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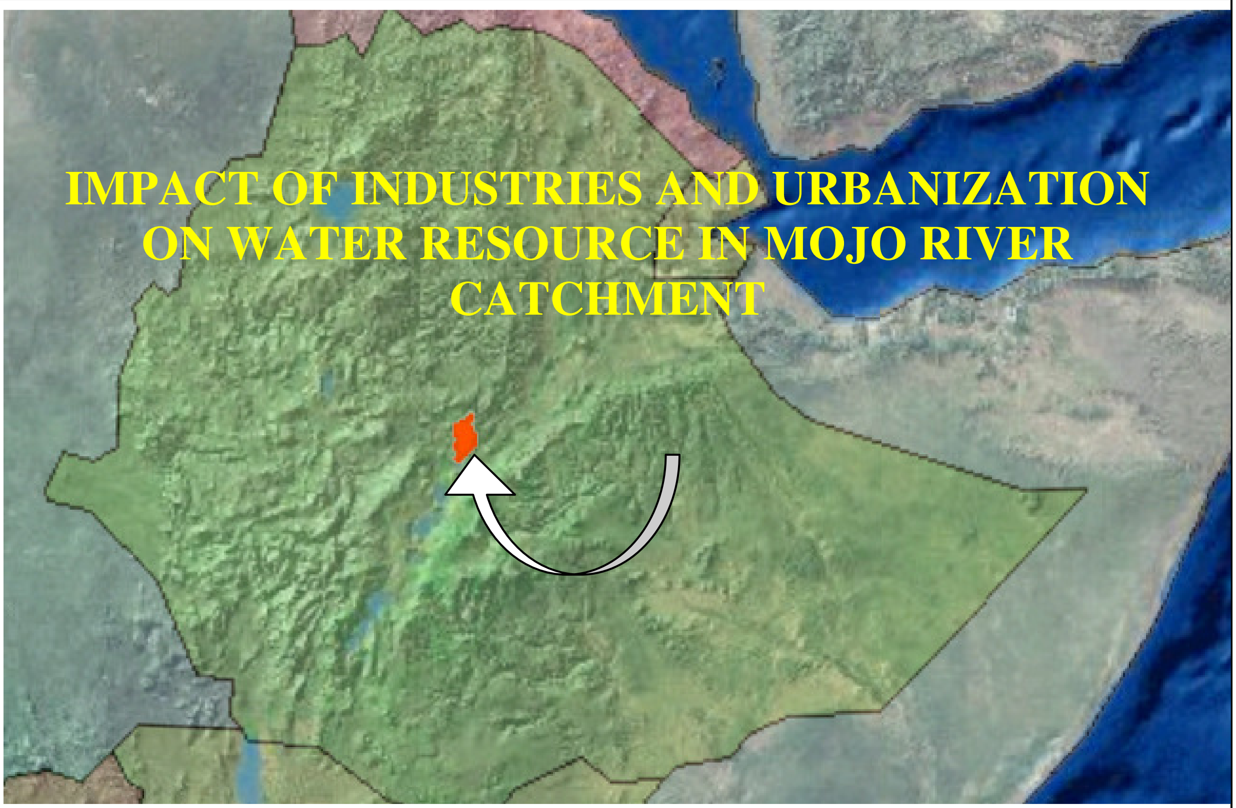

IMPACT OF INDUSTRIES AND URBANIZATION ON WATER RESOURCE IN MOJO RIVER CATCHMENT

A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment for the degree of Master of Science in Hydrogeology

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Table of content

List of Tables

Page

List of figures

ABSTRACT

This work is the study of the hydrogeochemical conditions of the 1506km^2 Mojo River Basin, within the Ethiopian Rift Valley, found about 70km^2 south east of Addis Ababa, between longitudes 38^0 56' E – 39^0 17'E and 8^0 34' N – 9^0 05' N latitude**.** The Mojo River Basin is in a state of progressive population growth and industrialization as well as agricultural activities, which are all potential sources of surface and groundwater pollution in the Basin.

The main objectives of the present research are identifying the major pollutant in the Mojo River, study the groundwater quality in the basin and identify its pollution condition of groundwater using hydrogeochemistry. The final use of such a study is to indicate the possible measures to be applied to prevent or reduce local sources of pollution of Mojo River in turn regional groundwater pollution.

Collection of water samples from surface (stream) and groundwater (borehole, dug well and spring) was done in two field operations at two different time periods. Physical and chemical tests have been carried out in the field and in the laboratory. In the field physical parameters such as pH, temperature and conductivity were measured in situ.

The main rock types in the Mojo River Basin range in age from Upper Miocene to Holocene and consist of consolidated volcanic(plateau and Rift Volcanic) and loose Lacustrine and alluvial deposit.

Overall, the water in the study area is a calcium-Sodium -Magnesium-Bicarbonate type which is characterized by a high concentration of Ca^{++}, Na, Mg^{++} and HCO_3^-. Mojo River is used for variety of purposes by inhabitants along their course. However, the discharge of domestic and industrial wastes from the town highly limits the applicability of surface water and also the quality of the groundwater in the area is deteriorated by infiltration of polluted water.

CHAPTER ONE

INTRODUCTION

1.1 Background

The health and welfare of humankind intimately tied to water. There fore the presence of adequate supply of uncontaminated water can dictate whether the contemporary region or community will grow prosper.

Water naturally contains a variety of dissolved substances like those resulting from the dissolution of minerals and some potentially quite harmful substances and manufactured contaminants that have reached the water system in varies ways posing a significant treat to water quality and community health. Moreover, the chemistry of water changes as agriculture becomes more intensive, the increase over time in population or extent of cities and town is more prominent and industry grow.

Pollutants enter the water system when we dispose of wastes improperly, such as by placing them in receptacles that rest and leak, by tossing them haphazardly into poorly designed land fills, or filling by them illegally on unmonitored land allowing them to seep directly to the water table or into an aquifer.

Both the biological and chemical quality of water are important in determining its suitability for domestic supply and each can have significant and well- documented health impacts on users. Poor microbiological quality arising from the contamination of drinking water sources by faucal matter is a major cause of water born illness.

Troublesome contamination of chemical substances that are of direct health concern can arise both from natural processes and pollution caused by human activities. Insecticides and fertilizers, salts and other chemical ice retardants washed from road ways, carcinogenic industrial by products from factories (such as PCBs), biological wastes from cattle feed lots and slaughter houses, and sewage from overworked septic fields and broken sewer lines are the major contaminant sources of water resource in Mojo area.

Moreover, as water usage has increased in an accelerated rate in recent years, and the growing industrialization and urbanization indicating this trend will continue, quality and proper utilization of waster need a great concern.

The project area, Mojo river catchment, is found in the Main Ethiopian Rift where Mojo town and other five small towns included namely Chefe Donsa, Robgebeya, Godino, Koka and Ejere. The area covers about 1506 Km^2 and is bounded with in 8^0 34' N – 9^0 05' N latitude and 38^0 56' E – 39^0 17'E longitude (fig 2.2). The average elevation in the catchment ranges between 1780m to 2700m above mean sea level at Mojo town and Mount Yerer respectively. The study area is about 70kms, south east of Addis Ababa. Near the catchment there is a meteorological station located at Debre Zeit Air Force. The mean annual temperature around Mojo is 20.4^oc and the mean annual rainfall is 969.35mm.The relief of the study area is generally flatland with an undulation of some ridges and mountains like eastern part of Yerer and the catchment generally shows an eastward decrease in mean sea level.

And Over the last few years there has been a radical evolution in industrial development, as significant changes in urbanization leads development of a number of industries, and evolution in agronomic practice in Mojo area associated with attempts to increase industrial outputs and agricultural productivity.

1.2 Previous work

Along with the main Ethiopian rift system, many researchers like Kazmin, Tsegaye Abebe, Seifemichael Berhe (1978) and Alem Tiruneh (2003) studied the geology of the area and produces a geological map with a scale of 1: 25000 and 1: 100000. Few hydrogeological studies made in the area are of reconnaissance nature and focus mainly on Mojo town water supply therefore, it can be said that they have little importance to understand the hydrogeological characteristics, pollution condition and variations in the whole catchment.

1.3 Objectives of the study

1.3.1 General objectives

This research work is conducted to evaluate extent of pollution of Mojo River and its interaction with the ground water in the basin.

1.3.2 Specific objectives

•Study the hydrogeology of the Mojo River catchment that covers a total area of 1506km2
•To identify the major pollutant in the Mojo River.
•To study the ground water quality in the area.
•To identify the pollution condition of he ground water in the area.
•Modifying hydro geological map of the area and indicating ground water flow direction.
•Analyze ground water potential of the area.
•Evaluate basic components of hydrologic cycles
•Recharge estimation using hydrologic components
•Study the hydrological characteristics and hydrochemistry of the area
•the final aim of the study is to indicate the possible measure applied to prevent or reduce pollution of Mojo River basin causing ground water pollution and Provide pure water for the community.

1.4 Methodology

The study was started with literature review. Collection of meteorological data like rainfall, temperature, sunshine hour, wind speed, relative humidity and pan evaporation data were done from Mojo, Debrezeyet, Nazret, Chefedonsa, Koka, Dertu leben, Ejere and from some other stations within and out of the study area. All other existing data like pumping test, topo sheets and aerial photographs were collected from relevant offices and used for interpretation. Then boundary of the study was delineated using topo sheets in conjunction with aerial photographs.

Techniques of water shade dividing points were in general followed to mark the boundary line of the area. Hydrological data (river discharge) of Mojo River was collected at different localities. Within the delineated area, the exact location and elevation for boreholes, dug wells and springs were recorded in the field using GPS and altimeter.

Conductivity meter and pH–meter have been used, in the field to collect chemical parameters, which also used to check the laboratory result. Discharge of springs measured in the field using buckets and watch**.** Water samples were collected from all existing water points both ground and surface water points giving emphasis the relationship between the aquifer chemistry and the water points chemical property. In addition, the water quality study is of important in measuring the degree of pollution in the vicinity due to the presence of waste disposal of different factories and human activities in the area.

Finally in addition to presenting laboratory test results of the different water samples and relating those with industries and urbanization, analysis based on different meteorological and hydrological data in order to observe the extent of ground water recharge were done.

Limitations of the research work

h Geological mapping is done with a limited field observations supported by interpretations of satellite imageries and topographic maps. No thin section analyses and no cross sections to see the depth and stratigraphy of the area have been made.

h Hydrogeological Map is only modified from Hydrogeological Map of Nazret EIGS 1985

h Enough water chemistry analysis is not done for River and Borehole samples to detect extent of pollution and to show surface water interaction with the groundwater system to the ultimate.

h Optimum data are not fulfilled to produce vulnerability Map of the study area.

CHAPTER TWO

GENERAL OVERVIEW OF THE STUDY AREA

2.1 Physiography, Land use and Land cover

2.1.1 Physiography

The major landform of the area, which is a direct reflection of the different volcanic stratigraphic succession, tectonic activities and the action of erosion between successive lava flows consists of flat to undulating plains, hilly plain, volcanic cones, etc. of these, major flat to undulating topography occupy the major parts of the catchment. Major landscape of the study area comprises of lava plateau at northern extreme of the catchment, and volcanic land forms, which are mainly falls in medium altitude range (1800 –2400 masl); hilly and valley landforms of the rift margin, which are relatively decrease in altitude (1602 –2000 masl) and the volcanic Lacustrine plain and flood plain of the rift valley part with slight altitude range (1650 –1750 masl). The plateau and hilly land form /landscapes are further sub divided into different relief forms thus, from fault scarps to gently slopping land forms, where as the volcanic Lacustrine plain shows variation in relief form. The average elevation in the catchment ranges between 1780m to 2700m above mean sea level at Mojo town and eastern side of mount Yerer respectively As to the geological set up, the area belongs to the Quaternary rocks of Pleistocene and Holocene, which is not yet differentiated to certain rock groups, and tertiary basalt of Paleocene-Oligocene-Miocene age of the plateaus adjoining to the rift.

2.1.2 Land use and Land cover

Soil type, mineral resources, vegetation, topography, climate and location influence the potential use of a piece of land. And based on these factors land can be used for urban development, small and large scale agricultural activities, and forestry, mining or solid waste disposal. Open bushy woodland being the dominant, open bushy wood lands, dense wood lands, grass land, and open shrub are the prominent types of vegetations that are found in the study area.

2.2 Water Resource

The water units found in the study area are Mojo and Gale Wemecha Rivers. As in most part of Ethiopia, a considerable part of the study area is affected by temporary watercourse, and surface runoff. This part of the study area is characterized by deep and active gullies, severe sheet erosion, rock out crops and small pockets of farmlands.

2.3 Cultivated land

The main land use categories are cultivation of annual crops and livestock grazing and urban centers. There is a significant difference in extent and intensity of utilization with in each land use type and each activity has not been equally practiced. So that, crop production has got a lion share of the existing land use than livestock rearing, this is considered as a secondary activity. Nevertheless it is an essential part of agricultural practices to back up the crop production. Cereal crops are entirely based on rainfall (rain fed cropping) but root crops, and vegetables are produced along Mojo River.

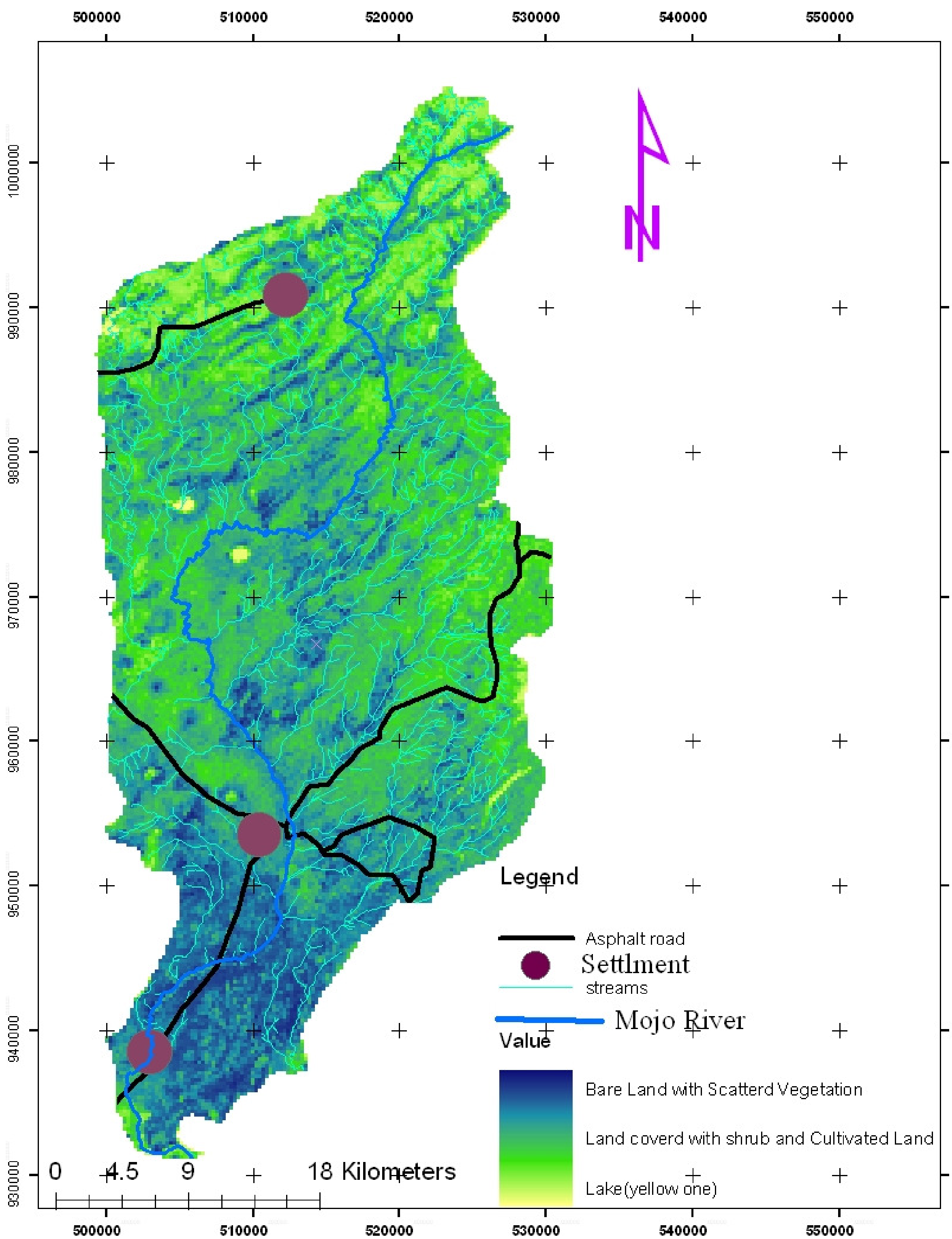

Fig. 2.1 Land use land cover Map of the study area

2.4 Accessibility

The study area is being served with both all weather road and dry weather roads. Road density is an indicator, which shows how road communication network is facilitated in a given area under consideration. Hence road density is 0.19 and 0.10 for all weather roads and dry weather road respectively.

2.5 Population and settlement

Mojo, Robgebeya, Chefedonsa, Ejere and Koka are some of the towns and villages found in the study area. Settlement has shared considerable size of land in urban areas whereas settlement patterns of the rural areas are in a very scattered way. According to the Ethiopian statistical office, 1994 population and housing census data, the population of the above mentioned commercial towns is around 198,065. In the study area, Socio-economic and industrial activities are growing in significant manner. And these urban and industrial developments are all potential sources of surface and ground water pollution in the Mojo River Basin

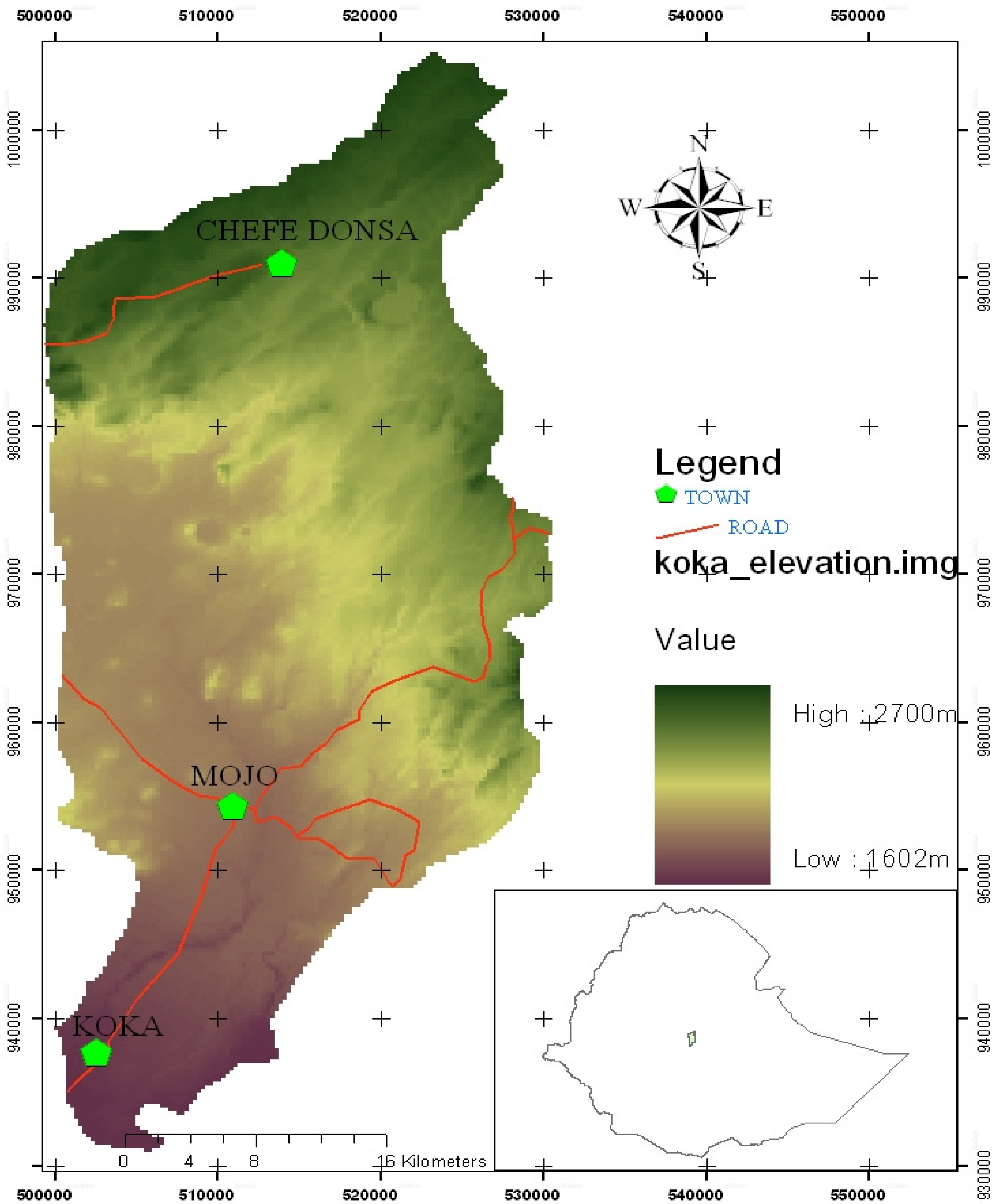

Fig.2.2. Location Map of the study area

CHAPTER THREE

GEOLOGIC SETTING

3.1 Regional Geology

In Ethiopia, the present morphology, Physiography, and geological settings are a result of two major post-Paleozoic events which were followed by important phases of volcanic activity (Mhor, 1964). The first tectonic event which occurred in late Mesozoic-Early Tertiary period produced the Afro Arabian Dome. The associated fissure volcanic activity gave rise to the extrusion of the Trap Series succession (plateau volcanism) which is considered to be the up-doming (Mohr 1967). The extrusion of the Trap Series fissure basalt during Eocene-Oligocene time was the major and the largest volcanic episode on both the South Eastern and the Western plateau of the pre-Miocene period (Kazmin, 1975). The second tectonic event resulted in rift development and related volcanic phenomenon during late Tertiary-Quaternary period. The extensional tectonics which produced the Ethiopian Rift is genetically related to the Great Rift Valley of East Africa.

