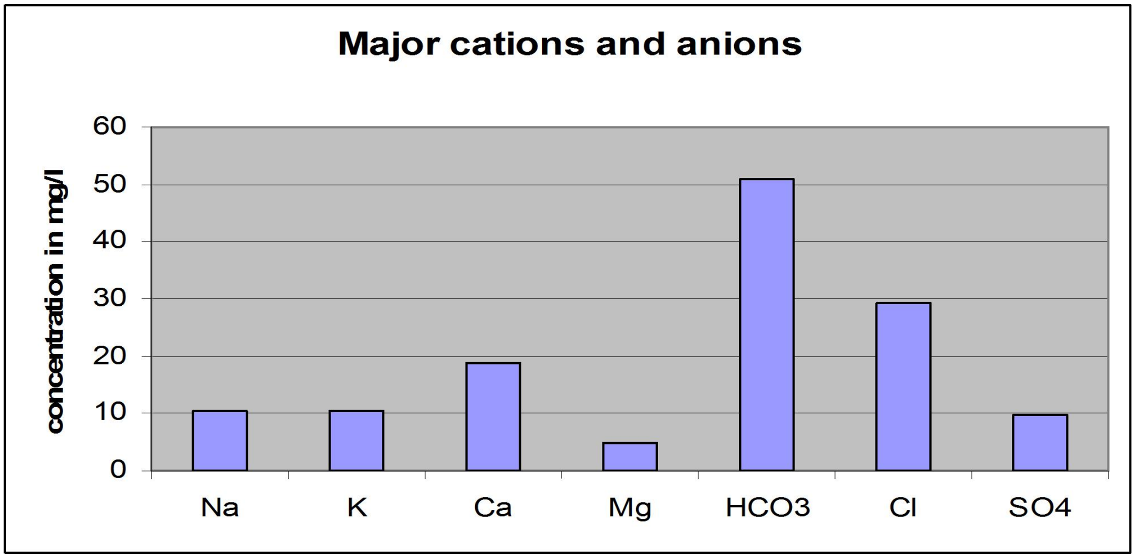


Figure 6.2 Major cation and anions from hand dug wells in the basin

6.4.3 Springs

Springs are dominant in the basin and have chemical analysis results which express the local geological and climate conditions in the basin. Their TDS value generally shows spatial variation of decreasing with increasing altitude. In all springs of the area dominant anion type is bicarbonate and cations, are dominated by calcium ion (Table 6.4).

6.4.4 Rivers

The flow of the tributaries of the main rivers starts from the high lands in the north eastern and western part and at the south east extreme of the basin. In some part of the basin they flow first on the mixed geological formations (intercalated tuff and basalt) which determine the geochemistry of the river. The major rivers in all over the flow paths, crosses pure basaltic formation and alluvial deposits.

The samples were taken at tow points (Barta water fall and at the immediate junction of Dincha and Guma rivers) along the main river. Total dissolved solids are increasing towards the low land. Chemical analysis is done for two of the samples. All major cations and anions increase with decreasing altitude along the river.

6.5. Water quality

The study of water chemistry gives important indication of the geologic history of the enclosing rocks, the velocity and direction of water movement, and the presence of hidden ore deposits (Davis, 1966). Accordingly, the subject of water analysis interpretation must often include some considerations of standards and tolerances that have been established for the intended use. To establish quality criteria, measures of chemical, physical, and biological, and radiological constituents must be specified, as well as standard methods for reporting and comparing results of water analysis (Todd, 1980). Based on major cations and anions, it is possible to show the general water quality for public supplies, irrigation and industry in the study area.

6.5.1. Quality of Water for public supply

The primary objective of water treatment and purification is to collect water from best available source and subject it to processing which will ensure water of good physical quality, free from unpleasant taste, or odor and containing nothing which might be detrimental to health (Punmia, etal, 1995).

The following important requirements of water quality for public supply are recommended by Punmia (1995).

- It should be colorless and sparkling clear. It must be free from solid insuspension and must not deposit sediment on standing.
- It should be of good test, free from odor, and it should be reasonably soft.

- It should be free from disease producing bacteria or organisms.
- It should be free from objectionable dissolved gasses, and
- It should be free from harmful salts.
- It should be free from objectionable minerals, such as iron, manganese, lead, arsenic, and other poisons metals.
- It should be free from radioactive substances such as radium, strontium etc.
- It should be reasonably free from phenolic compounds, chlorides, fluorides, and iodine.
- It should not lead to scale formation and should be non-corrosive.

Considering the evaluated chemistry of water the established goal of WHO and its member states is that “All people, whatever their stage of development and their social and economic conditions have the right to an adequate supply of safe drinking water.”

Ethiopia does not have national standards for drinking water, but recognizes the World Health Organization (WWO) standards as a target. Although, it is not easy to achieve these recommended standards. In general, the water quality of the sources investigated is good with only some hand dug wells and bore wells exceeding the WHO drinking water guidelines for some parameters measured.

The following standards are basically used as a guide line according to the WHO and commission of European communities (CEC) guidelines for drinking water (WHO, 1984; CEC, 1980) (Table6.3).

parameter	WHO Guidelines	CEC Standards		Result obtained			
		Guide	Max.Admis.Con.(MAC)	HDW	BH	SP	River
pH	6.5-8.5	6.5-8.5	Nm				
TDS (mg/l)	1000	Ng	1500	175	165	65	45
Calcium (mg/l)	Ns	100	Nm	14	30	8.5	6.8
Magnesium (mg/l)	Ns	30	50	5.6	8.16	5.4	2.4
Sodium (mg/l)	200	20	150	8.4	26	6	6
Potassium (mg/l)	Ns	10	12	7	6	4	3
Chloride(mg/l)	250	25	Nm	20	5	3.5	0.2
Sulphate(mg/l)	400	25	250	6	6	0.75	
Phosphate (mg/l)	ns	0.4	5	-	-	-	-
Ammonia (mg/l)	0.2	0.05	0.5	-	-	-	--
Nitrate (mg/l)	Ns	Ns	0.1				
Boron (mg/l)	Ns	1	Nm	-	-	-	-
Iron (mg/l)	0.3	0.05	0.2	-----	1.76	0.1	0.8
Manganese (mg/l)	0.1	0.02	0.5	-----	0.5	-----	0.7
Aluminum (mg/l)	0.2	0.05	0.5	---	-----	------	-----
Copper (mg/l)	1	0.1	Nm	-	-	-	-
Zinc (mg/l)	5	0.1	Nm	-	-	-	-
Fluoride(mg/l)	1.5	nm	Nm	-	-	-	-

MAC-maximum admissible concentration, NM-no maximum admissible concentration set, NS- no standard set

Table6.3 WHO and CEC standards for drinking water (WHO, 1984; CEC, 1980).

According to the above standards the water in the basin is suitable for drinking purpose since all the dissolved substances are in the limit of permissible range, except iron and Manganese which are beyond WHO standards. There are also other standards which are usefull for comparison and contain more comprehensive purpose of water for different applications such as industry, and irrigation. The bacteriological analysis of water for public supply should also be given due attention. Contaminated water may contain a host of microorganisms, due to which water born diseases may spread if water is not properly handled and treated before it is supplied for domestic use. Ground water may be contaminated due to improper disposal of liquid wastes, defective well construction and failure to seal the abandoned wells. Hence, the potablity of water from bacteriological activities is dependent on human being activities.

6.5.2. Water quality for irrigation

The suitability of ground water for irrigation is contingent on the effects of the mineral constituents of the water on both the plant and the soils. Salts may harm plant growth physically by limiting the up take of water through modification of osmotic processes, or chemically by metabolic reactions such as those caused by toxic constituents (Todd, 1980).

Irrigation –water criteria are dependent on the type of plants, amount of irrigation water used, soil and climate. In irrigation, in addition to salinity and boron, sodium hazard is the other problem most commonly encountered.

The two principal effects of sodium are a reduction in soil permeability and a hardening of the soil. Both effects are caused by the replacement of calcium and magnesium ions by sodium ions on the soil clay and colloids. The extent of this replacement can be estimated by the sodium adsorption ratio (SAR) which is expressed by the following formula.

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

Where the concentrations of the constituents are expressed in mill-equivalents per liter.

Most classification systems of irrigation water include limits on specific conductance (expressing total dissolved solids), sodium content, and boron concentration. Soils containing a large proportion of sodium with carbonate as the predominant anion are termed as alkali soils; and those with chloride or sulfate as the predominant anions are saline soils (Todd, 1980). Sodium content is usually expressed in terms of percent sodium (sodium percentage) defined by

$$\%\text{Na}=\frac{(Na+K)100}{Ca+Mg+Na+K}$$

Where all ionic concentrations are expressed in mill-equivalents per liter.

According to quality classification of water for irrigation (after Wilcox [53]), water quality of the study area is classified as good and permissible water for irrigation (table 6 .6).

WATER CLASS	% Na	Specific Conductance S/cm	Boron, mg/l			
			Sensitive crops	Semi tolerant crops	Tolerant crops	%Na of the study area
Excellent	<20	<250	<0.33	<o.67	<2.00	
Good	20-40	250-750	0.33-0.67	0.67-1.33	1.00-2.00	40.9
Permissible	40-60	750-2000	0.67-1.00	1.33-2.00	2.00-3.00	47.8,54.7, 55.9
Doubtful	60-80	2000-3000	1.00-1.25	2.00-2.50	3.00-3.75	
Unsuitable	>80	>3000	>1.25	>2.50	>3.75	

Table 6.6 Quality classification of water for irrigation (after Wilcox [35]).