The Addis Ababa- Nazret Area is covered by Miocene- Pliocene volcanic succession. In the exception of topographic highs resulted from volcanic centers of Wachacha, Yerer and Scoraceous cones and crater lakes in Debre- Akaki area, the topography is flat from Filuha to Mojo. A zone of intensive faulting like the Wonji fault belt which is found a certain kilometers east of Mojo are not seen regardless of the fact that the area is located where rift influences are significant.

These volcanic succession rests uncomfortably either on upper sandstone unit of Kimmeridjion age or limestone unit Collovial lower- Kimmeridjion age at Muger and Abay Gorge respectively.

3.1.1 Nazret Group

This group compromises a thick succession of ignimbrite, unwedded tuffs, ash flows, Rhyolites and trachytes out cropping mainly on the rift floor attaining a thickness of more than 250m and to some extent in the rift escarpments and on the adjacent plateau margins. According to Kazmin and Seifmicheal, this group name was informally used for lower welded tuff(related to Werchecha trachyte volcanism) , Aphanitic Basalt(shows vertically curved columnar jointing together with sub horizontal sheet jointing) and upper welded tuff(related to Yerer volcanism). The wide distribution of rhyolitic domes is an evidence at hand to say silicic centers dominate at the latest stage of Nazret volcanism which was accompanied by the Arba Gugu shield volcano and Chilalo and Badda volcanoes which occurred during the early and later stages of Nazret volcanism respectively. The Nazret group rests uncomfomably on the Addis Ababa Basalts and there is Bofa Basalt on the top of the Nazret volcanic succession. This group corresponds to the youngest age of Addis Ababa Basalt and to the oldest age of Bofa Basalt within a range in age of 6.4 to 2.8my.

3.1.2 Bofa Basalt

This young olivine porphyritic basalt of age 2.8my (Morton at el., 1978), dated in the Awash Gorge near Kereyu Logde, is characterized by big vesicles that are filled by calcite. Bofa Basalts are not restricted to the central part of the rift as are younger units, but are rather evenly distributed over the rift floor. And they represent an episode of fissure eruption which immediately followed a major faulting. The Bofa Basalts may include much older flows, for example an age of 3.5myr, which was established by Mohr (1971) for Basalts in the Nazareth vicinity which possibly belong to the same unit. They outcrop southward from Akaki River in the form of boulders 10m thick and appear to terminate a few kilometers west of Mojo. Bofa Basalts contains labrodorite, plagioclase, olivine and augite phenocrysts within crystalline andesine, clinopyroxene, and indigsitized olivine ground mass and some calcite vein in place of plagioclase. Bofa Basalt comprises a number of flows of compact fiamme ignimbrites in places intercalated with aphanitic basalt and unwedded pyroclastics

3.1.3 Wonji group

As pointed out by many authors (Mohr 1967 and others; Gibson 1970; Daken and Gibson 1971; Meyer et al.1975), this group of volcanism is related to the axial extensional zone of the Wonji fault belt. Although some volcanic manifestations such as eruption of basalts and central volcanoes occur outside the belt, the bulk of the Pleistocene-Recent volcanism is undoubtedly controlled by this tectonic feature. According to Kazmin and Seifemichael, 1978 the name Wonji group has been used for Dino ignimbrites, Pentelleritic volcanic centers, and sub recent and recent fissure basalt and with some minor units such as hyeloclastites, explosion centers and rhyolite domes. This group which covers a considerable portion of the rift floor is underline by the Nazret group and is the youngest in the area. This group is dated 1.7- .5my and found aligned en-echelon along segment of the Wonji fault belt. It is overlain by porphyritic plagioclase basalt near Nazret and underlain by the aphanitic basalt of the Nazret group at the same place.

3.1.4 Lacustrine cover and Alluvia deposits

Mojo and its surrounding areas are supposed to have been covered by ancestral lake during the pluvial period of the Quaternary. The Lacustrine sedimentations are the results of deposition in this large ancestral lake (Mohr, 1967 and Tsegaye Abebe, et al., 1999). The age of the lacustrine rift sediments is contemporaneous with the Wonji volcanic. They are mainly of volcanoclastic sediments and tuffs with silts, clays and diatomites; silts and clays are the dominant once. Alluvial deposits are also common in the Rift, associated with flood plains and at some places mixed with volcano clastics.

3.2 Tectonics

The East African Rift System (EARS), formed as a result of the brittle African continental 'plate' responding to stretching forces that are driven by very slow creep of rocks hundreds of kilometers deep in the Earth, is a region of continental break-up that accommodates the relative movement between the African and Somalian Plates. Within the EARS, the Main Ethiopian Rift (MER) represents a key area as it connects the Afar depression to the Kenya Rift. The MER is characterized by a fault pattern composed of a NE-SW border fault system and a N-S to N20°E-trending system, composed of en-echelon right-stepping faults obliquely affecting the rift floor (Wonji Fault Belt, WFB). The MER tectonic evolution is matched by an intense volcanic activity up to historical times, characterized by a typical bimodal composition. Correlation of pyroclastic deposits on the rift shoulders and within the rift depression suggests that these explosive deposits were associated with the main initial events of the MER opening, which took place around 6.5 Ma. This first phase of rifting was associated with a NW-SE extension direction and determined the development of the NE-SW-trending boundary faults and related fractures. Due to a lateral, extension-parallel, migration of magma from below the rift depression, important off-axis volcanoes formed on the MER shoulders during this rift event. A change in the extension direction to E-W to ESE-WNW determined a later (Quaternary) stage of oblique rifting with a left-lateral component of motion long the rift axis. This oblique rifting determined the development of the WFB system. The dextral components of displacement along some WFB faults can be explained as related to a counter-clockwise block-rotation internal to the deformation zone, as also supported by analogue modeling. The Quaternary stress field re-orientation also caused the off-axis volcanic activity to be strongly reduced by inhibiting the lateral transfer of magma. Particularly, during the second oblique phase, the development of the newly-formed en-echelon oblique and strike-slip faults of the WFB localized the uprising of melts within the rift axis and favored the volcanic activity to be concentrated along the en-echelon WFB segments.

3.3 Geology of Mojo River Catchment

A number of regional and local geological studies have been carried out by in several workers in varies parts of the rift valley. Most of the local geological information for the present purpose is taken however from geological map of the Ethiopian Rift (V. Kazmin, 1997) at a scale of 1: 25, 000. The study area is mainly covered by two classes of rock describing the geology in exclusive terms.

♦Volcanic rocks

The volcanic succession covers the area at large, (about 70% of the studied area), and have composition ranging from basalts to per alkaline Ryolites and define an age range between the Miocene- Pliocene boundary and the Pleistocene.

♦Volcano-Sedimentary deposits

Consist of alluvial cover and Lacustrine sequences (About 30% of the studied area).

The study area can geologically be represented by the following rock units:-

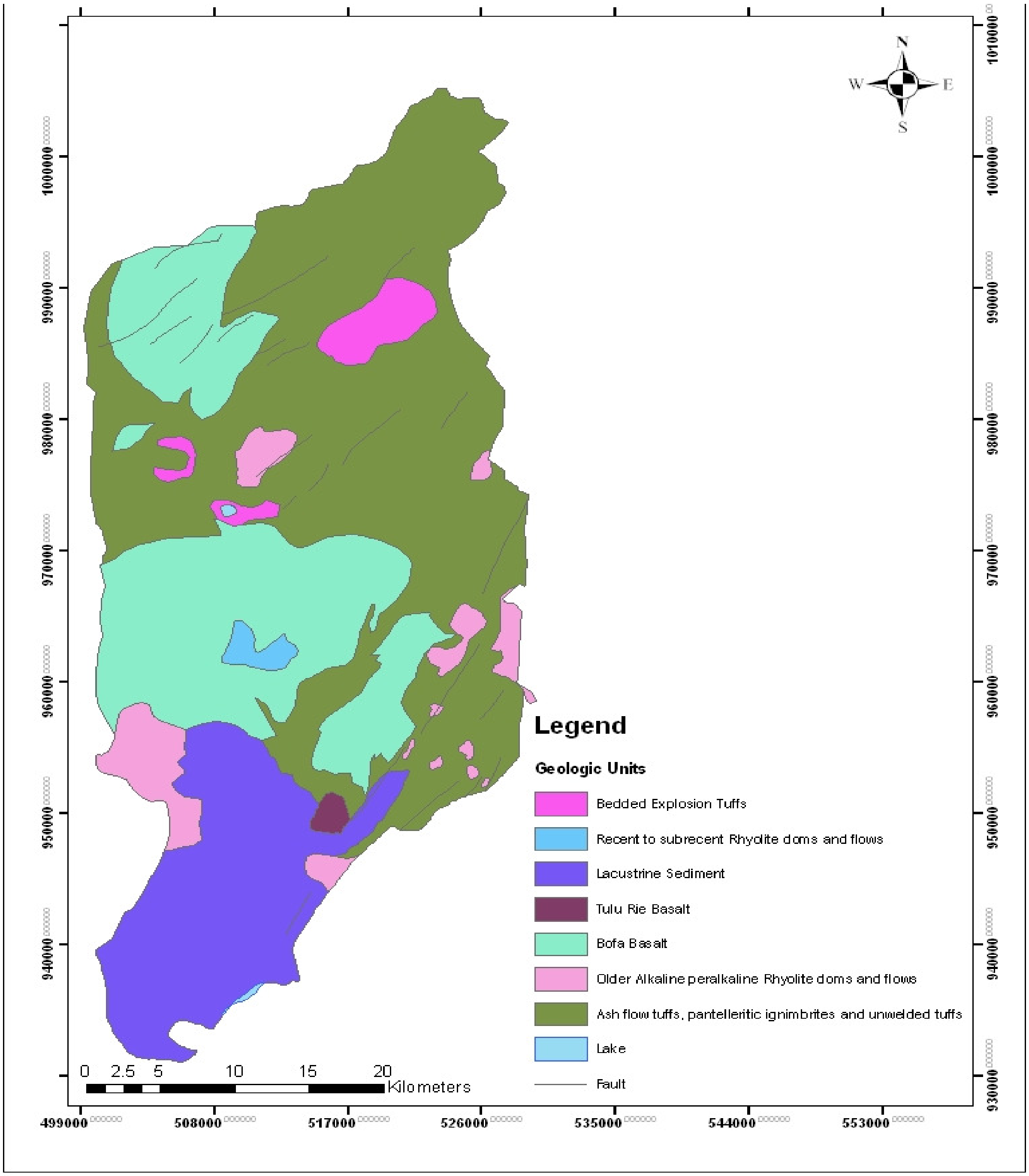

Fig. 3.1 Geological Map of the study area (modified from Geological Map of Nazret EIGS 1978)

3.3.1 Recent to sub recent Rhyolite domes and flows

Covers a small part of the study area and it is found in the central part intercalated within the Bofa basalt. This unit is compact, porphyritic rhyolitic lava flow described as the remnant wall of the volcano tectonic sub-circular collapse of the Pleistocene age. Berehane et al, 1978.

3.3.2 Tulu Rie Basalt (TRB)

Tulu Rie Basalt crops out in the southeastern section of the study area. The unit belongs to intra Rift complex where it covers the Nazret unit and forms the upper part of NE trending escarpments. Lavas have mainly olivine basaltic composition, and rare plagioclase–rich basaltic andesites are also found. The basalts show porphyritic or subaphyric texture, the phenocrysts are generally constituted by olivine. The age ranges between 2.7-1.8Ma. The Tulu Rie Basalt is considered, for its stratigraphic position and composition, as a part of Bofa Basalt of Kazmin and Seifemichael Berhe (1978). The TRB consists of sub horizontal or slightly tilted tabular lava flows. The maximum observed thickness is 20m at Tulu Rie Basaltic ridge at the southeastern catchment.

3.3.3 Bofa basalts

It is found on the northern, western and central parts of the study area. It covers about 880 km2 of the study area. The assemblages of the unit are mainly olivine, clinopyroxene, apatite and rare plagioclase–rich basaltic andesites are also found (Gezahagn Yirgu, 1980). The basalts show porphyritic or subaphyric texture is vesicular, less weathered and friable.

3.3.4 Ignimbrites

This grayish red in 0color, moderately to highly weathered rock units are medium to course grained with a kind of sheet flow structures and show eutaxitic texture with oblate glassy fragments sometimes with recrystallized rims. This is one of the youngest rock units found in the study area explained by the flow took place into preexisting valleys of the escarpment and it also climbs to mountains revealing that they occurred after trap series. This unit is a basal unit grouped under the intra Rift complex and may constitute the upper part of Nazret Group of Kazmin and Seifemichael Berhe (1978) with respect to age constraints.

3.3.5 Ash flows and welded tuffs

The ash flows are exposed in the study area forming a thin layer of 2-30cm thick intercalation of continuous horizontal layering. And are greenish gray in color. The fine grained compacted welded tuffs are less weathered at the bottom and highly weathered at the top with secondary fillings.

3.3.6 Lacustrine deposits and alluvial cover

The lacustrine beds are interbedded with Pliocene-Pleistocene ignimbrite in lakes region and on the rift shoulders in general and in Mojo and its surroundings in particular (Mohr, 1966). They are mostly redeposited volcanic sands, siltstone, sandstone, calcareous materials and diatomite with intercalation of water-laid tuffs. The deposition is found on the closest vicinity of Lake Koka, lake Hora, and Lake Kilole. They represent about 30% of the exposed rocks and are developed on a relative NE elongated depression in the central sector of the area. These deposits are generally brown-yellowish in color, fine to medium grained in texture, thinly stratified, very friable, and less compacted.

CHAPTER FOUR

HYDROMETEOROLOGY

4.1 Climate

The study area, which is about 70kms south east of Addis Ababa, is characterized by tropical rain climatic conditions. The seasonal changes in extent and intensities of these climatic elements dictate biological activities and life performance of plants. Climate also governs soil genesis, which intern influence plant growth either positively or negatively. Various climatological elements of the study area were summarized using the data obtained from National Meteorological Services Agency (NMSA) and are stated below

4.1.1 Temperature

The mean monthly temperature for about 30 years was taken from a number of stations in the study area. Referring from National Meteorological Services Agency, the study area has an average temperature of 20.4^{0}c with a minimum temperature of 11.6 ^{0}c and a maximum temperature of 29.2^{0}c. Maximum temperature values were obtained in the months of May and minimum temperature was recorded in the month of August and it has generally been observed that the average annual temperature decreases with an increase in altitude.

The monthly mean minimum temperature for Mojo station ranges from 8.5^0 C to 13.5^0 c, where as the lowest is being recorded in December. The monthly mean maximum temperature for Mojo station ranges from 25.6^{0}c – 30.8 ^{0}c where as the highest temperature is being recorded in May and the lowest in August.

Average	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	27.6	29.1	30.2	30.2	30.8	29.1	25.7	25.6	26.9	28.2	28.0	27.7
Min	10.3	12.1	14.1	14.25	14.66	14.31	14.38	14.11	13.36	11.61	10	9.31

Table 4.1 Monthly Mean maximum and minimum Temperature (^{o}c), Mojo

station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
Koka	20.3	22.2	22.5	23	23.6	23.1	21.7	21.7	22.2	21.7	20.5	19.9	21.9
D/Z	18.4	19.8	21.5	21.7	22.2	21.1	19.3	19.2	19.6	19.4	18.8	18.1	19.9
Mojo	18	19.3	20.6	20.9	20.9	20.1	18.8	18.7	18.8	18.4	17.6	19.7	19.3
MMT	18.9	20.4	21.5	21.9	22.2	21.4	19.9	19.9	20.2	19.8	18.9	19.2	20.4

Table 4.2 Mean annual temperature (^{o}c) of the area

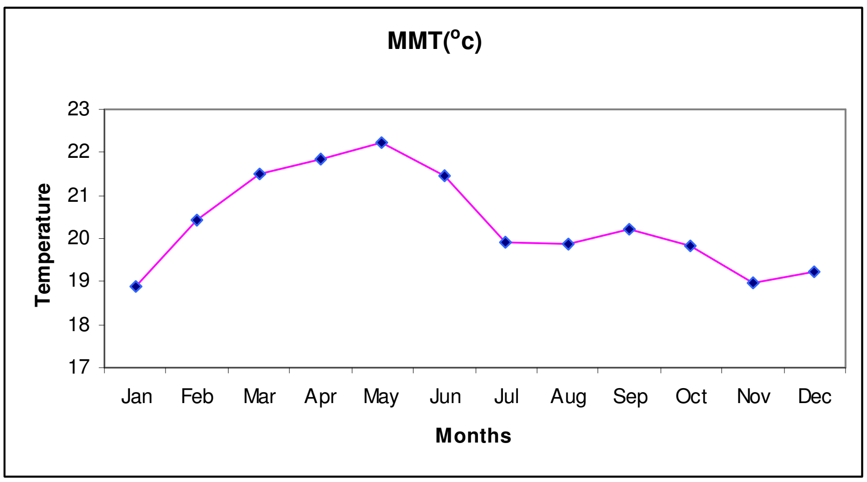

Fig. 4.1 Mean annual temperature in (^{o}c)

4.1.2 Wind speed

In the study area, data on monthly mean wind speed at 2meters presented only for Adama meteorological station. Accordingly, the mean monthly wind speed of the area measured at two meters above the ground varies from 1.8 to 3.5m/s. with maximum values observed in the months of January and December and minimum values in the months of September and October.