The figure blow is useful and summarizes way of classifying irrigation water based on their SAR and Salinity hazard, (Figure 6.3). In the graph, C1, C2,C3 and C4 represents the degree of salinity hazard expressed by the specific conductance and are grouped as low, medium, high, and very high. Similarly, S1, S2, S3 and S4 represents the degree of sodium hazard which is grouped as low, medium, high and very high respectively based on their value(After Richard, as indicated in Todd 1980).

Generally, the basin has suitable water quality for irrigation or is free from sodium hazard from natural condition and can be used for irrigation activity using both surface and ground water with proper drainage management system in the area given due attention to the technologies that have to do with the surface physiographic conditions .

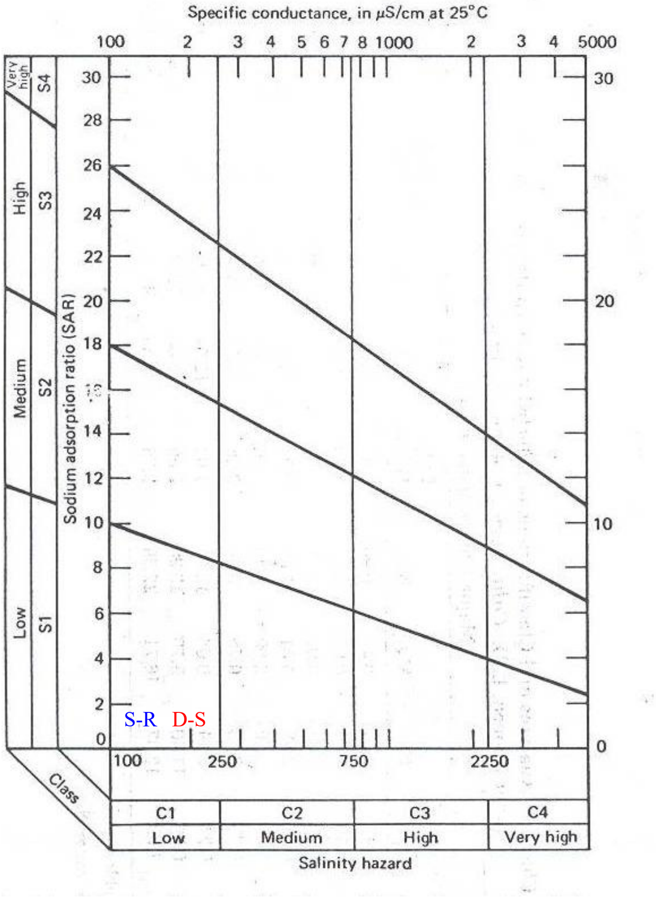


Figure 6.3 Diagram for classification of irrigation water (afterRichard[35]).(S-R=springs and rivers, D-S= deep and shallowells)

6.5.3 Industrial Water quality Assessment

An adequate ground and surface water supply of suitable quality often becomes a primary consideration in selecting new industrial plant locations. It should be apparent that the quality requirements of water used in different industrial processes vary widely. Even with in each industry, criteria can not be established; instead only recommended limiting values or ranges can be used. Salinity, hardness, and silica are the three parameters that usually are important for industrial water (Todd, 1980).

In the study area there are tea and coffee processing plants and for future industrial developments in the area, based on the general trend of major ions together with hydrogeological conditions it is possible to say that quality of water for industry is promising for many of industries as it is confirmed from water chemical analyses results.

Industrial water for food and drink, and medical drug industries, so far as it comes in to direct contact with the products, must have the quality of potable water. Water for cooling purposes should not be corrosive, nor should it become corrosive during the cooling process though the temperature dependant break down of the calcium-carbon dioxide equilibrium. The requirement of water for steam generation as in the case of tea processing plant in the study area depends first of all on the type of boiler construction and the working pressure, with low dissolved solids and gasses and no acid reactions.

Water can be treated for every purpose; however there is a practical limit, especially when large amount is needed. As a matter of economy it may be necessary to site water consuming industries in areas where there is an abundant supply of suitable water.

6.6 Water pollution

The possible pollutants in the water are virtually limitless. All solutes introduced in to the hydrologic environment as a result of man's activities are referred to as contaminants, regardless of whether or not the contaminations reach levels that cause significant degradation of water quality. The term pollution is reserved for situations where contaminant concentrations attain levels that are considered to be objectionable (Freeze and Cherry, 1979). Most pollution originates from the disposal of waste water following the use of water for any of a wide variety of purposes. Thus a large number of sources and causes can modify ground water quality, ranging from septic tanks to irrigated agriculture. The principal sources and causes of ground water pollution are categorized into four categories-municipal, industrial, agricultural and miscellaneous.

In the study area, the common possible sources of pollution are agricultural activities and municipal wastes. Agricultural sources and causes include fertilizer and soil amendments, and pesticides. Particular attention should be given not to use sites for fuel depot in well head areas as is common in the study area.

Nitrogen dissolved to form nitrate ($NO^-{}_3$) is gating increasingly wide spread because of agricultural activities and disposal of sewage on or beneath the land surface. Its presence in undesirable concentration is threatening large aquifer systems in many parts of the world (Freeze and Cherry, 1979). Although $NO^-{}_3$ is the main form in which nitrogen occurs in ground water, dissolved nitrogen also occurs in the form of ammonium (NH^+_4), ammonia (NH_3), nitrite (NO^-_2), nitrogen(N_2), nitrous oxide (N_2O) and organic nitrogen.

From the result of the water samples, there are hand dug wells with indication of down ward migrating Nitrate pollution in Bonga area along Chiri road due to down ward migration from municipal sources.

CHAPTER 7

WATER RESOURCE EVALUATION

7.1 General

Under clear definition of the basic geologic and hydrogeologic parameters required in the techniques of water resources evaluation the out come is supposed to be used in the identification of potential well field, to determine safe pumping rate, and to picture out the nature of surface and sub-surface water interaction of a given basin.

A development plan for the towns within the area prepared by Ministry of Urban Development and data taken from National population and housing census indicate population of above 40,000 for Bonga, Wushwush and Gimbo towns and the surroundings in 2006 and taking the bore wells and springs supplying the towns in the study area assuming 20l/c/d standard and projecting for the 2030 population, the annual water production shall not be greater than 2 MCM and the existing trend of annual groundwater recharge is far more greater than this demand, showing that the existence of dependable water resources, for water demanding developmental activities in the classified area in to residential, commercial, industrial, institutional, and green areas. In view of data gathered by CSA forecast based on 2000, population of Bonga town for example is projected to be 42,361 in year 2025.

7.1 Surface Water Resources

Bonga town in the study area is located near Dincha river on its upstream part known as Sheta river with main tributaries of Kajeti and Barta rivers all of which are perennial and the Dincha river joins further south, the Guma river. The Dincha and Sheta rivers are closer to the town and are 150m below the town level with separate gauging stations. No where in the basin has the water been diverted for agricultural development. An upland surface water source emerging from sparsely populated area, is the Barta river originating in the forested area in the eastern part and after several kilometers the river drops about 80m, at Barta waterfall about 3.5 km NE of Bonga. The water fall is 1700m a .s. l. or 100m above Bonga town center, which makes possible to the gravity water supply for the major part of the town. The majority of low flow of Dincha and Sheta Rivers at the gauging stations are respectively 145 l/s and 65 l/s which are well in excess of the water supply requirements in the projected period.

The rivers in the study area were once decided to be assessed for their potential for the installation of micro or small hydro power schemes aimed to supply electricity to the surrounding towns and preliminary socioeconomic studies conducted and for financial reasons further investigation was not conducted. Therefore the general picture of the surface water potential from the inter relation of precipitation surface runoff and base flow components is promising to conduct those activities dependable on the available water resources.

The river basin of the study area has a defined boundary and also has relationship with groundwater resources in most of the cases. The development of balanced plan for water resources utilization requires full knowledge of the quantity, quality and distribution of land use in the entire watershed and its influence on the river flows. In addition to the above uses, the available water resources can be used for major irrigation activities using suitable techniques and minor water needs for river side cultivations (Table 7.1).

Study area	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Ann.
P(mcm)	43.2	44.6	97.1	151.5	176.7	186.2	183.9	222.9	164.03	112.79	52.17	51.43	1476.63
TRO(mcm)	1.8	1.36	3.5	10.5	36.1	47.8	96.8	104.2	73.93	47.43	9.47	2.87	435.79

Table 7.1 surface water resource of the study area.

7.2 Assessment of groundwater resources

For reliable assessment of groundwater resources, detailed and authentic information relating to hydrogeological formations and the water balance of the entire catchment is required. Under this research collection of hydrological inventory data, hydrological evaluation of the formation characteristics of the water bearing strata and the hydrogeological mapping were undertaken. The rainfall contribution to the groundwater recharge is estimated by calculating the fraction of rainfall infiltrating into the ground over the catchment area. Progressive development of groundwater resources can be initiated through shallow tube wells and deep tube wells for the projected periods accordingly to satisfy the per capita water demand for domestic and non domestic water consumption such as industrial water use in Wushwush tea processing. Water production for Bonga town for the target year 2030 public supply is projected to be $1.008426 \times 10^{6} m^3$ production according to feasibility study of Bonga town by Ministry of Water Resources water demand estimation. Therefore, from the result of estimated annual recharge it is possible to see that the identified groundwater potential is significantly greater for the industrial and irrigation activities to be launched. There are numerous low-yielding springs in the study area situated on the slopes serving as water sources for local population; however the main sources of water supply in the towns are tube wells and shallow wells. Planning for maximum development of our water resources for the long time benefit of the people should take into account the trends in population growth, the resulting agricultural production requirement, the growing needs for industry and other needs. Conjunctive use of surface and groundwater can take the form of full utilization of surface water supplies supplemented by groundwater or the direct use of ground water during periods of low canal supplies or canal closures. The possibility of using this method of exploiting the resources in the study area is justifiable due to the prevailing water resources and physiographic conditions.

CHAPTER 8
SYNTHESIS

This study attempts to analyze and put appropriate discussions concerning water resource potentials in Guma-Sub Catchment based on meteorological, hydrogeological, and hydrochemical descriptions in the previous chapters. In this chapter, results of the study will be explained more briefly in order to show how the result is obtained using different evidences from the existing data and newly measured data.

8.1 Results from analysis of hydrometeorology and the water balance

The difference in precipitation in the basin is not that much great between low and high land areas. This is due to the source of the precipitation in the area is not dominantly affected by the topographic variations within the area. According to the data records, perception in the basin shows temporal variation of eight-month rainy season and four months of low rain season. Maximum and minimum rainfall from spatial point of view is in Wushwush and in Gojeb station respectively. August is a month that registers maximum rainfall and minimum rainfall in the basin is in January.

Significant elevation difference in the basin and limitations of meteorological stations in the southwestern part has led to use, averaging the Theissen polygon method and Isoheytal methods to determine annual precipitation in the basin.

In determining evapotranspiration in general, class A-meteorological stations are very essential with full capacity to measure all parameters. Data quality limitations are solved by applying appropriate methods of adjustments and estimation of evapotranspiration is performed based on the available methods.

Temperature, relative humidity, Wind speed and sun shine hour data are taken from stations and were used in hydrometeorological characterization of the area. Evapotranspiration is also subdivided into potential and actual evapotranspiration. To determine actual evapotranspiration, determination of potential evapotranspiration primarily is necessary. Again Penman and Thornthwaite methods are averaged to over come limitations of accuracy and is applied for the determination of potential evapotranspiration. Therefore, the maximum possible amount of evapotranspiration when there is excess amount of water in a soil is computed and tabulated in table 3.10 with a maximum value of 85.2 mm/ month in the month of February which is the windy month in the basin. Annual value of evapotranspiration is calculated as 849.4 mm for the basin.

Actual evapotranspiration is the real amount of water that evaporates and transpires depending on the available water and climatic conditions and Thornthwaite water balance model is used for the calculation. Three major soil categories are grouped with different vegetation cover for computing actual evapotranspiration. Clay loam, sandy loam and clay are the main soil categories. For this computation, a soil-water balance model was used based on crop coefficient for the above soils. For this model, surface runoff, precipitation, potential evapotranspiration and crop coefficients are the input data. According to the model result, actual evapotranspiration values are 816.2 mm, 722.9 mm and 796.9mm per year for clay loam, sandy loam and clay respectively. Annually the basin loses 800.7 mm in the form of actual evapotranspiration (Tabl3.14).

Measured values of Guma Sub-Catchment river discharges are the main data in providing information about the catchment characteristics and nature of rivers. The rivers show variation in rate of discharge as it flows from high land area to the low land area.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annl.
P(mcm)	43.14	44.63	97.10	151.55	176.69	186.15	183.96	222.99	164.03	112.79	52.17	51.43	1476.63
ET(mcm)	52.12	53.96	73.3	63.6	57.7	52.9	51.5	51.6	61.7	60	61.4	60.9	700.68
TRO(mcm)	1.79	1.36	3.48	10.47	36.10	47.83	96.83	104.23	73.93	47.43	9.47	2.87	435.79
GOF(mcm)	10.16	8.02	9.80	12.80	17.00	21.00	26.10	34.60	41.10	30.32	17.30	11.45	239.65

Table 8.1 Base flow and surface runoff relation

The annual total discharge of the river from long term mean monthly averaged flow is recorded as 435.8 MCM in the study area. The records were taken from the gauges on both Dincha and lower Guma rivers. Its base flow is greater than the surface run off as it can be seen from table 8.1 and the separation was done using hydrograph method. Therefore, accordingly the basin has a total volume of 240 MCM and 196 MCM annually as a base flow and direct run off respectively.

8.2 Results from analysis of hydrogeology.

Pump test results from a borehole in the delineated well field shows great variation in transmisivity and well yield as compared to other areas in the study area which is dependent on aquifer characteristics of the formation. According to the analysis of the wells in highly productive well fields, transmisivity is high in the alluvial deposit with an average value of 1.69×10^{-3} m^2/d from two wells and the yield of these wells are averaged to be 6-7 l/s with unconfined aquifer type. High land area around Wushwush has the intermediate to low values of transmisivity. Shallow wells are representative of aquifer with moderate transmisivity and well yield from such aquifer is 1.5-2 l/s.

8.2.1 Distribution of lithologies and structures: Lowland areas are characterized by alluvial deposits, which can serve as a big reservoir for the basin at shallow depth and intercalation of tuff at depth. Northern central part of the basin is basalt with shallower depth of weathering and the southeastern part is dominantly covered with fresh basalt. In high lands and between the high land and lowland, rhyolite and tuff formations are situated. From structural point of view, the central, northern and southeastern part is more affected by different structures, which can play great role in ground water exploration for locating specific well cites in the area.

Groundwater circulation is shallow as it is reflected by the presence of many springs in the southwestern part with low total dissolved solids. Most of springs are dipration and some are contact springs and their concentrations are high around southwester where jointed basalt which allows percolation of water exists. Groundwater flow is mostly influenced by topography and orientation of bedded or layered rocks away from the basin or to ward the basin. In this case there is no such layered rock formation dipping away from the basin. This is evidenced by the presence of successive springs from high land area to the low land.

8.3 Results from the analysis of water resources evaluation

Interpretation of water resource is done based on the meteorological and hydrogeological data analysis. In this analysis, the amount of water entered in to the basin is broken down into other components as surface runoff, Recharge, evapotranspiration and recharge. Under the assumptions made for the area, the only inflow to the basin is precipitation. The annual abstraction is assumed to be negligible, and amount of recharge is calculated to be 110.7 mcm. Separated base flow from the river discharge which is 239.7mcm is minimizing recharge part because of the presence of subsurface outflow through the alluvial deposit. Here this figure shows that the basin is mostly influenced by the wet climate and of surrounding high lands makes the total runoff to be high and the actual evapotranspiration which accounts for major part of the precipitation indicating that the use of these perennial surface water resources to be integrated with the groundwater resources available.

8.4 Results from the analysis of hydrochemistry of water

Laboratory analysis supplemented by field measurements provides the information necessary to characterize water sources according to their chemistry. Due to the volcanic terrain of the basin and shallow ground water circulation, almost all of the water sources are fresh water according to their TDS classification ranging from 52 mg/l to 140 mg/l in the catchment. Concentration of ions is maximum in the low land area with a general trend of increase from high land to lowland because of high residence time indicating hydrogeochemical evolution and high rock-water interaction. The minimum Ec value is 50 µs/cm in Sobra spring and the maximum E.C value is 507 µs/cm in the low land hand dug well around Bonga town. Chemistry of all other water sources (springs, rivers, and boreholes) reflect the local geology of the basin but chemistry of hand dug wells reflects the influence of pollution from the surrounding towns.

The bore wells in the highly productive well field have an iron content which increases with depth and is beyond the WHO guide line for consumption requiring some sort of treatment. Iron is one of the most important element in igneous rocks occurring in the ferromagnesian minerals as pyroxenes, amphiboles, biotite, and solid solution serious of end members fayalite ($FeSio_4$) and foresterite (Mg_2SiO_4).The liberation of iron by weathering and its content in natural waters results from chemical equilibra ,comprising oxidation and reduction solution and precipitation of hydroxides, carbonates and sulfates etc. with the combined effect of pH, Eh and dissolved CO2 and sulfur specious can be best made clear by stability field diagrams.(Hem 1960a,1960b). Soils develop as a result of physical, chemical and biological transformation of rock constituent, depending mainly on the type of temperature and amount of precipitation. In hummed climates and during wet seasons in other climates the downward movement and leaching is predominant for the soil moisture containing the dissolved constituents transporting them to the groundwater. Leaching of iron is low in alkaline and weakly acid soil horizons because under these conditions they form only slightly soluble oxides and hydroxides with decreasing pH the solubility raises and with it the degree of leaching. Fe and Mn are preferentially removed under reducing conditions as divalent ions (Schaffer and schahtscheble 1976). The occurrence or absence of iron and manganese in groundwater depends on their oxidation state and the pH conditions. in most oxygenated Groundwater dissolved iron often is measured between 1 to 10 mg/l. therefore, iron content of groundwater in the study area is enriched as described and should be given attention to modify it for the required purpose.