	J	F	M	A	M	J	J	A	S	O	N	D
Wind Speed (Km/hr)	3.5	3.2	3.1	2.7	2.7	3.2	3.4	2.9	1.8	2.5	3.2	3.4

Table 4.3 Monthly Mean wind speed at Nazret Meteorological Station

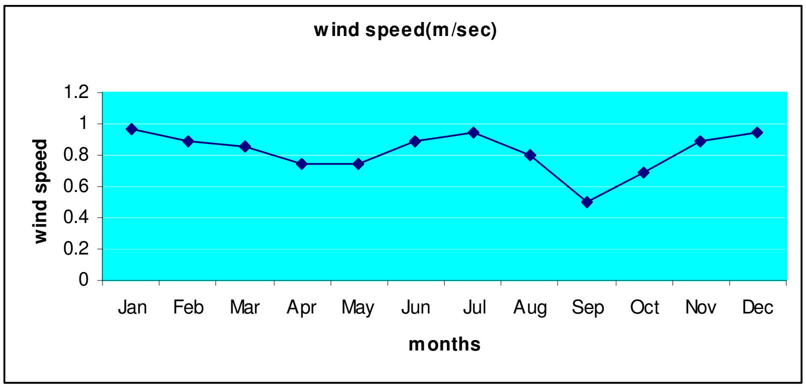

Fig.4.2 Mean annual wind speed (m/s)

4.1.3 Sunshine hour

Sunshine hour of the area is represented by data taken from Deberezeyet station. And a maximum sunshine hour of values above 9 is observed in the months of October, Novovmber, December and February; 5.5 and 6 are minimum values in the months of July and August

	Jan	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MMSD	8.9	9.4	8.4	8.4	8.6	7.2	5.5	6	7.7	9.3	9.8	9.7

Table 4.4 Monthly Mean sunshine duration (MMSD)

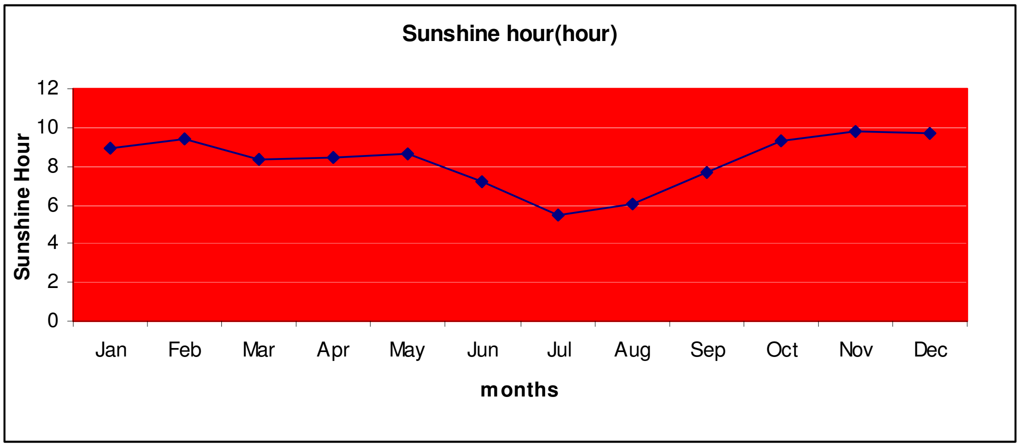

Fig. 4.3 Monthly Mean sunshine duration (hour)

4.1.4 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. The relative humidity of the air is largely dependent on temperature and rain fall. The study area at debrezeyet station has a maximum mean humidity value of 79.3 in the month of August and a minimum humidity value of 56 in the month of February.

	Jan	Feb.	Mar	Apr	may	Jun	Jul	Aug	sep	Oct	Nov	Dec
Relative humidity	59.1	56	57.7	60.9	59.8	68.2	76.8	79.3	75	60.3	59.1	59.7

Table 4.4 Monthly mean relative humidity (%)

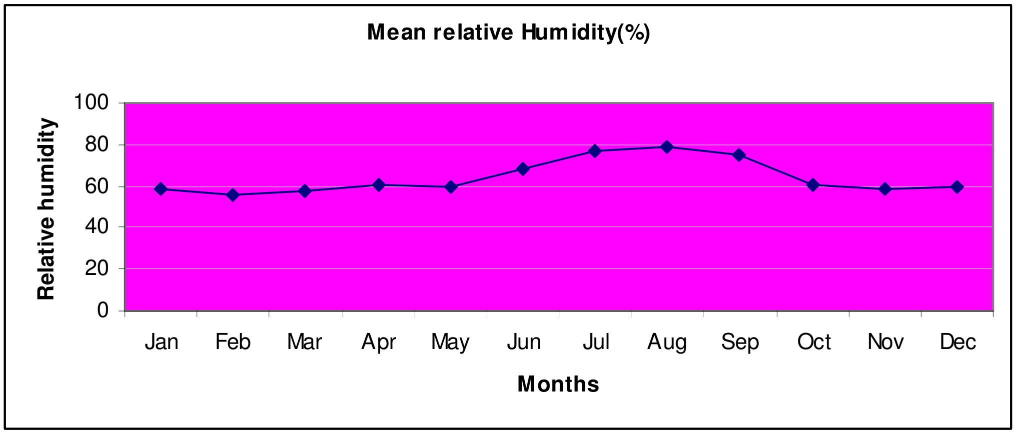

Fig. 4.4 Monthly mean relative humidity (%)

4.2 Hydrology

4.2.1 Rainfall

Atlantic equatorial westerlies, the southerly and easterly Indian Ocean air currents being the sources from which Ethiopia receives rainfall, the country can generally be classified in to four regions of rainfall, (Mesfin w/Miriam 1970). These are:-

►Southwest region which are wet most of the year

►West and central regions which receive summer rainfall

►Southeast region which receive spring and fall rainfall

►Red sea region which receive winter rainfall

The study area is located within the main Ethiopian rift and mostly affected by the southerly and easterly Indian Ocean air currents as a result the air currents supply rain with bimodal characteristics. According to data obtained from meteorological services agency, precipitation data from 12 stations in the area signify that there is high peak of rainfall from June to September, low from March to May and dry from October to February.

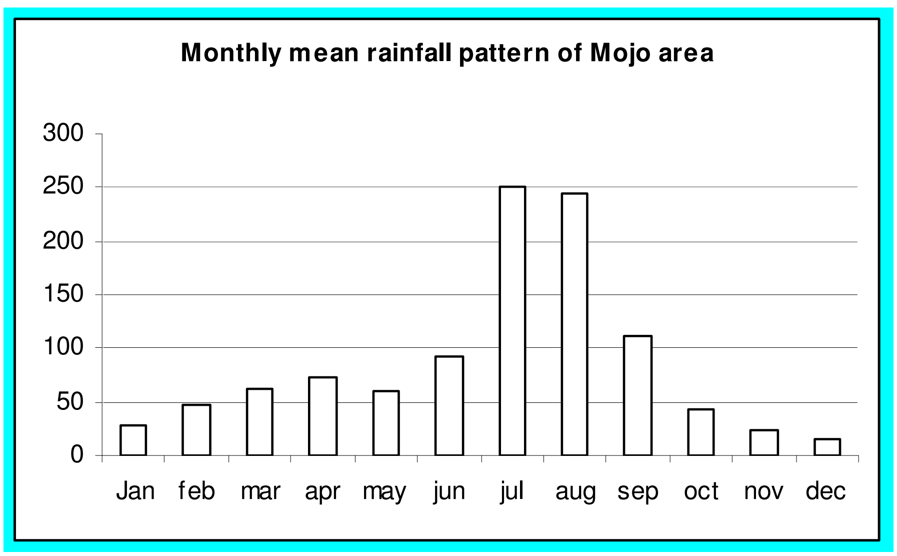

Fig. 4.5 Monthly Mean Rainfall pattern of Mojo area.

4.2.1.1 Average Aerial Precipitation

Measurement of rainfall depth with a point observation may not be used as a representative value for the area under study. In order to make these point measurements represent the catchment considered, the values need to be averaged over the area. Accordingly the rainfall depth analysis over the catchment is determined using three main methods for calculating average precipitation over the area.

a) Arithmetic mean (average)

This method is very simple. It involves the addition of all the measured gauges and then averaging them. This method can give good results in flat areas having uniform rain gauge distribution. The calculation can be done according to the following formula:

$$\overline{P} = \sum_{i=1}^{n} Pi / n$$

Where: $\overline{P}$: average precipitation depth (mm)

P: precipitation depth at gauge i

n: total number of gauging stations

Mojo, Koka, Debrezeyet, Chefe Donsa, and Ejere are the stations within the catchment used to compute the average rainfall using this method.

This method in our case is used due the fact that the stations are more or less distributed evenly and the topography is flat. Using this method the average rainfall over the catchment is calculated to be 980.58mm.

b) Thiessen polygon method

This method considers random nature of topography and distribution of stations. As a result good rainfall depth values are expected when the rain gauges are not evenly distributed over the area in both flat and hilly terrains. The method assumes that the recorded rainfall in a gauge is representative for the area half way to the adjacent gauges. The method involves the connection of the stations on the map by lines and drawing the perpendicular bisector of the lines joining the adjacent stations. And the observed precipitation (P_i) is weighed according to the area (a_i) of the polygon associated with it.

Five stations, three within and two out of the catchment are used. The table used to compute the average rainfall depth using thiessen polygon is given below.

S.No	Station	Area of influence(Km^2)	Mean RF(mm)	Weighted area%	Weighted RF(mm)
1	Mojo	339	961	23	224.06
2	Chefe-Donsa	501	1027	33	353.87
3	Koka	77	870	5	46.07
4	D/Z	553	934	37	321.83
5	Nazreth	36	950	24	23.52
	Total	1506		100%	968.13

Table 4.5 Theissen polygon method to calculate the average rainfall depth over the Mojo river catchment

As it is seen in the table, using thiessen polygon method of computation, the average annual rainfall depth over the catchment is 968.13mm.

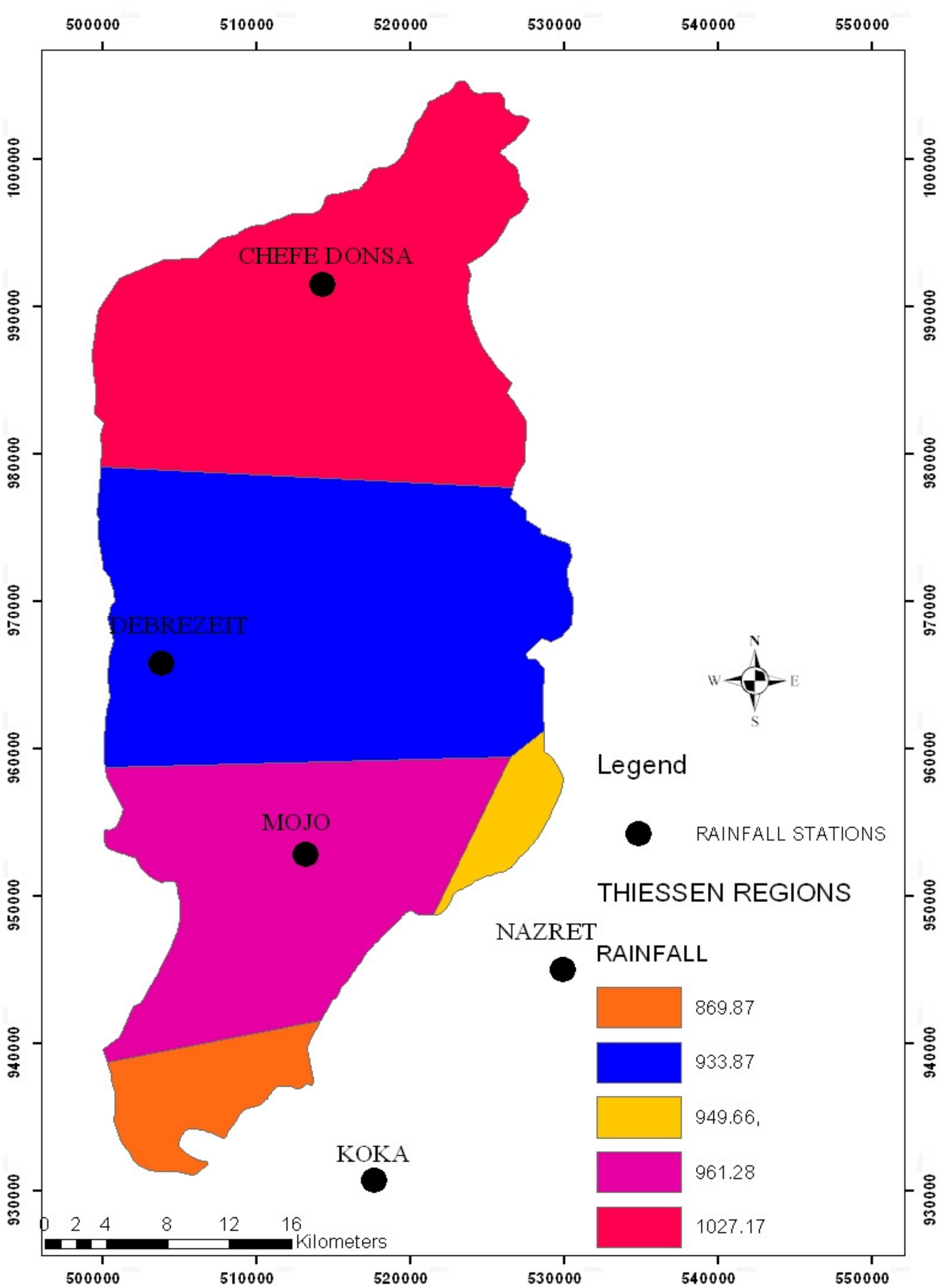

Fig. 4.6 Thiessen polygon Map of the area

c) Isohyetal method

Contours of equal precipitation (isohyets) are drawn for the area. The area between successive isohyets is calculated and multiplied by the average rainfall on that area. The average rainfall is the average value of the two adjacent isohyets. The average rainfall over the catchment is the total of all three products. This method is considered to be the most accurate method as it works for all types of terrains (flat or seep) and the stations do not necessarily be equally spaced. The method uses the following formula to calculate the average rainfall depth and as the insignificant differences of the results above gives value almost similar to the value computed using Theissen polygon method.

$$Pa = \frac{P_{12}a_{12} + P_{23}a_{23} + \ldots\ldots + P_{n-1.n}.a_{n-n.n}}{A_t}$$

Where p_{12}- rainfall depth between isohyets 1 and 2

a_{12}- area enclosed by successive isohyets 1 and 2

A_t- total area.

Therefore, the average rainfall depth over the catchment is the mean value of the results obtained; i.e. about 975mm

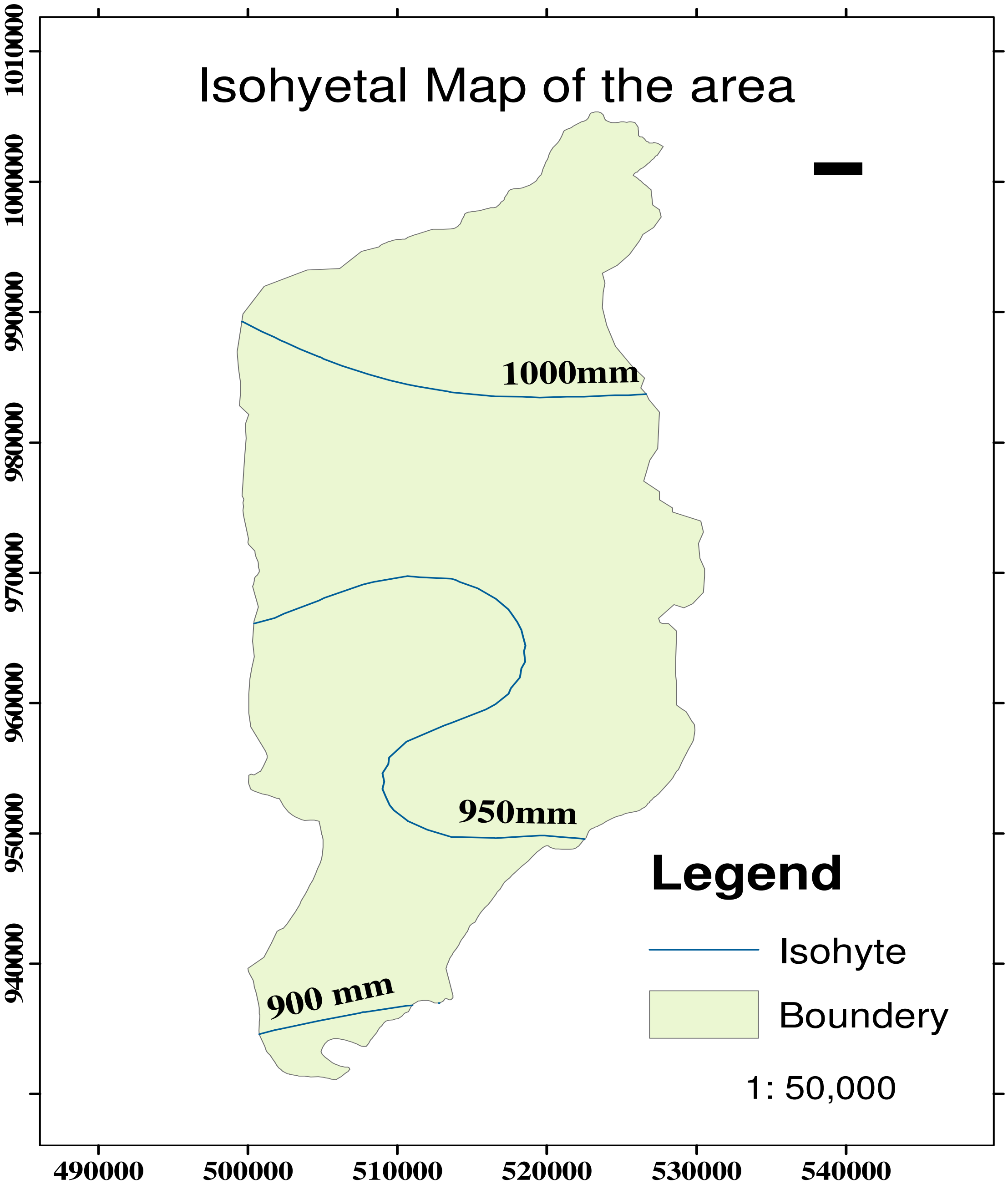

Fig. 4.7 Isohyetal Map of the study area

4.2.2 Evaporation and evapotranspiration

Water is removed from the surface of the Earth to the atmosphere by two distinct mechanisms: evaporation and transpiration. Evaporation can be defined as the process where liquid water is transformed into a gaseous state. Evaporation can only occur when water is available. It also requires that the humidity of the atmosphere be less than the evaporating surface

Transpiration is the process of water loss from plants through stomata**.** Stomata are small openings found on the underside of leaves that are connected to vascular plant tissues. In most plants, transpiration is a passive process largely controlled by the humidity of the atmosphere and the moisture content of the soil. It is often difficult to distinguish between evaporation and transpiration. So we use a composite term evapotranspiration**.** The rate of evapotranspiration at any instant from the Earth's surface is controlled by four factors:

♦Energy availability. The more energy available the greater the rate of evapotranspiration. It takes about 600 calories of heat energy to change 1 gram of liquid water into a gas.

♦The humidity gradient away from the surface. The rate and quantity of water vapor entering into the atmosphere both become higher in drier air.

♦The wind speed immediately above the surface. Many of us have observed that our gardens need more watering on windy days compared to calm days when temperatures are similar. This fact occurs because wind increases the potential for evapotranspiration.

♦The availability of water.

PET	60	69.44	80.15	85.6	88	81.1	70.1	69.4	68.8	63	57	70
T	18	19	21	21	21	20	19	19	19	18	18	20
Wind speed	3.5	3.2	3.1	2.7	2.7	3.2	3.4	2.9	1.8	2.5	3.2	3.4

Table 4.6 Monthly average PET (mm), Temperature (^{o}c) and Wind speed (m/s)

The process of evapotranspiration moves water vapor from ground or water surfaces to an adjacent shallow layer that is only a few centimeters thick. When this layer becomes saturated evapotranspiration stops. However, wind can remove this layer replacing it with drier air which increases the potential for evapotranspiration.

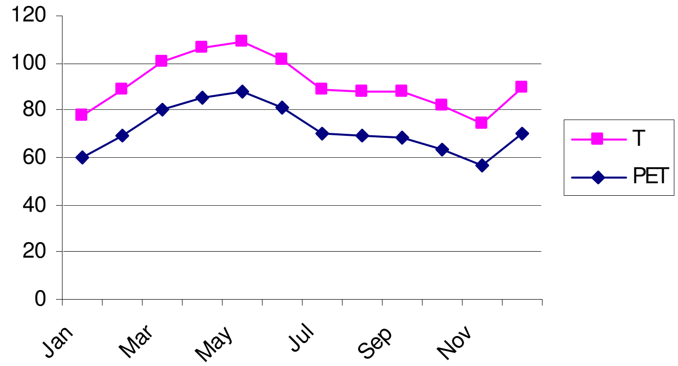

Fig 4.8 Correlation graph between PET and Temperature

Potential evapotranspiration (PET) is the amount of water that could be evaporated and transpired if there was sufficient water available. This demand incorporates the energy available for evaporation and the ability of the lower atmosphere to transport evaporated moisture away from the land surface. PET is higher on windy days because the evaporated moisture can be quickly moved from the ground or plants, allowing more evaporation to fill its place. Actual evapotranspiration or AET is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration**.**

4.2.2 .1 Estimating evapotranspiration

Evapotranspiration can not be measured directly. Pan evaporation data can be used to estimate lake evaporation, but transpiration and evaporation of intercepted rain on vegetation are unknown. There are two general approaches to estimate evapotranspiration indirectly. But due to lack of pan evaporation data, empirical formulas that use different meteorological data are used to calculate potential and actual evapotranspiration.

4.2.2.2 Estimation of potential evapotranspiration (PET)

a) Thornthwaite method

Potential evapotranspiration is usually measured indirectly, from other climatic factors, but also depends on the surface type, such as free water (for lakes and oceans), the soil type for bare soil, and the vegetation. Often a value for the potential evapotranspiration is calculated at a nearby climate station on a reference surface, conventionally short grass. This value is called the reference evapotranspiration, and can be converted to a potential evapotranspiration by multiplying with a surface coefficient. However, this method is based on the assumption that PET is affected only by meteorological conditions, does not consider the effect of vegetative density and maturity. The Thornthwaite method is known to systematically underestimate PET in more arid regions and seasons. An estimate of the potential evapotranspiration calculated on the monthly basis is given by

$$PET_m = 16N_m\,(10t/I)^{a}$$

Where

m is months

N_m is monthly adjustment factor depending on latitude and season

t is mean monthly temperature

I is annual heat index obtained by adding 12 months heat indices (i) each of which are defined as:

$$i = (t/5)^{1.514}$$

$$a = 6.75*10^{-7}I^{3} - 7.71*10^{-5}I^{2} - + 0.017921I + 0.49239$$

According to this formula potential evapotranspiration of the study area is found to be 862.46mm.

b) Penman method

The most general and widely used equation for calculating ET is the Penman equation. The Penman-Monteith variation is recommended by the Food and Agriculture Organization.

This equation uses climatic data like vapor pressure, sunshine hour, net radiation, wind speed and mean temperature.

The basic equation of penman that is used to compute potential evapotranspiration:-

$$\mathbf{PETm = (\Delta/\gamma)\ H_t + Ea_t / (\Delta/\gamma) + 1}$$

The procedures followed during calculation for the data presented in

(Annex 28) are given below:-

►H_t is the available heat and it is calculated from the formula given by

$\mathbf{H_t = R_I\ (1\text{-}r)\text{-}R_o}$, where **r** is the average albedo of the catchments part based on land cover type. In our case **r = 0.24** and $\mathbf{R_I}$ and $\mathbf{R_O}$ are incoming and outgoing radiation respectively and their empirical formulas take the form:

$$\mathbf{R_I\ (1\text{-}r) = 0.76 R_a f_a\ (n/N)}$$

r- is the albedo

fa(n/N)- takes several forms. Since the study area located south of $(541/2)^oN$ (10^oN), fa(n/N) takes the form

$$\mathbf{fa(n/N) = (\ 0.16+0.62n/N)}$$

and the empirical formula of the outgoing radiation takes the form

$$\mathbf{R_O = \sigma T^4\ (0.47\text{-}0.75ed^{1/2})\ (0.17+0.83n/N)}$$

Where $\mathbf{T^4}$ is the theoretical block body radiation at **Ta** which is then modified by functions of the humidity of the air(e_d) and the cloudiness (n/N)

►Temperature in ^{o}k is a converted result of temperature in ^{o}c.

►The parameter e_a (saturated vapor pressure in mm/d) at air temperature t_a (in ^{o}c) is obtained from standard table of air temperature and saturation as:

$$e_a (T_a) = 6.11\exp (17.3T_a / T_a + 273.3)$$

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

$$ed = ea \%RH$$ **(C.D.ARHENS, 1991)**

►Wind speed (U2) in m/s was converted to mil/day in column five

►the energy for evaporation (Eat) is given by:

$$Eat = 0.35(0.5+U2/100) (e_a-e_d)$$

►the value Δ/γ is found from weighing factor Δ/γ versus temperature from (FAO, 1967) give in (E.M. Shaw, 1996) where Δ is the slope of saturated vapor pressure versus temperature and γ is the hydrometric constant which has a typical value of 0.4859mmHg^{o}c (JAY RAMI, 1996).

►PET was calculated using this formula and accordingly a potential evapotranspiration of 1362.58mm found over the area.

4.2.2.3 Estimation of Actual evapotranspiration

Since the study area is located within the rift system, the actual evapotranspiratuion which is one of the components that are vital in calculating the water balance of the area is expected to be high. The methods by which AET is calculated are:-

a) Turc method (empirical formula)

The formula derived by Turc (1954) which is used to determine (actual evapotranspiration) AET assumes that the main parameters affecting AET to be precipitation and temperature. The Turc empirical formula is written as

$$AET = P/ [0.9+ (P/L)^{2}]^{1/2}$$

Where $L = 330+25T+0.05T^2$ or $300+25T+0.05T^3$

P = the annual mean precipitation

T = the mean annual air temperature

Based on this the actual evapotranspiration value of the area is determined to be 789.47.

b) Thornthwaite method (water balance method)

Thonthwaite and Mather method (1957) has been used to estimate the actual evapotranspiration using precipitation and soil moisture values. From which the water budget for different profiles vegetation distribution or land cover and available water capacity were done. When the soil reaches a saturation condition with moisture it will hold no more water. In this case actual evapotranspiration equals potential evapotranspiration (Shaw, 1988). Given the fact that the values of soil moisture deficit and actual evapotranspiration vary with soil type and vegetation, during times when 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 a result the actual evapotranspiration becomes less than the potential evapotranspiration. Parameters used as inputs for this method are precipitation, potential evapotranspiration and soil moisture values.

Accordingly, the value of soil moisture at the end of the month, if Pm > PET is computed as

$$S_m = \min((P_m - PET_m) + S_{m-1})\ S_{max})$$

And if Pm<PET, resulting a soil moisture deficit, the soil moisture is given as

$$S_m = S_{m-1} \exp\left(- \frac{PET - P_m}{S_{max}}\right)$$

Following these procedures and principles, AET for each month is obtained based on the amount of Precipitation and PET calculated from Thornthwaite method as

If P>PET…………AET= PET
If P<PET………….AET = P + ΔS_m ($S_{m-1} - S_m$)

The soil moisture deficit and surplus are also calculated for each month. Based on these the average AET computed for the entire basin from the soil water balance approach is 650.33mm.

Method	PET(mm)	AET(mm)	P(mm)
Turc	___	789.47	969.35
Penman	1362.58	_____	969.35
Thonthwaite	862.46	650.33	969.35

Table 4.7 summarized value of PET, AET, and PPT

4.2.3 Runoff

Runoff in crude terms is water not absorbed by soil or that does not soak into the soil but flows into surface waters. And runoff in water pollution concern is agricultural or industrial waste products that are carried by rainfall into surface waters. Geology, slope, and topography are the most controlling factors of runoff and area, actual evapotranspiration/ rainfall and vegetation cover least control runoff. In general, low rainfall, high evapotranspiration, gentle slope, very permeable volcanic falls and disappearing drainage pattern can confirm the lowest runoff. Runoff is that part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains or sewers. And it consists of precipitation that neither evaporates, transpires nor penetrates the surface to become groundwater.

Runoff occurs when the rate of rainfall on a surface exceeds the rate at which water can infiltrate the ground, and any depression storage has already been filled. This more commonly occurs in arid and semi-arid regions, where rainfall intensities are high and the soil infiltration capacity is reduced because of surface sealing, or in paved areas. The runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the catchment i.e. the larger the size of the catchment the larger the time of concentration and the smaller the runoff efficiency.

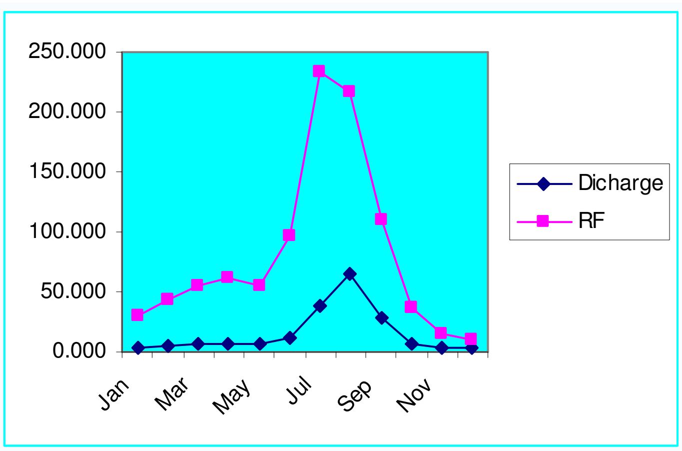

Fig. 4.9 Runoff rainfall pattern

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RF	29.7	43.1	54.3	61.1	54.7	97.1	233.3	216	109.9	37.1	14.7	10.6
Discharge	3.41	4.88	6.06	6.76	6.65	11.33	38.61	64.9	27.91	6.26	3.53	3.31

Table 4.8 Summarized value of Discharge and rainfall at Mojo Station

4.2.3.1 Base flow separation

Base flow separation is a vital component of hydrologic modeling. There have been numerous attempts to quantify the separation of base flow and direct runoff, including straight line, fixed base, and variable slope methods, each of which is not wholly valid. Precipitation-runoff models, base-flow-separation techniques, and stream gain-loss measurements are the appropriate methods to study recharge and ground-water surface-water interaction. The models can also be used to compute long-term average recharge and base flow. Base-flow separation methods were used to identify the base-flow component of stream flow at a number of currently operated and discontinued streamflow-gaging-station locations. Stream gain-loss measurements were made and were used to identify and quantify gaining and losing stream reaches both spatially and temporally. These measurements provide further understanding of ground-water/surface-water interactions.

For the quantitative determination of the different flow components a general procedure does not exist. However, the following procedures (graphical method, statistical method, and depletion curve analysis) have been developed for the separation of base flow and surface runoff.

In general runoff can be calculated by several ways, one of these ways is by means of a soil water balance, and another one is by means of runoff coefficients. Calculating runoff by means of a soil water balance is a conceptual way of calculating runoff while runoff coefficients are obtained by comparing river discharges with precipitation statistics.

For a basic soil water balance, it is necessary to have information on the following parameters:

- precipitation on a monthly basis or preferably at shorter intervals;
- actual evapotranspiration on the same time intervals as precipitation;
- Soil water storage capacity.

For more advanced soil water balance information is also necessary on other parameters such as:

- seepage from / to the groundwater in the saturated zone;
- land use;
- advanced soil characteristics (e.g. soil conductivity and soil moisture content at different pressure heads), necessary to calculate the water balance of the unsaturated zone.

But it is extremely difficult to parameterize a soil water balance. Therefore it was decided to calculate the runoff component for the water balance of the area was determined using Chow's (1988) runoff coefficient method as

$$C = \frac{R}{\sum_{M=1}^{M=12} P}$$

Where

C = runoff coefficient

R = depth of runoff

P = monthly precipitation

Accordingly, the runoff coefficient of the study area computed by the ratio of total discharge passing through the measuring station and the depth of rainfall over the catchment was determined to be 0.135

, then **R = (A*P) * C** gives runoff.

The rainfall depth of the study area is calculated to be 968.13mm and the total area of the study area is 1506Km^2. and using the formula given above, the runoff over the study area was computed and resulted value of 197 million cubic meter of water.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1973	0.120	4.978	5.221	5.612	4.418	6.658	34.971	59.197	31.056	11.156	9.344	15.70
1974	1.565	1.538	5.809	2.182	4.750	5.112	49.628	47.999	32.165	0.758	0.498	9.828
1975	0.980	0.535	0.379	1.282	2.420	12.922	68.793	48.962	27.608	0.740	0.475	0.373
1976	0.812	0.762	0.944	1.594	2.948	9.233	31.085	67.659	17.901	8.868	14.049	0.472
1977	8.029	6.455	10.597	8.686	5.089	9.107	38.678	61.996	24.252	31.699	7.097	9.239
1978	0.248	6.497	3.413	3.929	6.239	19.610	14.802	50.916	30.823	3.285	0.180	0.254
1979	7.525	11.801	13.220	31.534	18.851	2.393	27.988	35.055	5.594	0.575	0.436	0.174
1980	0.251	0.180	0.531	0.428	5.315	16.482	39.271	44.787	12.377	1.107	0.221	0.287
1981	2.675	25.772	48.568	50.332	32.610	33.843	118.705	120.448	124.763	34.920	25.494	0.265
1982	30.695	63.792	42.359	40.26	54.67	58.74	65.724	166.35	69.0507	39.22	25.689	24.442
1983	0.296	0.4423	4.981	1.483	4.217	6.325	17.69	119.11	54.33	0.4683	0.411	26.864
1984	0.2393	0.223	0.274	0.172	0.771	8.272	26.614	72.458	6.89533	0.4743	0.4147	0.2913
1985	0.323	0.221	0.2217	0.547	5.3	0.575	35.54	100.01	12.3947	0.5587	0.4777	0.3457
1986	0.459	0.669	1.466	3.196	1.871	19.03	19.248	34.98	51.1433	0.8793	0.2907	0.5513
1987	0.3817	0.5867	2.869	2.623	11.28	4.007	3.4373	9.7897	2.698	0.388	0.2897	0.4433
1988	0.4393	0.8393	0.267	0.899	1.123	2.772	16.601	47.727	21.8727	2.7313	0.1467	0.3093
1989	0.4413	0.406	0.5737	2.023	0.21	0.192	21.037	25.777	16.3003	1.2213	0.3853	0.361
1990	0.369	2.76	2.041	3.993	0.368	0.653	34.408	23.933	14.6473	0.9343	0.333	0.463
1991	0.4037	0.656	1.9103	1.237	0.288	1.299	36.042	80.311	26.026	0.5263	0.629	0.429
1992	0.956	1.2267	0.5427	1.533	0.362	6.626	7.8597	40.6	44.6503	1.27	0.3967	1.0243
1993	0.4177	0.453	0.3093	11.53	8.329	1.175	48.528	40.275	34.2263	3.4407	0.626	0.4617
1994	0.3357	0.2587	2.0757	0.763	1.853	1.613	13.614	40.389	43.2183	0.7807	0.5313	0.4327
1995	0.464	0.4863	0.8237	1.65	6.741	14.51	9.0637	31.668	21.5527	15.143	19.139	0.508
1996	20.16	18.536	22.65	16.42	24.68	51.86	89.427		28.183	0.864	0.554	19.875
1997	1.049	0.423	1.27	3.174	0.527	7.526	15.379	27.918	2.81133	4.792	1.1107	0.4773
1998	0.62	1.9853	2.4523	5.386	1.356	12.83	49.347	126.51	34.534	26.61	0.7897	0.586
1999	0.724	0.5757	0.9247	0.584	0.759	14.04	66.85	92.913	9.59967	3.2237	0.5067	0.7033
2000	0.064	0.0503	0.0393	0.061	0.137	3.49	15.192	29.636	4.485	0.365	0.0993	0.4883
2001	0.5567	0.5383	11.747	0.807	2.643	14.93	41.771	94.582	45.814	0.819	0.649	0.0647
2002	0.7047	0.55	0.8183	0.638	0.965	4.076	58.53	73.626	7.597	0.6513	0.544	0.6613
2003	1.469	1.327	1.9873	5.29	1.066	8.663	97.87	115.44	25.2397	0.998	0.629	0.71
2004	0.7467	0.5253	2.5317	6.463	0.542	3.911	21.782	80.804	9.29467	0.9407	0.597	1.0063
Average	2.641	4.877	6.057	6.760	6.647	11.328	38.609	64.898	27.909	6.263	3.532	3.303

Table 4.9 Summary of hydrometric discharge data at Mojo station

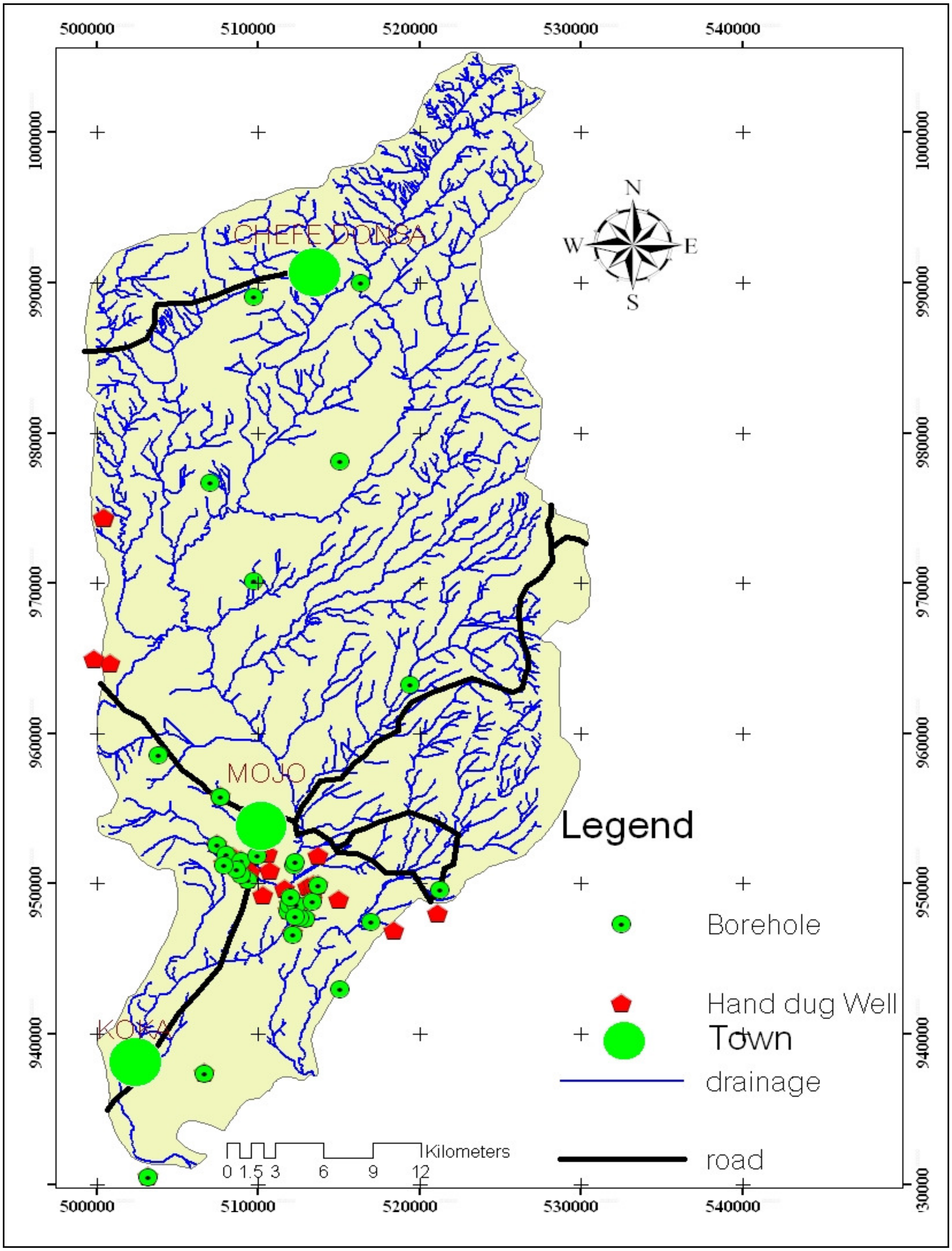
500000
510000
520000
530000
540000
1000000
990000
980000
970000
960000
950000
940000
CHEFE DONSA
MOJO
KOKA
N
S
E
W
Legend
Borehole
Hand dug Well
Town
drainage
road
0 1.5 3 6 9 12
Kilometers

Fig. 4.10 Drainage Map with well locations of Mojo River Basin

4.3 Water balance/ water budget

The concept of water balancing is a fundamental concept in water resources planning and management. However, the ability to perform the water balance calculations can be a tedious and labor intensive process. The water balance or sometimes called water budget considers the total water gained or lost from a specified hydrologic system during specific period of time to serially restricted place.