CHAPTER 9

CONCLUSION AND RECCOMMENDATION

CONCLUSION

♣ Upper Guma Sub-Catchment located in Omo-Gibe basin has a total area of 876 km^2 and is characterized by gently sloping to highly rugged topography that results in dense dendretic drainage patterns.

The basin is within temperate (Weynadega) climatic zone. From long term mean monthly precipitation the basin gets 1697mm annual rainfall. The actual and potential evapotranspiration is computed as 800.7 mm and 849.4 mm per annum respectively.

Evaluation of water resource potential of the catchment is done by conventional geological and hydrogeological description and mapping of different lithologic units, analysis of hydrometeorological data, river discharge and hydrochemistry of different water sources were done.

Accordingly, from geological map of newly produced with a scale of 1:50,000, three main litho logic units have been identified with sub-divisions. The weathered and fractured basalt and fresh basalt; Weathered and unweathered rhyolite units; and recent alluvial formation.

♣ In terms of chronology, those volcanic products of both acidic and basic rocks are Miocene to Pliocene and the alluvial deposit is the quaternary deposit. River beds are the recent results of alluvial materials from the highland eroded materials by its tributaries. From structural point of view north eastern edge of the boundary are affected by the NW-SE dominant faults.

Based on aquifer characteristics comparison from hydrogeological point of view, three hydrostratigraphic units are mapped. Highly permeable, moderately permeable and low permeability. The highly permeable unit is the alluvial deposits intercalated with tuff, weathered and fractured basalt at depth is the potential zone for groundwater exploitation. The moderately permeable unit consists of fractured and weathered basalt and part of rhyolite. The low permeable formation consists of all fresh basaltic and rhyolitic rock units. Recharge areas for the basin are those areas starting from the surrounding highlands while discharge areas are those low lands and other areas where more springs concentrate. Based on the successive location of springs and borehole yields, groundwater flow is generally following the topography.

♣ Analysis of the hydrochemistry of different water sources show that two types of water are identified based on their TDS value. All water sources range in the classification of fresh water. Dominant water type is Ca-Mg-HCO_3 followed by Ca-Na- HCO_3 with special case of the hand dug wells with water type of Ca-Mg-NO_3 which are manifestations of contaminants from the surrounding. Concerning chemical water quality, surface and shallow groundwater sources are with in the limit of acceptable value of WHO water quality standards for water supply except iron content of deep bore wells which has to be removed by aeration treatment system, irrigation, and industries excluding trace elements which are not analyzed in this study.

Recommendations

► Mechanism to treat excess iron content in bore wells should be designed considering an aeration tank for treating the water and a reservoir as part of storage in the distribution system.

► Surface runoff in the basin is not only pure water but eroded soils from elevated and rugged areas are moving together due to encroachments of natural forest for different purposes. This condition reduces water infiltration to the ground. Hence soil and water conservation program should be promoted specially in the high topographic areas.

► In order to evaluate the basin fully, distribution of bore holes are not uniform and even the drilled ones have no proper drilling and pump test data. Therefore, additional boreholes are recommended specially in the northern and southern part of the area and data should be properly stored.

► River discharge measuring stations should be checked for its proper functioning by the

responsible parties as it was cross checked from unreliable discharge reading above the available precipitation.

► There should be at least one meteorological station that can measure class A measurements and therefore, the dismantled station in Chiri town has to be reestablished.

► It is important to start irrigation practice using the river waters. To bring sustainable agriculture, utilization of groundwater for irrigation will be the final alternative. Trace element analysis is not done due to lack of budget and it needs analysis before implementation of any industry and for extensive irrigation of fruits.

► Bacteriological analysis should be accompanied with chemical water quality investigation. Therefore, proper well design and sanitation with regular disinfections is recommended.

► Further investigation on the lower Guma catchment and interrelation with upper Guma sub-catchment together with river basin ground water modeling is recommended for the practical utilization of the rivers for assessing the combined potential of the basin for hydropower and water resource for irrigation.

► Disposal of gaseous, liquid, and solid wastes can poison surface and ground water and infect by pathogens and impaired the intended use. Effect of sewage and wastewater disposal should be given attention by the municipality to avoid the direct discharge to the surface runoff and not harm groundwater resources.

► Planning and zoning of an area should take in to consideration to protect the recharging area from pollution

► Consequences of solid waste disposal on groundwater quality should be handled by properly identified sanitary landfills.

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Annexes

Annex 1 Monthly mean Sun Shine in hours for Chiri, Wushwush, and Bonga meteorological Stations													
stations	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De	Annual
Chiri	6.3	5.6	6.6	5.4	4.3	3.2	2.5	2.2	4.5	6.1	7.5	7.1	5.106667
Wushwush	6.7	5.1	6.5	5.7	6.1	3.8	2.7	3.3	4.50	6.8	7.5	7.2	5.492083
Bonga	7.6	6.6	6.4	6.6	6	4.9	3.1	3.6	4.9	6.8	7.6	8	6.008333
Average	6.9	5.8	6.5	5.9	5.5	3.4	2.8	3	4.5	6.6	7.5	7.4	5.5357

Annex 2 Monthly mean MIN temperature at Diri Station												
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1988	13.1	14.3	14	14.5	13.3	13	12.5	14.5	14.5	12.6	12.5	12
1989	11.5	10.5	13.3	10.9	11.2	13.1	11.8	10.5	11.8	12.3	12.6	13.1
1990	13.8	13.5	13.1	12.8	12.8	12.8	12	11.8	12.1	12.7	12.3	12.6
1991	13.8	13.9	15.1	14.8	14.1	14.5	14.5	14.4	14.6	14	13.6	15.1
1992	15.6	15.2	15.4	15.3	12.2	14.7	15.3	15.4	15.6	15.2	15.1	15.4
1997	19.1	19.3	15.5	18.3	20.5		20.5	20.4	20.4	20.6	20.7	
2000	12.9	14.3	14.8	14.7	14.3	14.2	11.8	9.9	10.3	10.4	10.5	11.1
2001	13.5	13.7	14.4	14.7	13.8	13.4	13.4	14.1	14.2	13.9	13.2	13.4
2002	12.3	12.3	13.7	13.6	14.1	12.9						
2003	12.2	14.3	15.5	15	14.6	13.8	13.3	13.5	13.4	13.3	13.2	12.6

	Annex 3 Monthly mean MIN temperature at Gojeb Station											
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oc	Nov	Dec
1982		14.4	15.1	16.9	17.3	16.6	15.7	16	14.6	14.8	13.9	12.5
1983	10.4	14	16.2	15.4	16	16						
1984	10.7	10.3		16.2		15.2	15	14.3	15.1		14.2	11.7
1985	11.2	12.8	14.9	15.7		15.2		15	14.7	12.8		14.9
1986	16.8	16.6	16.8	16.5	17.4	16.4	16.2	15.8	15.6	16.2	15.3	17.6
1987	14.4	14.6	15.9	15.2	15.5	15.7	15.9	16.2	15.7	15.5	12.8	11.6
1988	13.6	15.8	15.8	16.1	17.1	16	15.2	14.7	15.3	15.2	10.4	8.6
1989	9.2	12.5	13.5	13.7	15.2	15.3	15	15.7	16	14.5	12.3	14.6
1990	11.7	14.8		15.9		16.3	15.1	15.6	15.7			
1991	14.9	14.8	15.5	16.5	16.6	17.9	16.7	15.9	15.9	13.8	12.7	11.3

Annex 4 Monthly mean MIN temperature at WUSHWUSH Station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1957	9	10	11.1	12.8	11.7	11.6	10.8	10.7	10	9.1	10.4	9.7
1958	10.7	11.3	12.2	12.5	13.2	13	12.8	12.7	12.5	11	9	10.3
1959	10.6	11.5	10.8	12.6	12.8	12.5	11.6	11.8	12.4	12	9.8	10.1
1960	9.5	11	11.5	12.6	12.2	11.7	12	11.5	11.2	10.7	11.3	9.6
1961	8.6	10.3	10.4	12.1	12.6	11.3	11.7	11.5	11	10.5	11.6	
1962	8.9	8.6	11.4	12.5	12.8	12.6	12.2	11.7	11.8	9.4	9.8	9.2
1963	9.4	10.9	10.6	11.9	12.2	11.3	12.5	12.8	11.8	10.3	10.6	10.9
1964	10.7	11.2	11.8	12.3	11.1	9.7	10.5	10.7	10.6	11	9	9.7
1965	8.5	7.3	9.7	10.6	10	10.3	10.7	9.9	10.2	10.7	9.7	9.2
1966	9.1	8.8	11.2	10.7	10.3	9.8	10.1	10	9.7	9.9	9.6	7.1
1988			13.1	13.6	13.7	12.9	13	13.2	12.9	12.6	10.6	10.5
1989	11.2	11.5	12.9	12.2	12.7	12.4	12.4	12.1	12.5	12	11.8	12.4
1990	11.4	12.7	12.9	13.3	13.3	12.9	12.9	12.7	12.7	11.7	12.2	11.2
1991	12.3		13	13.1	13.2	13.4	13	12.9	12.5	11.6	11.4	11.4
1992	12.2	12.8	13.3	13.8	13.5	13.1	12.6	13.2	12.4		11.4	12.1
1993	12.2	12.2	11.8	13.5	13.3	13.1		12.7	12.4	12.5	11.4	10.2
1994	11.3	12.8	13.6	13.4	13.2	13.2	13.3	13.2	10.9	12.5	12.5	12.2