The general form of the water balance of a given basin or catchment is given by:-

$$P + I + Ar + Qi = R + Et + D + Qo + W \pm \Delta S$$

Where

P = precipitation

I = infiltration from surface water

Ar = artificial recharge

Qi = ground water inflow

R = surface runoff

Et = evapotranspiration

D = drainage

Qo = ground water out flow

W = withdrawal

ΔS = change in storage

But water balance method follows certain assumptions such as:-

i Surface water divide coincides with ground water divide

i No inflow from out and no out flow from catchments

i And abstraction by human is insignificant.

Therefore, the estimation of water reaching the ground water table can be calculated by:

$$\mathbf{R = P - Q - E_t}$$

Where

R = estimated recharge to the ground water in Mm3
P = the precipitation in Mm3
Q = runoff in MM3
E_t = the actual evapotranspiration

Parameter	Amount
Total area(Km2)	1506
Precipitation depth(mm)	969.35
AET(mm)	650.65
Ground water inflow	0
Artificial recharge	0
Runoff(Mm3)	197

Table 4.10 Database for water budget calculation

Water balances are mainly used to determine the ground water recharge that has important role for water resource management. And the ground water recharge of the catchment calculated using this approach gave an annual value of 282million cubic meter.

The ground water consumptions in the study area that is estimated by daily water demand of institutions and public water supply is as follows:

Textiles collectively 1400m^3/day

Tanneries " 700m^3/day

Addis Edible oil factory 50 m^3/day

Municipal including Chefe Donsa 1242m^3/day

From hand dug well (5% of the total) 169 m^3/day

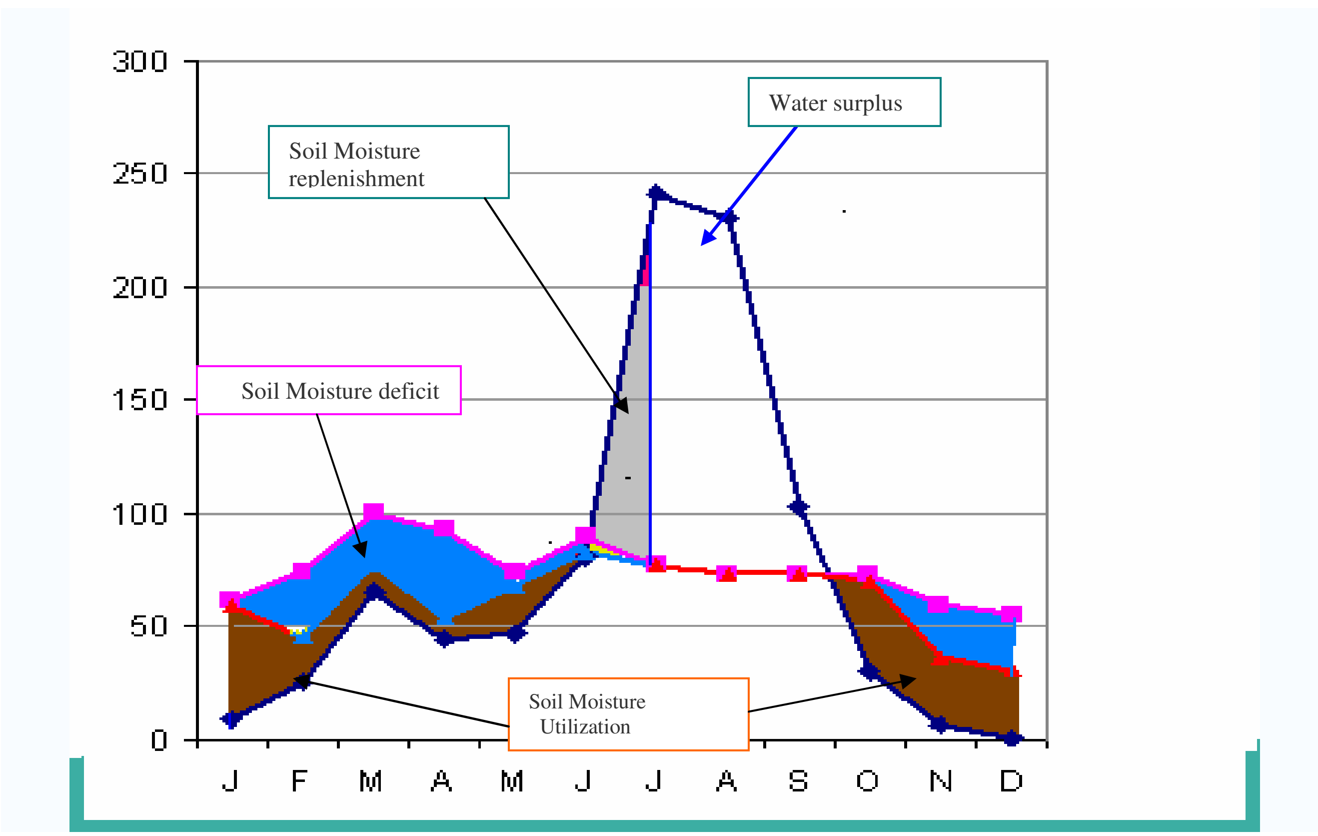

Fig.4.11 water balance pattern of Mojo River Catchment

CHAPTER FIVE

HYDROGEOLOGY

5.1 General

The ground water potential of an area depends primarily on the geologic formations and the structures associated with them. The study area is prominently covered by volcanic rocks and fluvo-lacustrine deposits to some extent. And the volcanic rocks have always been considered very important from hydrogeological point of view. These could be explained by the heterogeneous hydrogeological nature of volcanic formations.

Groundwater circulation and storage in the volcanic rocks depend on:-

◙ **the type of porosity and permeability formed during and after the rock formation**. These could be primary and secondary porosity. All rock structures possessing a primary porosity may not have necessarily permeability; i.e. without the original interconnection the primary porosity may not give rise to the primary permeability, but the later connection, by means of weathering or fracturing may results a secondary permeability.

Primary Porosities are made of original small and large scale structures contemporaneous to the rock formation; and include: Vesicles and flow contacts or interflow spaces, lava tubes or tunnels, clinker or rubble layers, tree moulds, shrinkage cracks or columnar joints etc.

Secondary porosities are due to weathering discontinuities, tectonic fractures or faults, inter-trappean beds, weathering zones, buried paleosols, etc.

◙ **varies volcanic structures affecting hydrogeological characteristics of aquifers.** According to Fisher, 1984 Williams, Turner, and Giblet, 1985; cited in Tamiru Alemayehu, 1994, the most important volcanic structures governing the ground water flow and storage in volcanic rocks are:-

I. Horizontal flow structure:-

These types of volcanic structures are generally structures parallel to the flow surface. These include Clinker beds, lava tubes, inter flow openings. These flow structures are so prominent that they actually determine so much of the horizontal permeability as compared to the vertical structures.

II. Vertical flow structure:-

These are structures in volcanic formations normal to the flow surface. Contraction joint is one of the examples of this type.

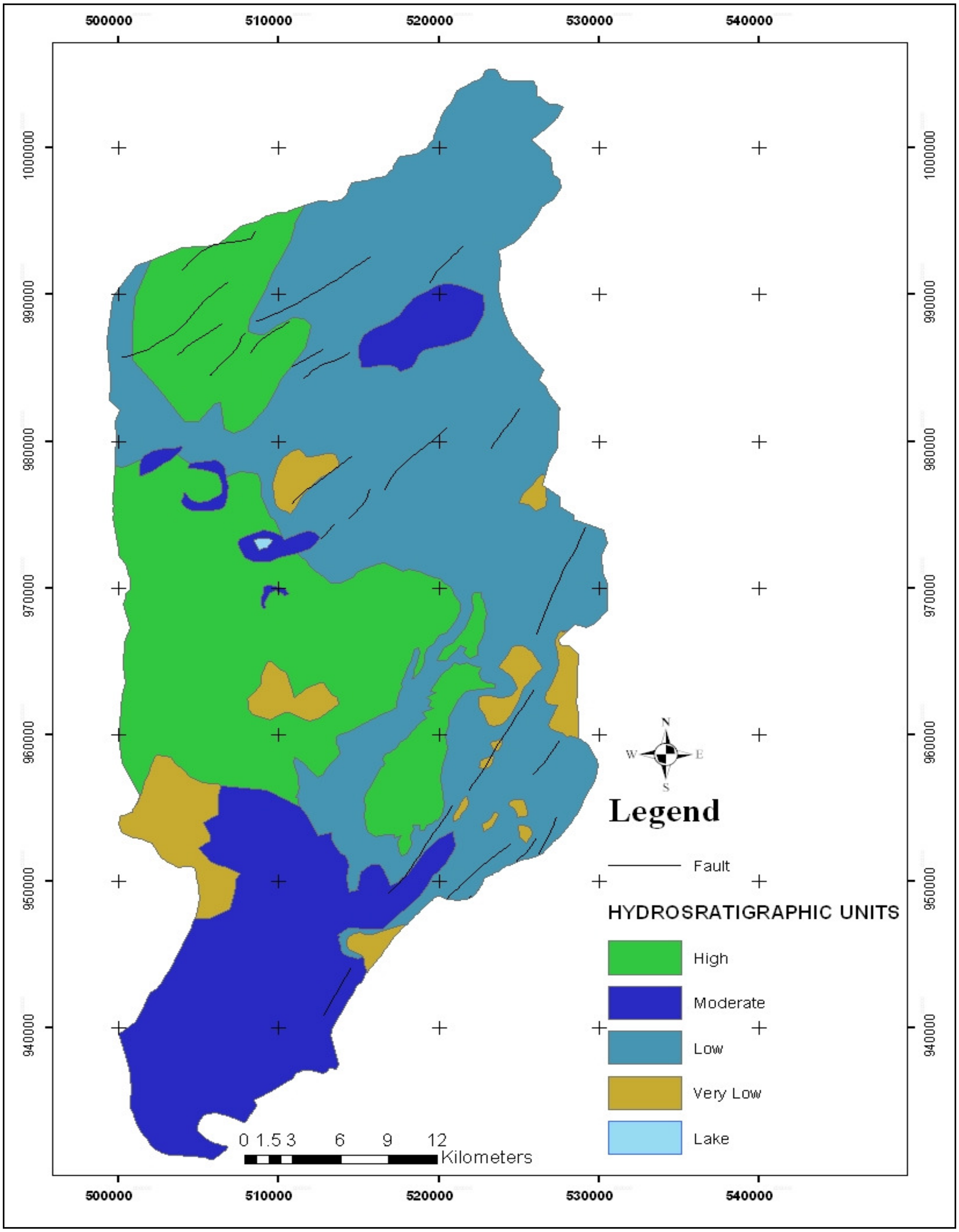
500000
510000
520000
530000
540000
1000000
990000
980000
970000
960000
950000
940000
N
W
E
S
Legend
Fault
HYDROSRATIGRAPHIC UNITS
High
Moderate
Low
Very Low
Lake
0 1.5 3 6 9 12
Kilometers

Fig.5.1 Hydrogeological Map of the area (modified from Hydrogeology of Nazret EIGS, 1985)

5.2 Hydrostratigraphic units

The major lithologic units found in the study area include Basalt, trachytes tuffs, Ignimbrite, and Lacustrine deposits. In the next section these units are treated individually. And generally the lithologic units are classified into four hydrostratigraphic groups as very low, Low, and moderately and high permeability group.

5.2.1 Trachyte domes and flows, (very low permeability groups)

Huge mountains at the rift margin (eg. Part of Yerer trachytic volcano in the study area) have poor hydraulic conductivity due to absence of primary porosity, massive nature of exposure. In addition, bare and steep nature of these highly elevated morphological features have poor groundwater storage and low infiltration property for the absence of vegetation which can delay the immediate rushing water that comes from precipitation.

5.2.2 Ash flows, unwelded tuffs and Rhyolitic ignimbrite, (Low permeability groups)

The ignimbrite and rhyolitic ignimbrite cover most part of the study area. Unfortunately, there are almost no well drilled in this unit in order to characterize the vertical extent of the aquifer but for the sake of classification, its permeability using visual observation, it is not that jointed and faulted hence it has a Low permeability and productivity. Even though not that significant the faults and joints can serve as an important groundwater recharging conduit in the absence of secondary filling material. And, as far as visual observation, the exposure of the unit does not show prominent devoid of the openings, which might show subsurface variation due to pressure and other factors.

The rhyolitic ignimbrite in the study area shows a bit difference from the non-rhyolitic ignimbrite by their well-welded nature and by having fractures and joints in more geometrically ordered fashion.

Joints like columnar basalt are also common but this joints form more of a rectangular shape rather unlike the basalts that shows joints with hexagonal shape.

As it is shown in structures, faults and lineaments are restricted to this unit without crossing the ignimbrite of Chefe Donsa unit which is less welded. This can be due to the intact nature of the rhyolitic ignimbrite that allows propagation of brittle deformation. The other difference is the rhyolitic ignimbrite unit shows a laminar structure, which might give a chance for development of fractures and ease for groundwater circulation.

5.2.3 Lacustrine deposits, Bedded explosion Tuffs (Moderate permeability group)

The alluvial cover mainly outcrops above the products of the western Rift margin complex and consists of regolith and alluvium with maximum thickness of about 2m. It is grouped under the Moderate permeable unit. The thickness increases from northwest to southeast. These sediments are exposed in the study area with thin but extensive spatial distribution and consist of sands, silts, clays, tuffs, pumice, and ignimbrites. These sediments, in most places are mixed compositionally with quaternary volcanic products and form a specific mixed volcano-sedimentary rock type.

Laterally where the lacustrine deposits are exposed at the surface of the study area they appeared to be a loosely cemented material texturally ranging from fine grained to coarse-grained. Based on the above visual observation one can group the lacustrine deposits by its superficial water conductive nature. However, in terms of productivity of the unit since it deals with both vertical and horizontal extension of the unit classifying it by its superficial hydrogeological character may be misleading. This can be supported by different drilling data in the unit which show the increase of fine grain materials such as clay that can indicate lower permeability condition.

Tuff, diatomite and ignimbrite are partially interbedded in the lacustrine sediments and at some places form an extensive layer. Therefore, the permeability of this aquifer unit is some how reduced due to the intercalation of tuff layers which is visible around the gullies and banks of the Mojo River.

Within this formation the existence of different units makes the hydrogeological nature heterogeneous. For instance the evolution of different volcanic products which is relatively abrupt in its origin and against the deposits of Lacustrine (Diatomite) that is sluggish in its nature will have difference in hydraulic conductivity since the latter have a well cemented nature and compacted due to stress exerted by the overburden. This can make the volcanic products relatively a better media for the groundwater circulation than the lacustrine deposits. But, it has to be noted that the lacustrine deposition took place along with most of the quaternary volcanic activity, which made it to be deposited in alternating manner with the volcanic tuff and pumice.

The tectonic evidence is not clear to detect easily in this area. Because the area is covered by lacustrine sediments and soils, the evidences are possibly obscured by them. Thus, except the watercourses, gullies and waterfalls, there are no indications of fault lines can be traced from the surface. But geophysical investigations conducted in the area show the existence of subsurface structures such as faults. This displays that the formations of tectonic elements around this area is older than the lake that had been covered the area during the pluvial times geologically.

5.2.4 Basaltic flows and domes (High permeability group)

Basaltic lava flows that are found in the northern, eastern and central part of the study area are scattered in the form of younger spatter and cone volcanic centers. These basalts are highly fractured and in several places they are scoraceous. Therefore, they have high permeability and productivity. The aquifer materials found in this area are very fine-grained rocks of volcanic origin with some silty sand and pebble beds. Furthermore the rocks in the area are fractured and jointed with concomitant secondary fine-grained that the entire sequence may provide hydraulic connection between the individual aquifers. However, the fine-grained nature of the aquifer materials and the adverse effects of the filling materials contribute to the low yield of water- bearing formation.

5.3 SPRINGS

Godino and Donsa are the two springs found in the study area. The springs are used for varies purposes in the domestic consumption. Both Godino and Donsa are perennial springs from which water is tapped by local population throughout the year. The main recharge of the Godino spring is provided by the water that percolates through the fractures developed in the ignimbrite (Tamiru Alemayehu, 1994). The two springs have equal average yield.

Springs	Type	Geomorphology	Spring Eye	Water use	Flow	Average yield (l/s)	Fluctuation
Godino	Contact	Hill side	Multiple	Domestic	Perennial	10	Low
Chefa Donsa	Depression	Flat area	Single	Domestic	Perennial	10	Low

5.4 Groundwater movement and recharge

Understanding where groundwater is and how it moves under the ground is essential in protecting this resource. By looking at the way that groundwater flows, it is possible to identify when it is at risk from pollution and how we can protect it by careful planning and land-use.

The steeper the gradient or slope, the faster the ground water will flow. And for water to move freely through a rock, the pores and/or fractures must be large enough and connected enough so that the friction from the water moving past the rock particle does not impede the flow. The degree of an aquifer's porosity and permeability is a key to movement of ground water through an aquifer. Groundwater movement in the Mojo River Catchment is topographically and Lithologically controlled. Moreover, most of the faults of the study area act as conduits to groundwater movement as they are aligned NE-SW and N-S to N20°E like that of groundwater movement which is from north east and east to southeast and south.

Recharge is the process by which aquifers are replenished with water from the surface. This process occurs naturally as part of the hydrologic cycle as infiltration when rainfall infiltrates the land surface and as percolation of water into underlying aquifers. A number of factors influence the rate of recharge including physical characteristics of the soil, plant cover, slope, water content of surface materials, rainfall intensity, and the presence and depth of confining layers and aquifers. Surface water bodies may also recharge ground water. This occurs most often in arid areas. Lakes and dry creek beds may fill up with water during heavy rains. If the water table is low in underlying aquifers, water may seep from the sides of these water bodies and percolate into the ground water.