Annex 5 Monthly mean MIN temperature at Chiri Station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1980	11.5	12.4	13	12.3	11.4	10.3	10.2	10.1	10.9	11.1	11.6	12
1981	12.4	12.9	12.2	11.8	11	11.7	10.5	10.6	11.3	10.6	11.7	12.3
1982			11.7	11.9	11.2	11.8	10.9	10.9	11	10.4		
1983	13.4	14	13.3	12	11.5	11.6	10.3	10.4	10.9	11.1	12.5	12.6
1984							9.3	10	12	11.5	13.2	14.3
1985	13.6	14.6	13.6	11.6	11.7	10.9	10.6	10.6	11.1	10.9	10.6	10.6
1986	11.3	12.1	11.7	12.4	12.6	12.1	11.5	11.5	10.3			

Annex 6 Monthly mean MIN temperature at BONGA Station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1986	6.3	12.3	12	14	14.8	14.4	14.3	13.8	13.7	13.3	13.1	12.9
1987	11.7	10.9	13	13.3	14.1	13.5	13.1	13.4	13.8	13	12	13.6
1988	13	13	14	14.3	13.1	12.1	12.8	14.3	12.6	12.4	13.3	9.2
1989	9.1	10.2	11.7	13.7	13.9	13.5	13.9	13.1	13.5	12.3	12.1	12.7
1990	10.4	12.9	13	14	14.4	14.2	13.4	13.4	13.3	12.2	11.6	10.2
1991	12.1	10.9	12.7	11.2	10.9	10.2	10.3	13	12.5	12.2	11.6	9.8
1992	8.9	10.8	12.2	11.1	12.5	10.6	11.9	10.5	11.3	11	12.3	12
1993	11.4	10.6	12.1	12.5	12.5	12.7	11.3	11.7	12.2	12.6	10.1	8.2
1994	9	10.8	13	13	13.9		13.7	13.7	12.6	8.3	10.1	9.2
1995	8.8	10.8	10.4	12.5	13.1	12.3	11.4	11.7	12.6	9.7	9.2	10.9
1996	11.5	11.1	11.1	9.6	10.6	10.1	10.5	11	11.5	11.9	10.9	10.5
1997	10.8	9.9	12.2	12.8	12.9	13.1	12.7					
1998		12.6	12.3	11.4	11.3	12.1	11.8	11.9	11.4	12	9.9	8.2
1999	8.8	10.2	11.9	11.9	11.5	11.9	11.3	11.6	12.3	12.7	9.8	9.2
2000	9.5	7.8	12	12.3	12.5	12.9	12.9	13.6	12.9	13.3	12	8.5
2001	9.5	11.9	12.2	14	13.6	13.2	12.6	13.4	13.1	13.3	12.3	11.5
2002	11.8	10.1	12	13.9	13.5	13	13.2	12.9	13.1	12.8	12.7	14.1
2003	10.8	11.7	12.2	13.5	14.2	12	10.9	10.8	11.5	10.2	10.1	10.5

Annex 7 Monthly mean Maximum temperature at DIRIGOMA Station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1990	26.4	26.9	29.2	29	25.8	24.6	22.8	23.2	24.1	24.9	25.4	27.2
1991	24.7	26.3	25.6	25.6	26.5	25.3	23.8	23.7	23	25.3	25.6	25.6
1992	24.6	26	26.2	25.1	24.6	24.9	24.8	24.1	24.8	24.4	25.8	25.7
1993	25.7	25	25.5	25	25.1	25.3	25.3	25.6	25.6	25.8	25.6	25.4
1997	26.7	28.3	29.2	26.9	23.1	23.5	23.4	23.6	23.5	24.5	21.2	25.3
1998	25.3	26.4	26.4	26.2	27.3	26.8	24.6	24.7			26.4	27
1999	28.3	30	28	28.1								
2000												
2003	24.6	28.9	28.3	27.6	27.4	24.9	23.3	22.9	25.8	27	27.2	28.1

Annex 8 Monthly mean Maximum temperature at Chiri Station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	SEPT	Oct	Nov	Dec
1980	25.1	26	25.9	24.7	24.9	24.2	23.3	23.9	24.2		24.9	25.1
1981	25.6	27.3	26.8	27.6	26.9	26	26.5	28	27.3	26.8	28	27.1
1982			27	25.7	25.7	24.5	24	23.7	24	24.4		
1983	26.4	27	27.6	26.6	27.2	26.4	23	23.1	23.1	24.1	25	26.1
1984	28.7	26.4	27.3		25.3	25.5	22.6	21.7	21.3	23.9	22.8	24.3
1985	26.1	26.9	27.1	24.8	23.7	22.4	21	20	21.6	23.9	24.4	24
1986	25.3	24.9	24.6	24.2	23.5	21.1	20.4	21.4	21.3	23.8	24.2	24.5

Annex 9 Monthly mean Maximum temperature at Wushwush Station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1957	25.2	25.5	25.7	27.2	28.2	27.5	26.2	24.8	26.9	27.9	27.9	29
1958	28.6	28.7	29.7	28.2	28.7	25.3	24	24	25.2	25.8	26.7	26.5
1959	25.5	27.5	37.5	27.6	26.7	25	23.4	23	24.3	24.6	25.5	25
1960	26	25.5	26.6	27.3	29.3	25.8	23.3	24.3	24	25	25.5	28.4
1961	29.9	28.2	28.9	29.1	26.5	27.5	25.4	25.3	26	26.5	23.9	
1962	26.2	29	25.3	26.6	267	26.6	25.2	24.3	24.8	27.5	26.6	26.1
1963	25	26.3	27.9	26.4	27.7	26.8	24.2	24.7	26.3	27.2	25.7	25
1964	25.7	26.4	28.5	28.3	27.9	26.8	24.3	24.5	23.8	24	24.6	24.1
1965	25.1	27.2	28.1	26.6	28.1	26.9	27.7	25.3	25.4	24.2	24.2	24.3
1966	25.8	24.9	25.8	26.8	27.9	26	25.8	24.4	24.8	25	24.7	24.9
1988			28.2	26.9	23.8	22.9	21.5	21.6	22.8	23.8	25.8	25.8
1989	26	26	25.5	24.8	25.9	22.8	20.8	22.8	22.7	24	25.3	24.5
1990	25.6	24	25	26.2	24.7	23	22	22.3	22.9	24.8	25.4	26.2
1991	25.5	24.75	25.7	25.2	25	24.8	22.1	22.7	24.1	24.9	25.7	25.4
1992	25.7	25.5	27.5	26.1	25.9	23.4	21.7	20.2	23.1	24.75	25.1	24.5
1993	24.5	24.4	26	24.4	24	22.5	21.2	21.9	23.2	24.6	26.1	26.4
1994	27.9	29.2	27.3	25.9	24.4	22.9	20.7	21.6	23.4	25.5	25.2	26.1

Annex 10 Monthly mean Maximum temperature at BONGA Station

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1986	28.2	27.7	28.4	28.6	28.7	26.5	27.6	27.6	27	27.8	27.4	27.1
1987	27.3	27.2	28.1	27	27	26.9	27.3	27.3	27	27	27.4	28
1988	27.2	27	28.6	28.1	27	25.7	25.9	25.8	26	26.6	28.3	28.3

1989	28.1	27.8	27.9	26.5	27	26.2	24	23.3	25	26.7	27.9	26.8
1990	28.2	26.8	27.6	28.1	27.9	26.2	26	26.7	26	28.7	28.6	27.3
1991	28.6	29.4	28.4	27.8	27.8	27.3	25.6	25.9	27	27.7	28	27.8
1992	27.9	27.9	29.2	28.2	28.3	26.3	25.8	25.2	26	26.7	28	27.9
1993	26.8	27	28.6	27.2	27.7	27.2	26.3	27.2	27	26.8	29.5	30.1
1994	31.2	32.1	29.3	28.5	26.8	27.15	25.3	25.5	27	29.6	27.6	27.9
1995	30	29.5	29.8	28.1	27.2	27.1	25.2	25.7	27	27.8	29.5	27.7
1996	25.6	29.2	28.3	26.4	26.4	25.5	24.3	24.1	26	27.4	27.7	27.7
1997	27.4	29.7	28.9	26.7	25.9	25.6	25.2	25.6	27	26.5	26.4	27.9
1998	28	28.4	27.4	29.1	26.6	27.2	25	24.8	26	26.4	28.5	29.3
1999	29	28.5	28.6	27.6	26.1	26.4	24.6	25.1	26	26.4	28.3	28.9
2000	29	28.9	28.6	27.7	26.6	26.5	25.2	24.8	26	26.4	26.5	27.4
2001	27.5	26.8	26	27.1	25.4	23.5	24.6	24.9	26	26.8	26.3	26.2
2002	27.1	28.5	26.6	26.7	26.3	25.9	26	25.3	26	26.8	26.7	25.8
2003	26.5	27.8	27.3	27.2	26.6	25	24.8	24.4	26	26.8	26.8	28

	Annex 11 Monthly mean Maximum temperature at Gojeb Station											
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1978		30.5							27.4	28.7	29.3	28.1
1979	28.2	29.1	29.8	30.8	28.9	28.3	27	26.8			30.7	30.8
1980	30.7	32.8	32.1	29.9		28.2	27	27.1	28.1	29.5	30.1	31.2
1981												
1982		30.6	33.1	29.8	29.5	28.1	26	26.4	27.7	28	28.7	29.5
1983	29.7	31.4	32.1	31	28.7	29.1						
1984	31.1	33.3		31.8		27.1	27	27.1	27.8		30.1	30.8
1985	32.4	32.7	32.5	29.6		27.8		27.1	27.5	28.6	30.4	30.7
1986	32.1	32.2	31.8	31.4	30.8	29.7	30	28.7	29.1	31.1	31.6	33
1987	39.9	33	31.4	31.9	30.9	29.7	30	30.2	30.2	30.4	31.4	32.3
1988	32.5	32.4	33.3	33.2	32	29.7	29	28.4	29.4	29.4	31.3	32
1989	32.6	32.2	31.6	31.8	31.2	29.7	29	29.5	29	29.6	30.6	30.7
1990												
1991	32.4	33.3	33	32.5	32.1	29.5	29	29	29.6	31.1	33.3	33.1

	Annex 13 Monthly R.H at 1200 Lst Wushwush Station											
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1988			66	86	83	79	75	83	75	66	48	50
1989	52	51	57	66	58	69	79	70	72	61	55	66
1990	55	69	61	64	66	74	75	75	71	57	57	53
1991												
1992	56	61	50	61	64	73	78	78	69		58	65
1993	65	75	58	70	72	79		74	69	62	53	49
1994	42	36	56	73	69		85	81	67			

Annex 14 Monthly R.H at 1800 Lst Wushwush Station												
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1988			66	86	83	79	75	83	75	66	48	50
1989	52	51	57	66	58	69	79	70	72	61	55	66
1990	55	69	61	64	66	74	75	75	71	57	57	53
1991												
1992	56	61	50	61	64	73	78	78	69		58	65
1993	65	75	58	70	72	79		74	69	62	53	49
1994	42	36	56	73	69		85	81	67			

Annex 15 Monthly mean Sun Shine in Chiri Station												
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1987			5.4	5.9	4.2	3.1	4.2		6.1	6.4	7.7	8
1988	7.4	6.4	8.4	6.2	3.3	3.3	2.5			6.5	8.8	8.5
1989			5.5	4.6			2.8	4				4.7
1990	4.9	4.5	5.8	3.2	4.6	3.9			4.6	6.8	7.4	8
1991	7	6.7	6.2	7		3.6	1.3	1	3.6	6.6	7.3	
1992			7.1	6.6	5.6	3.4	1.3	1.5	3.8	4.1	6.5	6.1
1993	5.6	4.8	8	4.5	3.9	1.7	2.6					

Annex 16 Monthly Sun Shine Wushwush Station												
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1988			8.3	6.3	5.2	4.3	2.7	3.4	3.8	6.8	8.8	8.5
1989	7.9	6.9	5.2	5.4	6.8	4.2	2.9	4.7		6.7		
1990	7.9	3.7	6.1	4	6.3	3.6	3.1	4.1	4.8	7.8	7.8	8.5
1991	6.3				4.5			2.2	4.2	6.2	6.9	5.8
1992	4.8	4.1	6.3	5.4	6.2	3.7	1.9	1.6	4.1		5.9	5.8
1993	5.6	4.3	7.5	5.2	5.5.	3.4		3.6	5.1	6.4	8	
1994	7.9	6.2	5.7	7.7								
average	6.7	5.1	6.5	5.7	6.1	3.8	2.7	3.3	4.4	6.8	7.5	7.2

Annex 17 Monthly mean wind speed in m/s at 2m Gojeb Station												
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1985	0.8	0.8	0.5	0.9	0.6	0.7	0.5	0.4	0.4	0.5	0.6	0.6
1986	0.6	0.9	0.9	0.7	0.6	0.6	0.4	0.5	0.4	0.4	0.4	0.5
1987	0.6	0.5	0.7	0.7	0.5	0.4	0.4	0.5	0.4	0.4	0.5	0.5
1988												
1989	0.6	0.7	0.7	0.6	0.5	0.5	0.4	0.5	0.5	0.5	0.4	0.4
1990	0.5	0.5	0.6	0.6		0.4	0.4	0.4	0.4	0.4	0.3	0.4
1991	0.4	0.5	0.6	0.5	0.4	0.5	0.3	0.4	0.4	0.4	0.5	0.4

Annex 18 Monthly mean wind speed in m/s at 2m Wushwush Station												
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1988			1.1	0.9	0.8	0.9	0.8		0.8	0.9	0.9	0.9
1989	0.9	0.1	0.4	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.7
1990	0.9	0.8	0.8	0.9	0.8	0.7	0.5	0.7	0.7	0.8	0.7	0.8
1991	0.9	0.9	0.9	0.9	0.7	0.7	0.6	0.6	0.7		0.7	0.7
1992	0.8	0.7	0.2	0.2	0.2	0.8	0.7	0.7	0.8		0.7	0.7
1993	0.8	0.7	0.9	0.8	0.7	0.6		0.6	0.8	0.8	0.8	0.8
1994	0.9	0.9	0.9	0.9	0.9	0.7	0.7	0.6	0.7		0.7	0.7
1995	0.6	0.8	0.8	0.7								

	Annex 19 Monthly Mean PAN Evap.Chiri Station											
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec

1987							114.6	145.9	131.52	143.7	134.6	129.53
1988	127.89	123.55	171.78	165.21	184.13	140	73.72	189.63	125.23	146.9	144.31	124
1989	160.4	140.9	169.02	158.48	125.81	97.99	134.76	101.86	115.41	115.1	116.98	92.16
1990	79.13	95.74	1o7.45	98.16	126.89	108.01	99.22	84.34	110.36	119.8	110.87	103.23
1991	92.71	110.96	144.51	148.14	140.18	117.3	87.12	92.64	131.76	104.3	94.57	92.14
1992	78.54	89.78	114.92	54.76	126.99	125.17	126.65	102.9	97.21	84.54	100.7	85.29
1993	82.91	73.12	124.03	85.4	94.28	52.82	53.7	75.85	102.7	83.1	96.29	79.13
1994	98.28	133.34	94.52	71.09	65.42	57.12						
average	102.8371	109.6271	136.463	111.606	123.39	99.7729	98.5386	113.303	116.31	113.9	114.05	100.78

Annex 22													
STATION:-		dincha nr. Bonga			2005			OG2005					
BASIN:-		OMO-GHIBIE			Co-Ordinate:- 8d11'n 37d28'e								
DRAINAGE AREA,2005 Km^2:-			286		MEAN ELEVATION, m.a.s.l.:								
YEAR	*	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1988		4.37	2.02	1.79	2.1	5.5	16.5	35.7	80.3	63.3	64.9	9.0	4.1
1989	I	3.26	2.58	3.38	17.0	8.8	23.6	37.8	44.4	43.4	31.1	8.4	9.8
1990	I	2.53	2.49	9.57	14.8	27.5	47.8	38.7	60.8	55.5	28.6	8.6	8.2
1991	I	21.23	29.8	28.76	3.9	3.6	7.3	49.7	57.8	56.6	21.1	8.3	5.3
1992	I	12.52	12.65	5.28	4.7	23.5	35.9	34.0	48.7	52.0	80.5	16.3	5.9
1993	I	5.84	2.19	7.66	17.2	39.5	49.8	45.9	34.5	42.8	37.5	10.5	6.2
1994	I	7.17	2.64	3.81	4.7	25.8	54.3	58.4	57.6	41.2	7.1	5.8	1.8
1995	I	4.20	3.35	1.82	5.6	12.1	23.1	35.6	50.0	53.7	19.8	5.3	5.1
1996	I	7.94	3.89		19.2	41.5	56.2	44.7	51.9	56.9	32.1	84.2	6.8
1997	I	5.67	2.75	7.32	23.5	39.8	71.4	60.	42.6	32.0	59.7	62.0	27.0
1998	I	20.4	10.83	13.79	15.8	60.8	59.	61.3	144.7	51.7	87.4	11.9	4.3
1999	I	-	-	-	7.43	14.3	21.1	35.3	28.5	23.2	39.2	8.0	3.7
2000	I	2.06	1.66	2.52	3.8	9.9	9.7	38.	16.8	18.8	44.7	7.1	3.7
2001	I	2.39	2.20	2.85	4.6	24.6	52.6	44.4	51.6	-	33.6	9.4	5.3
2002	I	8.47	5.21	7.05	10.9	10.1	12.9	32.7	32.5	24.0	13.0	9.2	9.5
average	MCM	7.71	6.02	7.35	10.3	23.2	36.	43.5	53.5	43.9	40.0	17.6	7.1