The study area is found in the low lying parts of the rift and this area direct recharge occurs from the rainfall while much of this rainfall is lost through evapotranspiration.

CHAPTER SIX

HYDROCHEMISTRY

6.1 General

The regional quality of groundwater within the surficial aquifer system can be characterized by the hydrochemical facies of the water and its dissolved-solids concentration. Hydrochemical facies are determined by the dominant anions and cations in the ground water.

Most of the water from volcanic rocks tends to be Calcium- Magnesium-Bicarbonate water type in the case of basic rocks and Sodium-Bicarbonate water type in the case of acidic volcanic rocks. Owning to extremely high permeability of some volcanic rocks, biological contamination through surface infiltration is however a potential danger. Fortunately, volcanic rocks tend to weather quite rapidly, so thick soils that developed can locally act as a filter to pathogenic organisms (Davis and DeWiest, 1966). Some of the basic physical and chemical characteristics of water are discussed below.

6.2 Turbidity, Color, Odor, Taste

Turbidity is a cloudiness or haziness in water (or other liquid) caused by individual particles that are too small to be seen without magnification, thus being much like smoke in air. Liquids can contain suspended solid matter consisting of particles of many different sizes. While some suspended material will be large enough and heavy enough to settle rapidly to the bottom of a container if a liquid sample is left to stand (the settleable solids), very small particles will settle only very slowly or not at all if the sample is regularly agitated or the particles are colloidal. These small solid particles cause the liquid to appear turbid.

There are frequently standards on the allowable turbidity in drinking water. The allowable standard is 1 NTU (Nephelometric turbidity unit), with many drinking water utilities striving to achieve levels as low as 0.1 NTU

Data set of the physical parameters such as odor, color, taste and turbidity of water sample collected from dug wells, springs, and boreholes show that most but some of the ground water in the area is colorless, tasteless and clear.

Physical characteristics of the samples collected from surface water show that the Mojo River has green and dark green color, Bad odor, high turbidity and a lot of suspended material due to industrial and sewage waste.

6.3 Hydrogen ion activity (pH)

The pH of a solution measures the degree of acidity or alkalinity relative to the ionization of water sample. Pure water dissociates to yield 10^{-7} M of $[H^+]$ and $[OH^-]$ at 25 ^oC; thus, the pH of pure water is neutral i.e. 7.

$pH_{water} = - \log [H^+] = - \log 10^{-7} = 7$

Solutions with a higher $[H^+]$ than water (pH less than 7) are acidic; solutions with a lower $[H^+]$ than water (pH greater than 7) are basic or alkaline.

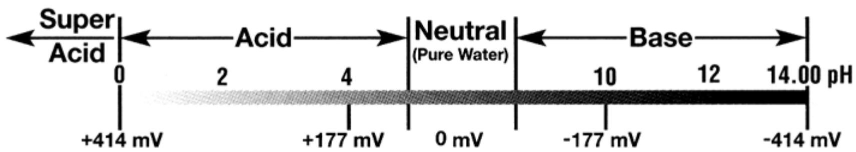

Fig. 6.1 levels of hydrogen ion activity

The pH of any solution is a function of its temperature. One pH unit corresponds to 25 °C. Since pH values are temperature dependent, pH applications require some form of temperature compensation to ensure standardized pH values.

The pH of the water samples obtained from most of the samples varies from 7.7 to 8.3 and in these waters bicarbonate is dominant. And in general the water of the study area has an alkaline pH.

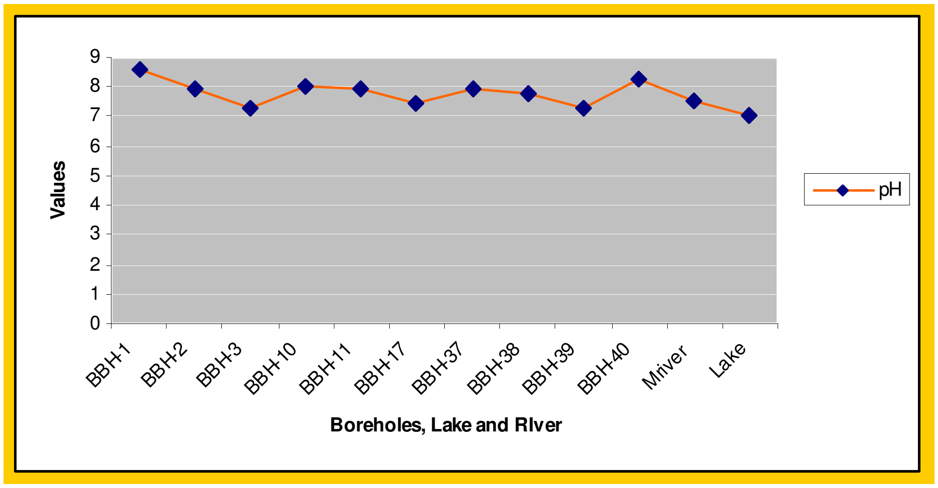

Fig. 6.2 pH values of different Boreholes, Lake and River in the area

6.4 Electrical conductivity (EC)

Electrical conductivity is proportional to the quantity of dissolved ions present in solution and can provide a rough idea of the total dissolved solids (TDS). For most ground water, the EC value, in µS/cm corrected to 25^{o}C, is about 50% greater than the TDS expressed as mg/L, and can be estimated according to:

$$TDS = A \times EC\ (\mu S/cm)$$

$A \cong 0.55$ in bicarbonate waters

0.75 In high sulphate waters

0.9 In high chloride waters

In some situations, however, conductivity may not correlate directly to concentration. The graphs below illustrate the relationship between conductivity and ion concentration for two common solutions. Notice that the graph is linear for sodium chloride solution, but not for highly concentrated sulphuric acid. Ionic interactions can alter the linear relationship between conductivity and concentration in some highly concentrated solutions.

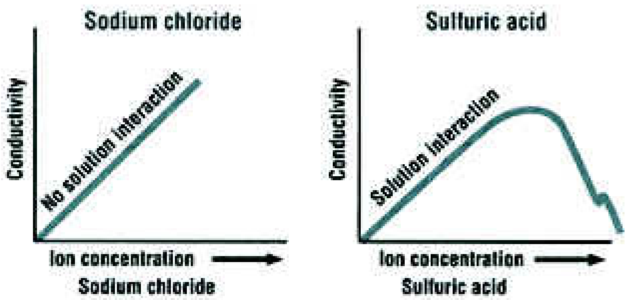

Fig. 6.3 Relationship between conductivity and ion concentration

Conductivity measurements are temperature dependent. The degree to which temperature affects conductivity varies from solution to solution and can be calculated using the following formula:

$$\mathbf{Gt = Gt_{cal} \{1 + a (T-T_{cal})\}}$$

Where: **Gt** = conductivity at any temperature **T** in °C, $\mathbf{Gt_{cal}}$ = conductivity at calibration temperature $\mathbf{T_{cal}}$ in °C, a = temperature coefficient of solution at $\mathbf{T_{cal}}$ in °C.

The conductivity value of most ground water in the area is lower than 1000 with notable exception from some dug wells, where high conductivity value in a stream is taken as a good indication of pollution.

Locality	Red Fox Flowers	Koka	Mojo Abudab stab	Shimbra Meda	Biyo Beseka hand dug	Mojo Bekele Mola	Air force
conductivity	1930	755	392	578	811	700	628

Table 6.1 Locality in the study area verses EC

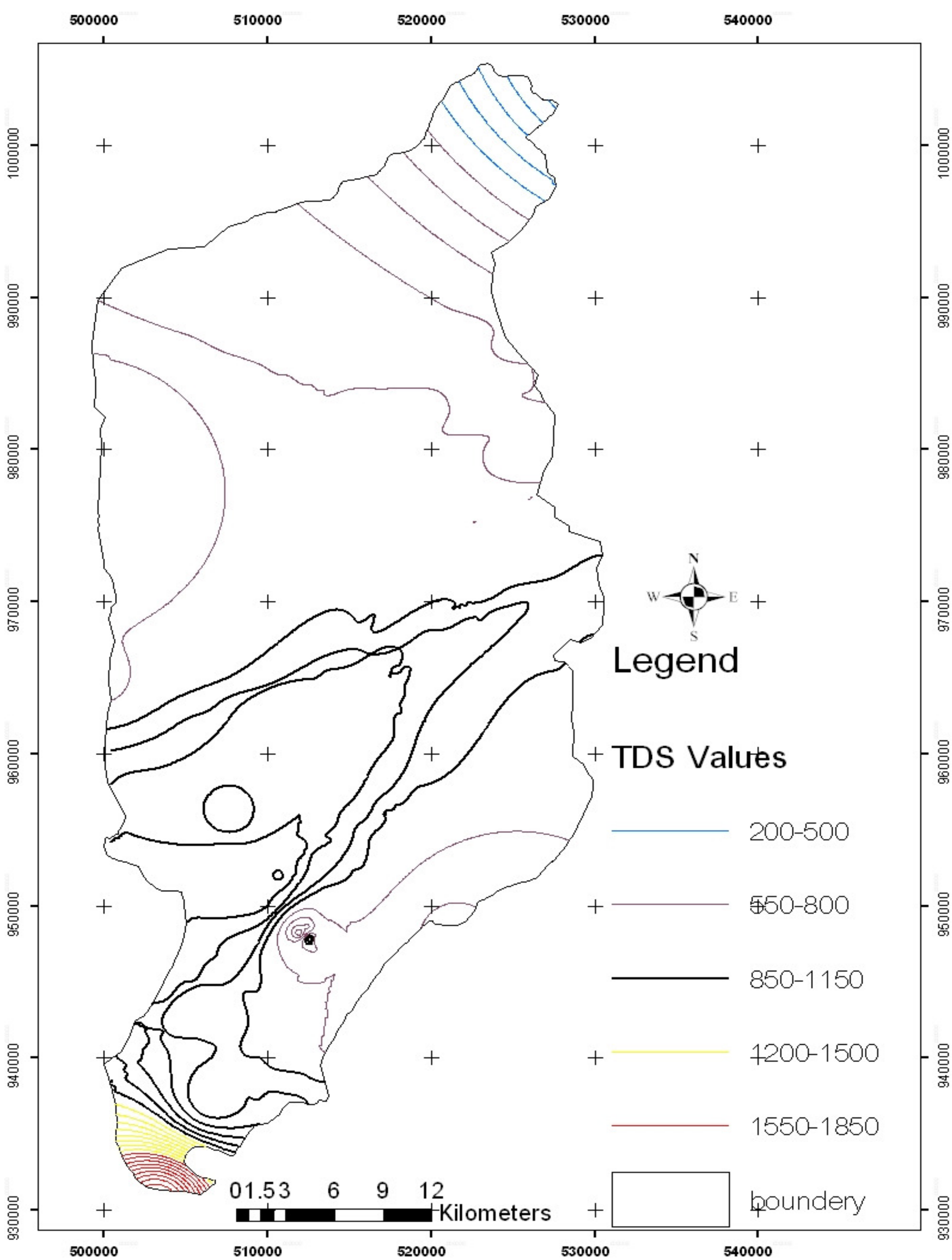
500000
510000
520000
530000
540000
1000000
990000
980000
970000
960000
950000
940000
930000
N
W
E
S
Legend
TDS Values
200-500
550-800
850-1150
1200-1500
1550-1850
boundery
0 1.5 3 6 9 12
Kilometers

Fig. 6.4 Conductivity distribution Map of the area.

6.5 Total dissolved solids (TDS)

TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. A certain level of these ions in water is necessary for aquatic life. Changes in TDS concentrations can be harmful because the density of the water determines the flow of water into and out of an organism's cells (Mitchell and Stapp, 1992). However, if TDS concentrations are too high or too low, the growth of many aquatic lives can be limited, and death may occur.

Similar to TSS (total suspended solids), high concentrations of TDS may also reduce water clarity, contribute to a decrease in photosynthesis, combine with toxic compounds and heavy metals, and lead to an increase in water temperature. TDS is used to estimate the quality of drinking water, because it represents the amount of ions in the water. Water with high TDS often has a bad taste and/or high water hardness, and could result in a laxative effect.

The TDS concentration of a water sample can be estimated from specific conductance if a linear correlation between the two parameters is first established. Depending on the chemistry of the water, TDS (in mg/l) can be estimated by multiplying specific conductance (in micro homs/cm) by a factor between 0.55 and 0.75. TDS can also be determined by measuring individual ions and adding them up.

TDS of natural water range from less than 10ppm of dissolved solids for rain and snow to more than 300,000ppm for some brine. Water types are divided in to four categories depending on their TDS value as shown in the table below.

Water type	TDS inppm
Fresh water	0-1000
Brackish water	1000-10000
Salty water	10000-100000
brines	More than 100000

Table 6.2 Classification of Water on the basis of TDS

Locality	**Red Fox Flowers**	**Koka**	**Modjo Abudab stab**	**Shimbra Meda**	**Biyo Beseka hand dug**	**Modjo Lume**	Mojo river	Lome/Lak e	**Air force**
TDS	915	294	196	397	479	530	1332	276	391

Table 6.3 TDS values of some localities within the study area (highlighted are boreholes)

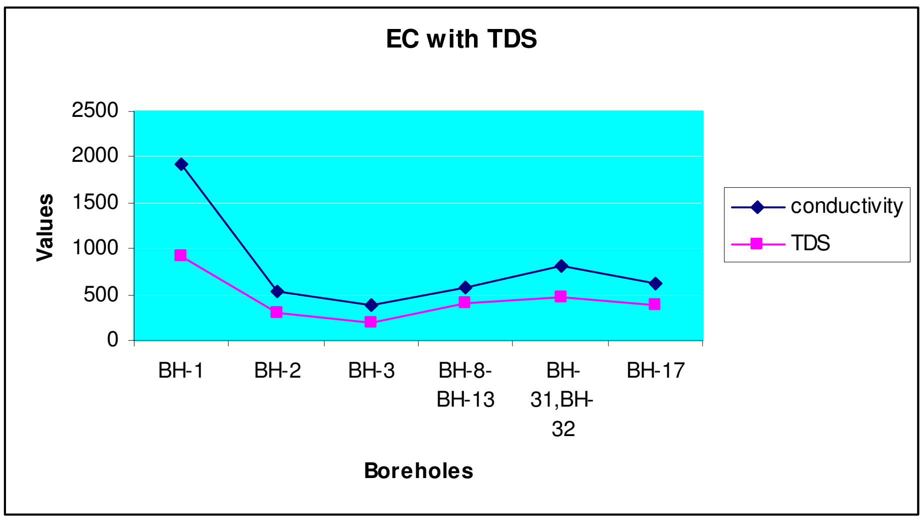

Fig. 6.5 Relationship between TDS and Conductivity

The amount of total dissolved solids for water samples in the area range from 50mg/l to 1332mg/l. Most of the values are below 1000mg/l for ground water and In the case of surface water higher value of 1332mg/l is recorded at Mojo River.

6.6 Hardness

When water is referred to as 'hard' this simply means, that it contains more minerals than ordinary water. These are especially the minerals calcium and magnesium in the form of carbonates**,** but may include several other metals as well as bicarbonates and sulfates. The degree of hardness of the water exceeds, when more calcium and magnesium dissolve.

Magnesium and calcium are positively charged ions. Because of their presence, other positively charged substances will dissolve less easy in hard water than in water that does not contain calcium and magnesium. This is the cause of the fact that soap doesn't really dissolve in hard water.

Temporary hardness is hardness that can be removed by boiling or by the addition of lime (calcium hydroxide). It is caused by a combination of calcium ions and bicarbonate ions in the water. Boiling, which promotes the formation of carbonate from the bicarbonate, will precipitate calcium carbonate out of solution, leaving water that is less hard on cooling.

Permanent hardness is hardness (mineral content) that cannot be removed by boiling. It is usually caused by the presence of calcium and magnesium sulfates and/or chlorides in the water, which become more soluble as the temperature rises. Despite the name this can be removed using a water softener or ion exchange column**.**

Hardness, $CaCo_3$ (mg/l)	**Description**
0-60	**Soft**
61-120	**Moderately hard**
121-180	**Hard**
>180	**Very hard**

Table 6.4 Range of hardness concentration

The hardness of water bodies of some localities within the study area was analyzed and it is shown in table below.

Locality	Sample Type	Hardness(Mg/l)
Koka	BH	265
Modjo Abudab stab	BH	150
Shimbira Meda	BH	214
Air force	BH	239.8
Tulube	BH	264.2
Biyo Beseka hand dug	BH	284.2
Modjo Lume	BH	178
Modjo Ethio Japan Nylon	BH	160
Mojo	River	129
	Lake	84

Table 6.5 the hardness of the different water bodies of the study area.

From the table above the ground and surface water of the study area fall under the category "Hard" to "Very Hard" water whereas, the lake water fall under "Moderately Hard" category.

6.7 Redox potential

Redox measurements provide a measure of the electromotive force of water, or the relative dominance of oxidized versus reduced species in solution.

Oxidation-Reduction Potential (ORP) or Redox potential measurements are used to monitor chemical reactions, to quantify ion activity, or to determine the oxidizing or reducing properties of a solution.

ORP is found to be a reliable indicator of bacteriological water quality for sanitation - determine free chlorine parameter. Eh is a function of depth and the presence of oxygen demanding wastes. And in general, surface waters (rivers and lakes) are expected to have higher values of Eh than sub surface waters. Moreover, the absence of molecular oxygen below the water table and the presence of reducing organic matters and sulfide minerals in the aquifer results lower values of Eh.

6.8 Dissolved oxygen (DO)

Many gases mix with water like nitrogen and oxygen without chemically reacting with it. Some gases chemically react with water e.g. ammonia, CO2, and HCl. Oxygen does not react with water. Dissolved Oxygen (DO) is really a physical distribution of oxygen molecules in water. There are two main sources of DO in water: atmosphere and photosynthesis.

The amount of DO that can be held by water depends on 3 factors: water temperature, salinity, and atmospheric pressure; Amount of DO increases with decreasing temperature (colder water holds more oxygen). Amount of DO increases with decreasing salinity (freshwater holds more oxygen than saltwater does); Amount of DO decreases with decreasing atmospheric pressure (amount of DO absorbed in water decreases as altitude increases).

The chart below shows the solubility of DO in mg/l in water at various temperatures.

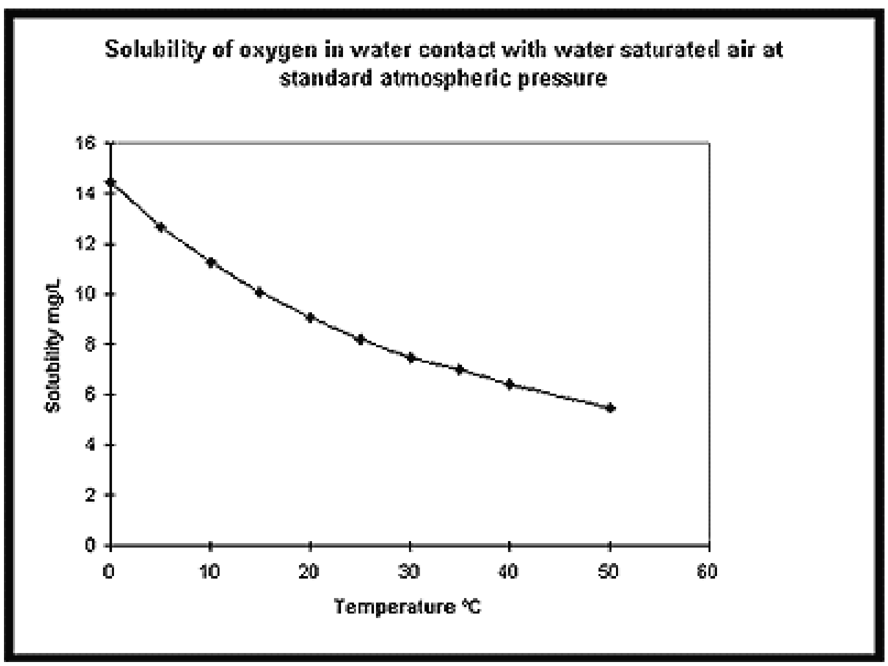

Fig. 6.6 Solubility of Oxygen

6.9 Presentation of water chemistry data

Piper diagram, Stiff diagram, Schoeller semi-logarithmic diagram, Bar graphs and radial diagram are the most common graphical presentations of chemical analysis results. Besides, tables of data are also the methods by which water chemistry is reported. In this work Piper and Schoeller diagram are described briefly and analysis using these methods is shown.