	Annex 21 Monthly mean Wind speed at ____Gojeb Station											
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1985	0.8	0.8	0.5	0.9	0.6	0.7	0.5	0.4	0.5	0.6		
1986	0.6	0.9	0.9	0.7	0.6	0.6	0.4	0.4	0.4	0.4		
1987	0.6	0.5	0.7	0.7	0.5	0.4	0.4	0.4	0.4	0.5		
1988												
1989	0.6	0.7	0.7	0.6	0.5	0.5	0.4	0.5	0.5	0.4	0.4	
1990	0.5	0.5	0.7	0.6		0.4	0.4	0.4	0.4	0.3	0.3	
1991	0.4	0.5	0.6	0.5	0.4	0.5	0.3	0.4	0.4	0.5	0.5	

	Annex 23 Monthly R.H at 0600Lst Gojeb Station											
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1981	93	94	88	94	94					95	94	99
1982	99	94	95	99	87	99	83	97	95	97		98
1983			98	96	97	95	93	97	97	97		96
1984	94	96	94	96	95							
1985				92	92	97	97	97	97	93	92	94
1986	92	92	84	76	93	95	97	98	96		93	95
1987	94	94	96	97	99	95	98	99	93	97	96	93
1988	95	94	93	95	93	97	99	99	98	98	96	96
1989	92	66	65	72	67	96	66	69	70	71	71	77
1990	92	94	95	94		91	94	80	96	97	96	97
1991	94	94	95	95	95	94	90	95	93	96	95	92

Annex 24														
STATION:-		GUMMA NEAR ANDARACHA							STATION No.:-	OG2004				
DRAINAGE AREA, Km^2:-			231.25			co-ordinate 7d09'n 36d15'e								
BANIN	GHIBIE OMO						MEAN ELEVATION, m.a.s.l.:	2350						
Year	*	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1981	I					17.730	15.530	37.520	39.460	43.390	34.980		1.930	
1982	I	2.160	1.470	1.680	5.210	7.960	13.820	28.580	69.260	18.620	33.160	5.520	3.400	190.840
1983	I	2.270	1.200	2.550	7.780	15.420	11.940	37.140	113.700	118.000	89.030		2.970	
1984	I	1.150	1.040	1.440	5.420	12.460	63.750	150.500	110.400	99.160	8.230	5.160	4.860	463.570
1985	I	1.470	1.200	2.690	12.530	14.480	22.100	66.080	80.300	88.300	20.090	7.130	5.950	322.320
	I	1.750	3.130	7.830	12.070	14.720	36.540	35.520	22.770	88.560	26.010	4.640	5.700	259.240
1987	I	1.880	1.320	2.710	4.200	48.090	26.660	111.420	84.280	52.120	26.550	4.910	5.240	369.380
1988	I	4.690	6.470	3.890	4.880	8.020	20.740	188.500	195.400	132.200	63.490	4.600	1.740	634.620
1989	I	4.150	1.640	4.330	25.160	12.100	26.300	119.400	77.620	54.200	24.270	5.820	15.210	370.200
1990	I	4.160	6.300	26.590	8.770	18.040	27.190	64.120	111.700	59.200	31.740	8.940	3.830	370.580
1991	I	4.900	2.710	8.510	11.830	20.190	40.320	79.800	105.730	55.450	21.950	4.620	7.030	363.040
1992	I	3.200	7.810	8.550	10.190	21.040	90.080	88.380	67.690	106.310	89.420	14.240	8.820	515.730
1993	I	4.480	6.410	5.320	23.860	41.070	41.100	53.950	38.180	34.160	47.770	7.830	3.320	307.450
1994	I	2.250	1.120	3.150	5.400	25.770	28.920	131.190	94.210	78.830	8.090	9.580	4.480	392.990
1995	I	2.020	3.100	4.360	14.860	18.510	16.390	107.910	106.700	60.110	14.380	4.620	5.240	358.200
1996	I	7.150	2.610	11.930	33.200	49.160	56.440	48.250	59.870	108.410	25.130	8.340	4.380	415.120
1997	I	5.070	2.390	4.320	41.470	33.180	51.870	169.520	25.640	118.060	248.740	324.800	15.400	1090.460
1998	I	9.530	4.570	26.870	13.190	44.440		68.000	142.980	69.910	67.810	11.020	3.540	
1999	I	2.138	1.276	3.450	3.538	41.603	44.046	102.926	62.627	40.540	39.657	10.480	3.822	356.103
2000	I	1.873	1.083	1.169	4.314	26.694	9.163	140.447	147.663	54.264	59.552	10.473	5.235	461.930
2001	I	14.263	18.309	21.185	14.739	101.695	87.117	101.483	65.216	39.892	29.597	9.215	11.623	514.334
mean Q	mcm	4.028	3.758	7.626	13.131	28.208	36.501	91.935	86.733	72.366	48.078	24.313	5.891	422.568

Annex 25 Element: MONTHLY CUMULATIVE RAINFALL (mm)												
Region: KEFA					LAT.	LONG.	ALT.(m)					
Station: BONGA					7.22	36.23	1650					
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1986	10.2	98.5	108.1	131.5	189.0	174.4	261.5	175.1	168.4	73.4	78.1	79.9
1987	46.5	100.5	144.4	170.5	247.5	126.2	150.5	207.9	120.4	222.3	34.8	108.7
1988	87.9	89.9	35.8	119.7	135.4	223.1	226.8	286.8	213.1	219.7	23.7	42.2
1989	42.2	38.5	128.5	201.8	108.9	98.5	179.8	205.2	169.6	164.3	34.3	118.0
1990	60.6	134.6	138.3	143.0	254.4	182.4	189.6	233.5	238.5	74.4	85.5	65.2
1991	73.2	47.2	127.2	226.1	202.3	199.6	194.2	263.5	201.5	66.2	52.0	51.8
1992	88.3	69.0	102.2	103.6	155.6	257.8	191.5	194.9	171.0	285.0	99.9	59.1
1993	88.7	89.8	99.3	250.0	277.1	234.9	176.2	124.2	202.8	183.1	11.4	2.7
1994	10.2	9.1	71.2	179.4	244.8	227.6	236.5	139.9	126.3	46.2	111.6	19.1
1995	0.0	41.7	52.3	139.9	153.4	160.7	172.6	214.4	223.3	56.8	31.6	151.8
1996	45.5	36.6	155.3	202.0	188.9	159.1	127.5	177.2	214.0	100.3	94.8	21.7
1997	86.2	12.0	127.4	231.7	205.9	212.7	181.8	146.0	138.4	239.9	248.2	125.9
1998	128.2	47.6	64.7	173.4	197.9	217.0	207.5	260.4	192.3	154.2	14.5	0.0
1999	33.8	6.0	108.1	174.6	181.9	138.2	165.1	121.9	138.0	146.7	23.0	22.2
2000	6.30	4.6	94.4	194.3	214.1	151.6	232.1	135.1	147.5	260.4	38.7	18.4
2001	11.1	45.9	119.4	202.9	262.6	192.5	178.3	197.3	195.7	118.1	69.7	6.4
2002	36.1	22.0	172.5	131.1	102.0	253.2	142.1	159.0	166.4	158.8	33.1	125.7
2003	47	23	52	213	48	252	463	433	314	27	46	49
Sum	902.00	916.80	1900.60	3188.80	3369.40	3461.65	3676.50	3675.70	3027.20	2596.60	1131.30	1067.50
No Yrs	18.00	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Avr	50.11	50.93	105.59	177.16	187.19	192.31	204.25	204.21	185.64	144.26	62.85	59.31

Annex 26 MONTHLY CUMULATIVE RAINFALL (mm)												
Region: KEFA	KAFA				LAT.	LONG.	ALT.(m)					
Station: WUSHWUSH					7.32	36.13	1950.00					
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1986	8.9	102.4	100.7	192.7	228.0	301.0	206.7	217.7	181.7	127.9	33.3	139.9
1987	28.6	88.6	118.9	173.5	212.7	140.8	122.1	233.9	143.4	209.1	37.9	76.6
1988	72.5	34.7	2.9	85.6	151.6	251.9	254.4	425.4	455.3	203.5	3.4	25.5
1989	66.5	29.8	169.9	186.2	123.3	171.2	293.8	217.9	234.1	152.2	50.3	74.4
1990	18.0	114.9	276.4	153.1	252.4	205.9	171.1	228.3	295.2	40.9	91.9	46.2
1991	73.9	46.4	137.9	216.6	256.6	247.7	143.9	272.9	180.9	77.8	87.7	33.5
1992	53.0	73.8	78.9	154.8	205.1	233.9	183.8	214.7	236.6	171.5	67.8	83.6
1993	73.2	79.6	176.0	177.9	204.2	268.2	243.9	112.7	219.6	118.8	7.9	29.1
1994	20.3	27.0	92.7	191.0	338.3	278.4	352.3	225.0	160.2	70.2	120.6	72.3
1995	1.2	56.5	75.6	161.7	202.8	169.8	153.2	211.0	227.0	68.2	50.8	161.7
1996	47.8	42.8	185.8	273.3	166.0	171.2	213.6	139.3	186.5	112.6	74.3	32.6
1997	75.6	7.1	145.3	276.6	222.3	248.2	197.3	215.1	161.0	322.0	151.2	188.6
1998	106.7	26.6	127.8	233.1	217.5	276.8	174.4	358.8	190.3	247.0	16.9	0.50