6.9.1 Piper Trillinear diagram

A Piper diagram is a form of the trilinear diagram that provides a visual representation of the concentrations of major ions in water (Hem, 1992). This diagram can be useful for looking at similarities and differences among water samples. The Piper diagram plots the major ions as percentages of milli-equivalents in two base triangles. The total cations and the total anions are set equal to 100% and the data points in the two triangles are projected onto an adjacent grid. This plot reveals useful properties and relationships for large sample groups. The main purpose of the Piper diagram is to show clustering of data points to indicate samples that have similar compositions.

Plotting of the chemical analysis of samples collected in the area using this graph show that most of the water is clustered in the left part, suggesting that the water in the study area is a Calcium-Sodium-Magnesium-Bicarbonate type, which is characterized by a high concentration of HCO_3, Ca, Na and Mg.

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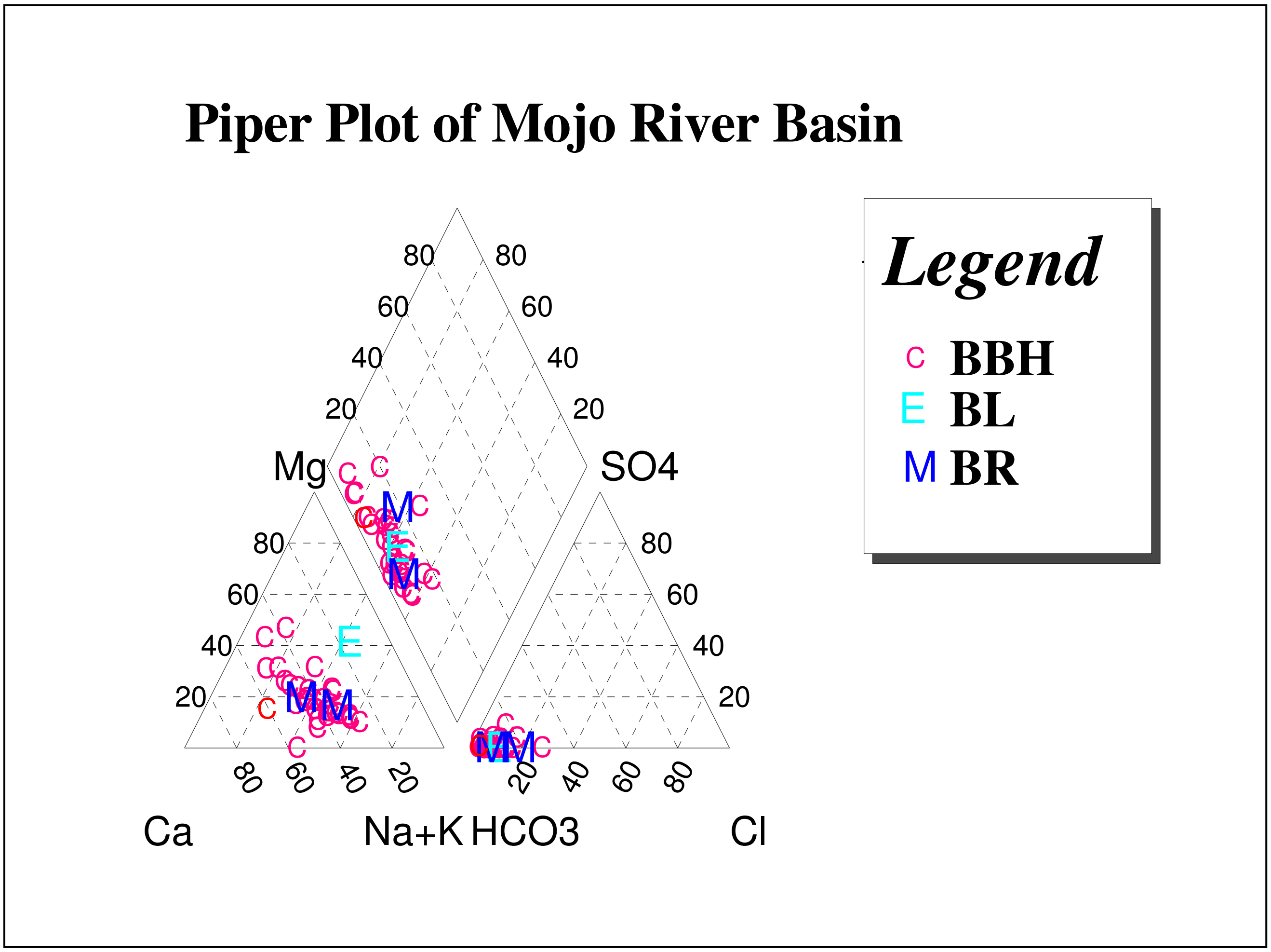

Fig. 6.7 Piper Plot of Mojo River Catchment

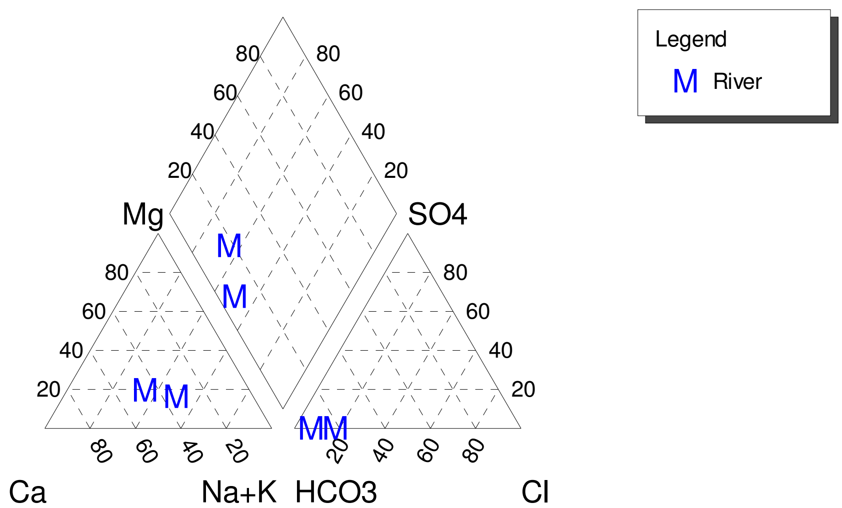

Fig. 6.8 Piper Plot of River Samples of the study area

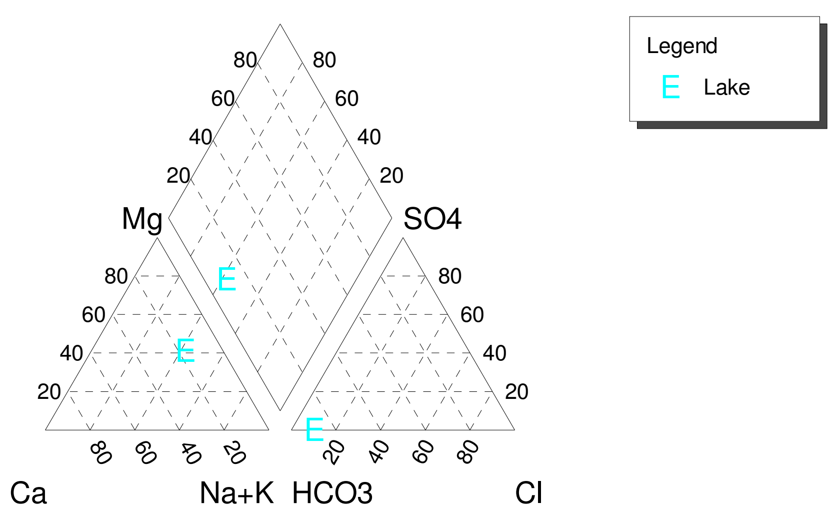

Fig. 6.9 Piper Plot of Lake Samples of the study area

Schoeller Diagram

Schoeller (1955) proposed the use of semi logarithmic graph to plot the concentration of the anions and cations. The concentrations re plotted in Meq/l. this type of diagram allows us to make a visual comparison of the composition of different waters. And in our case, water chemistry data of samples in the study area are plotted resulting the same type of water as that of the Piper Plot.

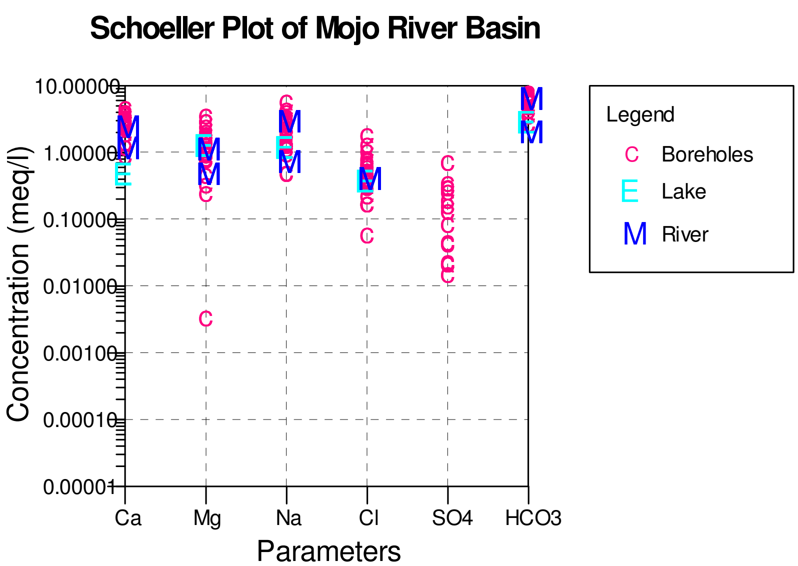

Fig. 6.10 Schoeller Plot of Mojo River Basin

6.10 Bacteriological Analysis

Bacteriological analysis is important for detecting bacteriological pollution of water. Most of the pathogenic bacteria found in the water are indigenous to the intestinal tract of humans and animals. Standards test to determine their presence and absence in the water samples are taken as a direct indication of the safety of water for drinking purpose.

In the study area bacteriological analysis data is available for boreholes near Mojo River (which were collected by AAWSA). Result of the bacteriological analysis showed that two important bacteriological parameters have been determined, they are E.coli and total coliform count (MPN).the coliform group of organism are used worldwide as indication of faucal pollution.

According to the available data, in some of the bore hole near the Mojo River values in excess of 10 counts per 100ml total coliform indicate that the ground water is faecally polluted Surface water of the Mojo River give values up to $10*10^7$, which confirm that the river is totally polluted by a raw sewage.

CHAPTER SEVEN

WATER POLLUTION

General

Water pollution is a contamination of water by sewage, toxic chemicals, metals, oils or other substances. It can affect such surface waters as rivers, lakes and oceans, as well as the water beneath the earth's surface, ground water. Water pollution can harm many species of plants and animals. According to the World Health Organization, about 5 million people die every year from drinking polluted water.

7.1 Point and Non-point Sources Of Pollution

Two types of water pollutants exist; point source and non-point source. The direct chemical discharge to a certain water body best illustrates point source water pollution. A non point source delivers pollutants indirectly through environmental changes. An example of this type of water pollution is when fertilizer from a field is carried into a stream by rain, in the form of run-off which in turn affects aquatic life. Non point sources are much more difficult to control. Pollution arising from non point sources accounts for a majority of contaminants in streams and lakes.

7.2 Industrial activities

Although industrialization is considered as the corner stone of the development strategies due to its significant contribution to the economic growth and hence human welfare, it led to serious environmental degradation in most developing countries. Currently the big challenge is not targeting the qualitative and quantitative treatment of industrial waste, but it is aiming at minimization of their hazards to human health and restoring the quality of the environment.

The large and medium scale-manufacturing sub-sector in the study area is dominated by four consumer goods producing industrial groups, Such as, food and beverage, chemical, textile and leather and shoe groups.

A number of pollution related studies have confirmed that about 90% of industries in Ethiopia, which is also true in the case of the study area, are simply discharging their effluent into nearby water bodies, streams and open land without any form of treatment. The harmful industrial waste liquids are those mixed with organic or heavy metals, with corrosive, toxic or microbiologically leaded substances.

7.3 Sewage, domestic wastewater

Most of the people that live in the towns like Mojo have no access to sewer systems and the rest use septic tanker or release the sewage into the streams through tube. These burdens lead the pollution of surface and ground water bodies. And when the water is used for household consumption it creates sever public health problems. Typhoid, paratyphoid, infectious hepatitis and infant diarrhea are some of the epidemic diseases that occur due to this contamination. This sewage also create toxic affect or promote eutrophication on the water bodies and upset aquatic biota and ecosystems.

7.4 Water quality standards

Water quality standards are fundamental tools that help protect valuable surface and ground water resources and serve as the foundation for the water-quality based approach to pollution control and are a fundamental component of watershed management. Water quality standards should have objectives like: restoring and maintaining chemical, physical, and biological integrity of waters providing, wherever attainable, water quality for public water supplies, recreation, agricultural and industrial purposes.

The term “water quality standards” is sometimes used more broadly to include minimum wastewater treatment requirements, effluent limits for point-source dischargers, and all the provisions and requirements in the state’s water quality rules. The suitability of the existing water supply for domestic use, industrial purpose, and agriculture has been analyzed by comparing the water quality analysis with international and local standards.

7.4.1 Domestic Water Quality Criteria

Water quality is relative and is defined as the characteristic of water that influences its suitability for a specific use. Quality is defined in terms of physical, chemical and biological characteristics.

a) Physical or appearance test

The appearance, taste or odor of water from a well or other source offers some information on obvious contamination, but chemical analysis is needed to detect most contamination in water. Obvious contaminates include silt (turbidity) and hydrogen sulfide, which can be detected by smell. As a rule, the senses will not detect impurities that cause hard water, corrode pipe and stain sinks. There fore the other two types of tests are needed.

b) Bacteriological Test

Bacteriological tests are used to determine if water is bacteriologically safe for human consumption. There are tests based on detection of coliform bacteria, a group of microorganisms recognized as indicators of pollution from human or animal wastes. Coliform bacteria are found in the intestinal tracts and fecal discharges of humans and all warm-blooded animals.

c) Chemical Test

Water is a solvent and dissolves minerals from the rocks with which it comes in contact. Ground water may contain dissolved minerals and gases that give it the tangy taste enjoyed by many people. Without these minerals and gases, the water would taste flat. The most common dissolved mineral substances are sodium, calcium, magnesium, potassium, chloride, bicarbonate, and sulfate. In water chemistry, these substances are called common constituents.

Chemical tests identify impurities and other dissolved substances that affect water used for domestic purposes and are needed to detect water contaminants such as nitrates, sodium, chlorides and the hardness capacity of water.

The analysis result of the water sample collected in the area have been compared with the Ethiopian standards (ESA, 1990) and with the standards established by World health Organization (WHO) and EU (European Union). (Table 7.1)

Parameter(mg/l)	WHO	EU	ETHIOPIAN
Color(TCU)	15	200mg1^{-1}pt-co	50
Odor	Odorless		
Taste	Tasteless		
Turbidity(NTU)mg/l	5	4JTU	25
pH	<8	6.5-8.5	7-8.2
Calcium	75		
Manganese	0.05		
Magnesium	50		
Sodium	200	500	
Potassium	*		
Carbonate	*		
Bicarbonate	150		
Chloride	250	25	600
Sulfate	250	250	400
Fluoride	1.5	1.5	1.5
Chromium	0.05	0.05	0.05
Iron	0.3	0.2	1
Nitrate	50	50	50
Total alkalinity as CaCO3	400		
Total Dissolved Solids	500	1000	1500
Microbiological Variables	**WHO**	**EU**	**ETHIOPIAN**
Faucal coliform	No per 100ml	No per 100ml	No per 100ml
Total coliform	No per 100ml	No per 100ml	No per 100ml

Table **7.**1 Maximum allowable concentration of selected water quality parameters.

The analyses indicate that from more than 80 samples collected from ground water (borehole, dug well and spring) in the area, about 40% of water samples are unfit for domestic use due to high concentration (above maximum allowable limit) of No_3, F, Fe+2, or total coliform bacteria count.

As for the surface water in the area, present data set indicate that Mojo River water is totally un fit or domestic use, because of high organic pollutant (which is indicated by high BOD COD and low DO), high total coliform bacteria count, suspended solid and high turbidity and bad color.

7.4.2 Industry water quality criteria

The three primary users of water are industry, irrigation, and municipal given the fact that industry water usage takes the highest share. Water quality criteria generally include the following components:

- **Beneficial uses** – identification of the uses our water resources provide to people and wildlife.
- **Numeric standards** – allowable concentrations of specific pollutants in a water body, established to protect the beneficial uses.
- **Narrative standards –** statements of unacceptable conditions in and on the water.
- **No degradation** – extra protection for high-quality or unique waters.

And accordingly, the quality requirement of water used in different industrial processes varies widely. Even within each industry, criteria cannot be established, instead, only recommended limiting value or ranges can be stated. Salinity, hardness and silica content are the three most important parameters for industrial water.

Industry and process	Turbidity unit	Colour unit	Test and Oudour	Dissolve solid	Hardness as $CaCO_3$	Alkalinity	pH	Maximum Total Alkalinity
Food processing Factory	1-10	5-10	low	850	10-250	30-250	>7.5	300
Tanning	20	10-100	low		50-500	130	6.0-8.0	135
Textile	0.3-25	0-70	low	0-50				50-200

Table 7.2 Ranges in recommend limiting concentration for industrial process water (mg/l) (Todd, 1980)

Comparing analysis result of water sample data with the above standard (Table 7.2) show that most of the ground water in the area is not fit for food processing and textile due to high value of hardness (>250ml/l as CaCO3 for food processing and <50mg/l for textile) and unfit for tanning process due to high value of alkalinity. Concerning surface water quality they are not fit for all purpose due to high turbidity, color and odor.

7.5 Results and Discussion

As indicated in the objective part, the main aim of this research work is to study the pollution of Mojo River basin and its interaction with the ground water in the basin. The quality condition of the water in the area is explained based on the chemical data of the surface and ground water collected in the area.

The analysis result of water sample collected from the Mojo major stream show that Mojo River is highly polluted. The high degree of pollution is shown by high organic pollutant, which is characterized by very high BOD(535mg/l), very high COD(542), low DO(<7.8), high coliform bacteria count($8*10^7$)dark green color, high turbidity, high suspended solids, high dissolved solids, phosphate(13.2), NH4(44.8mg/l), Cl(511mg/l) and high conductivity value.

The quality condition of groundwater in the area indicate that, from over 80 samples analyzed a number of samples confirm pollution of groundwater from where the samples are collected. Ground water pollution which can be defined as the artificially induced degradation of natural ground water quality resulted from infiltration of polluted water in to the ground (aquifer), the principal source and causes of which are likely municipal, industrial and agricultural waste.