1999	14.5	16.3	108.9	255.1	187.2	120.0	203.5	150.3	196.5	124.7	20.3	28.9
2000	2.7	7.4	68.6	166.4	235.8	149.7	253.3	155.9	110.1	160.9	16.1	29.2
2001	16.3	43.5	124.5	130.7	279.7	251.2	223.3	145.6	195.8	164.6	72.0	28.6
2002	36.7	5.4	157.	154.9	150.9	174.7	195.9	161.5	141.7	117.9	34.8	127.
2003	54.6	15.4	137.9	222.1	109.0	270.9	211.6	243.5	227.1	56.30	65.20	37.4
SUM	771.	818.2	2285.7	3405.3	3743.4	3931.	3798.1	3929.	3743.	2546.1	1002.4	1216.
COUNT	18.	18.0	18.	18.0	18.0	18.0	18.	18.0	18.	18.0	18.0	18.
AVG	42.8	45.46	126.9	189.1	207.97	218.4	211.	413.6	207.9	141.4	55.69	67.5

Annex 27 NTHLY CUMULATIVE RAINFALL (mm)												
Region: KEFA					LAT.	LONG.	ALT.(m)					
Station: Chiri					7.22	36.23	1830					
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1987	37.50	94.55	78.90	154.70	226.90	223.10	78.90	196.80	127.60	209.20	29.10	38.80
1988	160.80	80.70	57.00	132.20	205.00	147.70	230.30	338.40	251.20	214.50	4.70	38.40
1989	59.60	92.60	152.30	264.50	127.20	148.00	289.50	148.90	179.30	167.50	69.10	120.50
1990	58.20	121.50	201.90	237.00	179.00	177.00	195.20	196.30	127.80	96.10	143.10	52.60
1991	118.40	91.50	145.50	203.80	224.80	185.60	141.70	267.30	183.40	55.10	42.60	42.30
1992	42.10	76.00	105.90	143.70	203.60	201.60	185.80	139.80	155.00	235.80	84.90	131.20
1993	59.30	120.60	113.40	213.80	245.60	139.90	117.00	127.00	102.40	211.50	55.30	15.90
1994	2.20	12.80	139.90	209.60	235.30	176.70	294.40	182.45	143.25	58.20	116.10	82.00
1995	0.60	49.30	63.50	150.00	132.60	165.70	162.90	212.80	225.15	62.50	41.20	156.75
1996	46.65	39.70	170.55	237.65	177.45	165.15	170.55	158.40	200.25	106.45	84.55	27.15
1997	80.90	9.55	136.35	279.15	214.10	230.45	189.55	249.75	149.70	280.95	199.20	157.25
1998	117.45	24.70	173.70	187.60	310.60	106.60	316.50	264.60	86.10	136.50	43.60	3.00
1999	11.60	11.10	119.50	129.40	188.40	138.70	119.80	198.50	213.70	126.20	19.30	21.80
2000	0.00	5.40	37.20	182.10	106.80	240.50	211.80	142.50	176.90	149.40	6.00	11.80
SUM	795.30	830.00	1695.60	2725.20	2777.35	2446.70	2703.90	2823.50	2321.75	2109.90	938.75	899.45
COUNT	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
AVERAGE	56.81	59.29	121.11	194.66	198.38	174.76	193.14	201.68	165.84	150.71	67.05	64.25

Annex 28 MONTHLY CUMULATIVE RAINFALL (mm)												
Region: KEFA					LAT.	LONG.	ALT.(m)					
Station: BONGA	Diri Goma				7.22	36.23	1650					
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1988.00	128.20	58.00	73.00	59.60	29.00	186.20	197.30	314.80	231.00	171.80	0.00	15.00
1989.00	85.90	33.90	151.20	157.20	214.60	160.80	264.20	281.50	191.60	133.30	9.30	92.70
1990.00	12.00	47.70	186.40	169.20	228.40	351.50	138.50	186.60	213.10	64.10	78.40	39.50
1991.00	68.90	45.60	87.60	230.80	199.20	176.60	212.10	283.30	205.10	37.00	20.20	39.10
1992.00	18.10	0.00	47.40	149.70	159.70	231.40	296.30	193.20	260.40	157.90	37.90	46.70
1993.00	138.80	98.50	169.70	140.40	225.80	152.70	285.50	245.00	200.30	179.30	21.29	36.40

1994.00	18.40	4.50	53.60	157.50	351.50	253.00	317.40	252.80	184.20	19.70	75.60	20.10
1995.00	15.90	35.90	31.30	229.70	190.10	195.70	257.40	256.80	223.30	73.40	38.10	121.30
1996.00	41.90	68.40	120.90	172.80	161.70	183.30	227.30	142.00	110.50	8.70	102.20	58.70
1997.00	78.90	0.00	137.30	216.20	421.70	411.70	165.40	99.40	128.00	200.70	11.50	142.90
1998.00	156.70	53.80	175.90	183.60	180.30	266.00	240.40	376.70	191.30	200.60	47.60	0.00
1999.00	20.60	23.50	22.10	199.50	273.60	215.90	207.40	120.00	199.60	105.80	9.70	30.10
2000.00	7.80	2.30	44.90	168.90	312.70	230.70	209.00	122.90	148.50	172.30	53.30	18.40
2001.00	19.70	67.70	90.60	162.30	253.50	276.50	145.10	190.20	188.80	127.00	46.40	47.40
2002.00	77.90	19.60	116.80	75.10	84.30	197.90	179.70	192.70	151.20	115.90	39.20	119.60
2003.00	59.30	48.10	60.20	187.40	74.80	300.00	150.40	158.90	147.20	29.30	59.90	30.80
SUM	949.00	607.50	1568.90	2659.90	3360.90	3789.90	3493.40	3416.80	2974.10	1796.80	650.59	858.70
COUNT	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
AVERAGE	59.31	37.97	98.06	166.24	210.06	232.66	218.34	213.55	185.88	112.30	40.66	53.67

Annex 29 Rainfall data of Gojeb station												
GOJEB-KEFA	LAT	LON	ALT		RAIN							
	7.42	36.38	1250.00									
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1974	11	59	105	58	314	157	145	156	160	32	0	7
1975	23	69	73	126	150	269	146	151	150	97	22	17
1976	44	100	118	78	226	299	190	190	167	74	68	30
1977	101	43	89	45	173	161	209	182	165	78	64	54
1978	25	65	158	207	247	201	247	222	91	98	49	46
1979	91	147	78	78	147	219	178	70	112	47	33	62
1980	16	45	82	213	217	135	136	116	84	28	56	25
1981	6	20	132	64	209	189	118	149	139	9	52	8
1982	38	37	66	150	131	243	99	182	193	125	118	80
1983	45	44	49	108	198	238	99	235	239	131	219	0
1984	11	0	61	168	189	267	251	264	160	37	320	45
1985	14	81	28	154	256	161	66	195	92	60	65	18
1986	0	49	100	149	151	153	255	193	168	19	17	43
1987	22	58	86	111	120	232	247	251	143	78	11	38
1988	19	16	7	106	170	335	379	489	266	125	0	11
1989	23	39	139	48	138	198	334	219	166	131	7	114
1990	5	113	132	122	167	218	169	187	244	92	31	86
1991	84	25	125	151	196	342	314	289	196	53	55	58
1992	40	52	107	146	296	201	220	297	310	239	79	55
SUM	616.30	1060.60	1735.20	2284.60	3691.60	4217.90	3802.60	4036.00	3245.20	1553.30	1264.20	796
AVERAGE	32.44	55.82	91.33	120.24	194.29	221.99	200.14	212.42	170.80	81.75	66.54	41.87

ANNEX 30 SUMMERY OF HYDROCHEMICAL DATA

SampleID	Site	Location	Date	pH	Cond	TDS	Na	K	Mg	Ca	Fe	NH4	F	Cl	SO4	NO3	NO2	HCO3
	Dincha	Dincha river		7.22	77	50		6	3.1	2.67	8	0.3	0.45	0.34	3.46		4.92	8.8
B H	Bonga Sheta BH	Bonga		7.01	257	182		30	7	8.27	23.2	1.56	0.6		1.74		8	5.72
	Dincha	Dincha river		7.22	77	50	6	3.1	2.67	8	0.3	0.45	0.34	3.46	4.92	8.8	0.05	41.48
Gojeb bore well	Gojeb		03 - 06 9			124		8.8	7.2	26.4	0.11			5	0.5	9.24		122
Hand Dug W	Bonga	Bekele Nega		7.16	190	169	6	19.2	3	12				17	12	16.2		59
HAnd Dug W	Bonga	Demise Bngo		8.64	267	179	9	3	7	23			0.06	32	6	68		13
Hand Dug w	Bonga	Getachew B		6.36	143	138	7	6.2	3	11			0.06	20	11	0.68		45
Hand Dug W	Bonga	W/Micicahl G/M		6.73	507	348	26	19	9	40			0.1	69	11	58		102
Mera Sprin	Mera							1.5	9.12	9.6	0			5	2.4	13.64		85.4
Sheta R	Sheta river at gageing			6.8	95	62	9	5.7	2.4	8	0.85	0.92	0.1	3.46	8.92	15.84	0.04	43.92
Sobra Spri	Sobra		13-6-97	7.46	50	50	5.75	8.5	3.84	9.6				5	1.6	17.6		48.8
Wongi Bore	Wushwush	Wongi	04-6-97E	7.32	47.9	168	3.77	3	7.2	20	0			5	0.5	8.36		102.5