The polluted boreholes in Mojo area are located along and close to the bank of the highly polluted Mojo River. The possible conditions in favor of high degree of infiltration being high hydraulic head difference, the geology (fractured basalt and ignimbrite) of the area and a very shallow static water level, therefore, the infiltration of surface water from the River can be the main source of the ground water pollution in the area. In addition to the river, the leakage from the towns sewage can introduce high concentration of Nitrate, organic chemicals and bacteria directly in to the ground water. As most of the population in the towns use dry pit latrines and septic tanks which often overflow, and as there is a lack of on site sanitation system, so the leakage from them also is one of the possible source of the ground water pollution in the area.

7.6 Impact of industries on water quality

The industrial sector, consisting of medium and large scale manufacturing, small scale industry and handicrafts, electricity and water and construction, is both a major user of water resources and a major contributor to economic and social development. To move towards sustainability, industries must be assured of having an adequate supply of water. In return, industries should undertake to see that water used in industrial processes is used efficiently and not returned to nature as untreated waste that pollutes the environment. Untreated chemical effluents from industries are the most important sources of contamination. Food, Beverage, Textile, and Tannery are the dominating manufacturing establishments found in the study area.

Fig. 7.1 Direct discharge of industrial effluents to surface water body (photo taken from a paint industry along Debrezeyet Mojo road)

7.6.1 Pollutants from textile industries

The textile industry can be broadly classified in two groups, namely cotton industry and woolen industry and processes natural fibres together with synthetic fibres produced by chemical industries from raw materials such as cotton, flax, silk, polyvinyl chloride, which are spanned into yarns and weaved into fabrics. The technology of transforming cotton and synthetic fibres into fabrics and dyed fabrics generates various kinds of waste, such as shaft and seed waste (while spinning), organic and chemical materials (while dyeing), minerals, and fibrous materials in the process of finishing. These kinds of wastes are sources of environmental pollution.

The textile industry is responsible for releasing highly contaminated colored effluent leading to intense water pollution. And the influence of effluents on water reserve depends on the physico-chemical properties of the contained organic and inorganic impurities.

Typically, textile waste waters have high biological oxygen demand/chemical oxygen demand (BOD/COD), a substantial proportion of which is represented by substances present in a highly emulsified and/or soluble form. The organic polluting load can be many times greater than that in ordinary domestic sewage and can also be highly colored.

Effluents produced from textile dyeing and finishing processes often contain substantial concentrations of chloride, sulfate and to some extent carbonate, which contribute to TDS/salinity, due to dyeing processes that utilize sodium and/or alkali solutions. In addition to elevated salinity, textile effluents frequently contain commonly used organic chemicals such as naphthalene sulfonates, lignin sulfonates and nonylphenol ethoxylates: The presence of these anions in effluents may similarly affect the toxicity of other chemicals present in textile effluents.

7.6.2 Pollutants from tanneries

Tanneries are one of the biggest pollutants that use the rivers and ocean as a dumping ground. Out of a number of factories only few of them have some form of treatment for their liquid waste while the rest discharge their effluent without any treatment directly in to Mojo River.

Tannery waste has got a high heavy metal content and comes from sources that are not too easy to control. Tannery wastewaters are characterized by being strongly alkaline with a high oxygen demand, a high salt content and contain large quantities of organic and inorganic compounds, including toxic substances such as sulfides, Cadmium and chromium salts. (Bajza and Vrcek, 2001).

The effect of the industrial waste on the river quality has been dramatic. This can be seen by comparing DO, COD, BOD, suspended solids, Chlorides, NH3, coliform bacteria count of Mojo River upstream and down stream of industrial effluents (table7.3).

Chemical Analysis of Waste Water from industries and Mojo River														
	pH	**DO**	**COD**	**BOD**	**Sus.Solid**		**Dissl.Sol**		**Settlable sol**	**NH_3**	**Cl**	**So_4**	**Po_4**	**Total Colliform**
					Inorg	Org	Inorg	Org						
Tannery effluent	11.6	0	8982	2018	0	14213	12010	15517	14920	806.2	5875	14	8.5	9E+07
Textile effluent	12	3.5	2332	1023	0	0	4594	2413	0	42.2	70		3.5	34000
Mojo River up stream	7.9	0	166	102	40	54	479	32	163	42.6	60	10	8	5E+07
Mojo River Down stream	8.2	0	202	117	80	110	526	69	225	45.2	75	14	8.5	8E+07

Table 7.3 Chemical analysis of Waste water from industries and Mojo River

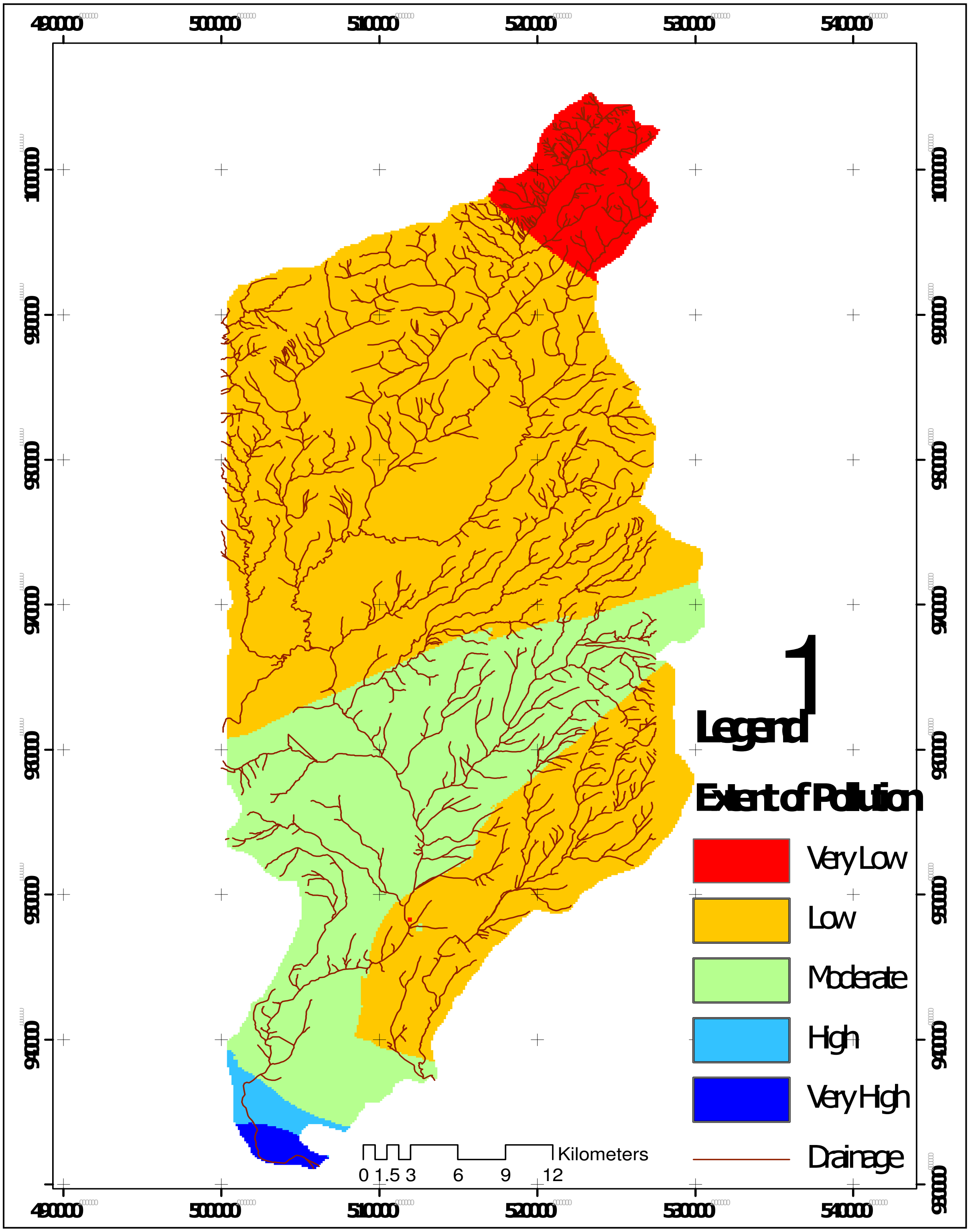
Legend
Extent of Pollution
Very Low
Low
Moderate
High
Very High
Drainage
Kilometers
0 1.5 3 6 9 12
490000
500000
510000
520000
530000
540000

Fig. 7.2 Simulated Map of pollution Extent in Mojo River Catchment

7.7 Impact of Urbanization on water quality

Introduction

The water in river reservoir comes from a variety of sources including direct rainfall, local runoff, and imported water. The chemical composition in the local runoff reflects the urban, industrial, rural, and natural land-use activities in the watershed (Lopes and Dionne, 1998).

Hydrologic impacts due to urbanization cause water quality problems such as increased sediment loadings, increased temperatures, habitat changes, and the loss of fish populations, changes in stream physical characteristics (channel width and depth), and decreased base flow. There is widespread recognition that these problems are caused by increased runoff volumes and velocities from urbanization and associated increases in watershed imperviousness. And it is generally understood that diminished water quality comes with increased urban intensity of the watershed.

Urban development is bound to:-

- increase surface flow at the expense of groundwater recharge
- deteriorate surface water quality
- affect groundwater quality by direct pollutant release into the ground (leaky pipes, cesspits) or to surface drainage systems from which contaminated runoff may eventually percolate.

7.7.1 The flow-related impacts of urbanization (unmitigated development)

Stream flow is a measure of how much water passes a point in the stream over time. Stream flow affects the transport of chemicals, habitat characteristics, and biological communities in a stream. And streams in urbanized areas are subjected to additional overland runoff from impervious land surfaces that can increase nutrients, water temperature, and suspended solids or water column particulates during wet weather

All components (physical, chemical, biological) in a stream can be influenced by changes in the hydrologic regime (characteristic behavior and quantity of stream flow).

The major flow related impacts of urbanization include:-

- Frequent flooding from storm runoff
- Significant sediment problems
- Debris from intense storm scour is washed into Holmes Run and its tributaries, blocking flow and impairing water quality.

7.7.2 Temperature related impacts of urbanization

Water temperature is a measure of the hotness or coldness of the water in a stream. It is important component of water-quality assessments and affects physical, chemical, and biological characteristics of streams. Water temperature can affect the types of biological communities and chemical reactions in streams. Temperature data will be used to characterize changes in water temperature due to urbanization using measures of daily water temperature, variability in daily temperature,

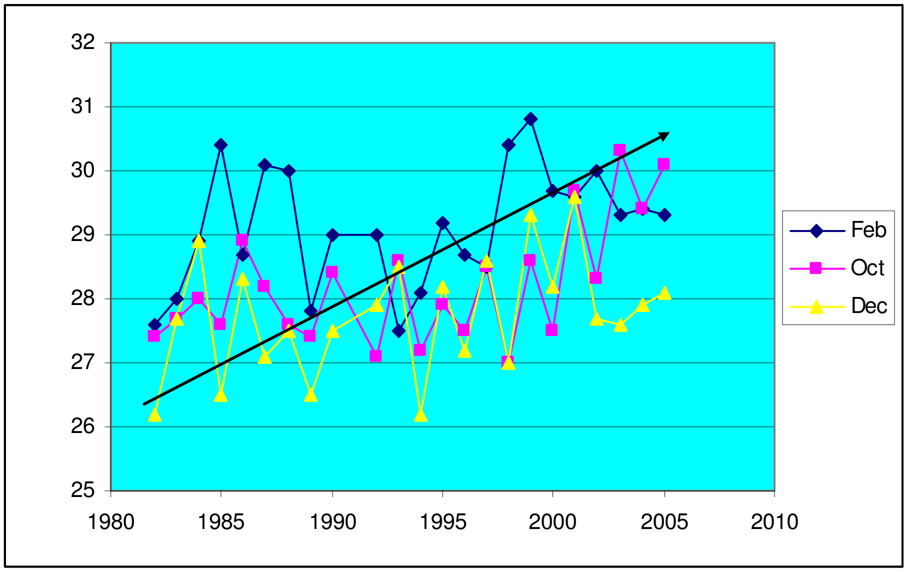

Fig. 7.1 Temperature pattern with Urbanization

In general Stream flow and water temperature can be altered as urban intensity in a basin increases. In this study, water temperature and stream flow were used to compare sites along a gradient of urban intensity from low to high and to determine the relation to other physical, chemical, and biological factors

Problems of stream channel erosion and suspended sediment have developed in Mojo area because of land use changes in the drainage basin. Urbanization in this area has consisted of residential development as well as industrial and commercial development. Urban development would double the mean annual flood peaks in portions of the streams.

Annual runoff and rainfall data for the watershed from 1958 to 1988 indicate the urbanization and impacts on streams are closely correlated. During the latter half of those 30 years (1973 to 1988), the analysis indicated that urbanization had resulted in stream runoff volumes even greater than those which had been expected based on the relationship derived from the data. During dry years in the same period, in contrast, the data pointed to a decrease in stream flow during low flow periods as a result of urbanization, to levels below normal.

This result was not surprising and is an expected result of urbanization, which typically decreases the quantity of water that seeps into the ground to replenish ground water supplies. It is the level of ground water, not rainwater runoff that is primarily responsible for keeping streams running during periods of low rainfall. Increased evaporation during these dry years could also have contributed to the low flows.

CHAPTER EIGHT

SYNTHESIS

According to data obtained from meteorological services agency, precipitation data from 12 stations in the area signify that there are only four months (June, July August and September) with high peak of rainfall. In this study, conventional hydrogeological investigation has also been carried out in order to define the basic hydrogeological factors controlling the occurrence, movement and storage of groundwater in the Mojo River basin. Estimation of Water balance and calculation of actual and potential evaporation gave important contribution for the calculation of groundwater recharge of the catchment that was estimated to be 197 MCM.

Using hydrogeological map, Qualitative characterization of different geologic units, according to their prevailing physical nature, has been carried out. The hydrogeological characteristics of the geological units indicated that basaltic flows and domes and alluvial deposits are high permeable units, while Lacustrine deposits and bedded explosion Tuffs are considered as moderate permeability group and are also good water bearing units and Ash flows, unwelded tuffs and Rhyolitic ignimbrite, are considered to be Low permeable groups. The rest of geological units such as massive ignimbrites and lacustrine deposits are considered to be low permeable units.

The groundwater flow in the basin seams to be topographically controlled. The sub surface barriers as intrusions and fracture conduits also play an important role in the local and regional ground water circulation. Groundwater flow can be said fairly follow the surface drainage pattern from north east and east to southeast and south.

The study area, the Mojo River catchment, is highly exposed to activities which possibly cause pollution. The pollutants identified in surface and groundwater bodies in the study area include organic wastes, inorganic constituents, nutrients and micro organisms.

The increase in the amount of discharges and types of pollutants in the Mojo River Basin is due to population growth, intensive urbanization, as well as increased industrial and agricultural activities. In Mojo areas, most industries dispose of untreated wastes directly into streams or rivers. Sources of industrial effluent range from pulp-and-paper mills to fertilizer factories and granulation plants, abattoirs, tanneries, textile manufacturing using dyes and noxious cleaning chemicals, chemical and steel industries and others. These industrial processes produce large quantities of different kinds of pollutants.

In recent years, the growth of industry, technology, population, and water use has increased the stress upon both land and water resources. Locally, the quality of ground water has been degraded. Municipal and industrial wastes not properly contained have entered the soil, infiltrated some aquifers, and degraded the ground-water quality. Other pollution problems include sewer leakage, faulty septic-tank operation, and landfill leachates. In recognition of the potential for pollution physical chemical and biological analyses are made on municipal and industrial water supplies in the area.

Data set of the physical parameters such as odor, color. Taste and turbidity of water sample collected from dug wells, springs, and boreholes show that most but some of the ground water in the area is colorless, tasteless and clear. Physical characteristics of the samples collected from surface water show that the Mojo River has green and dark green color, offensive odor, high turbidity and a lot of suspended material due to industrial and sewage waste.

The amount of total dissolved solids for water samples in the area range from 50mg/l to 1332mg/l. most of the values are below 1000mg/l for ground water and In the case of surface water higher value of 1332mg/l is recorded at Mojo River.

The polluted boreholes in Mojo area are located along and close to the bank of the highly polluted Mojo River. The possible conditions in favor of high degree of infiltration being high hydraulic head difference, the geology (fractured basalt and ignimbrite) of the area and a very shallow static water level, the infiltration of surface water from the River can be the main source of the ground water pollution in the area. In addition to the river, the leakage from the towns sewage can introduce high concentration of Nitrate, organic chemicals and bacteria directly in to the ground water.

In the future the public water supply should be mainly from groundwater and well-developed springs other wise any form of water in the catchment can be utilized for agricultural and industrial purpose. The surface water alternative source is not advisable for public distribution at present due to its polluted nature. In order to satisfy clean water demand of most of the rural areas and peasant associations shallow wells are recommended due to reasonable cost as compared to deep boreholes and the short coming of dug wells to intercepting groundwater table. In addition to shallow wells structurally controlled springs if developed seem to be with good potential.

CHAPTER NINE

CONCLUSION AND RECOMENDATION

Conclusion

The study area, the Mojo River Basin, covering 1506 Km2, within the Ethiopian Rift, is located between 8^0 34' N – 9^0 05' N latitude and 38^0 56' E – 39^0 17'E longitude and accessible through out the year by car. The Mojo River Basin is divided in to four major physiographic division; High land, Central plain, Rift floor and Escarpment. The physiographic variation results to a difference in precipitation of the area, the area get the highest rainfall during the four month of June, July, August and September, with the highest rainfall during the month of August, and higher rainfall recorded is 1148.79 mm at Dertu Leben, and minimum record is 869.6mm at Koka, With high flow occurring in the rain month of July, August and September.

The main rock unit in the Mojo River Basin range in age from upper Miocene to Holocene and consist of consolidated volcanic (plateau and Rift volcanic) and Lacustrine and loose Alluvial deposits. Volcanic rocks consist of different type of Basalt (Scoraceous and vesicular), rhyolite, trachyte and welded tuff of varying age. The Lacustrine sediments are compact and fairly welded tuff, ashes, silts, clay and diatomaceous sediments. The alluvial deposits are unconsolidated and consisting of sand, silt and clay beds with brown, red or black color and showing variation in thickness from place to place. The Mojo River Basin, which is part of the Main Ethiopian Rift have a number of fault parallel to sub-parallel to the Main Ethiopian Rift fault, which is characterized by normal fault with ENE-WSW trend.

The volcanic rocks in the area namely, basalt, trachyte, ignimbrite and welded tuff exhibit a wide range of hydrologic properties. The basalts range from fresh, dense, and massive type to highly fractured, jointed or vesicular type. Ignimbrite and tuff also range from massive, dense, and fresh to highly weathered and fractured. Alluvial and Lacustrine sediment differ in grain size distribution and thickness from place to place, which contribute to the variation in their hydrologic properties.

Aquifer in the area grouped in to four based on permeability: very Low, Low, moderate and high. Very good aquifer are included in scoraceous and vesicular basalt, discharge value up to 70 1/sec and Transmissivity value up to 7900 m^2/day recorded in the well drilled in these formation. Fine grained and well-compacted lacustrine deposit is moderate aquifer. Ash flows, unwedded tuffs and Rhyolitic ignimbrite are low aquifer and massive rhyolite and trachytic lava flows and domes are very low potential aquifer.

The physical parameters such as odor, color, taste and turbidity of groundwater in the area is in good condition, but Mojo River has green and dark green color, bad odor and high turbidity and a lot of suspended material due to direct discharge of industrial and domestic sewage waste on it. Both groundwater and surface water in the area are alkaline with pH in the range of 7-8. The conductivity values of most of ground water in the area is lower than 1000 µs/cm, but value above 1000 µs/cm have been recorded in the area in polluted Mojo river. Also the value of total dissolved solid (TDS) for most of groundwater in the area is lower than 1000 mg/l which is in the range of acceptance but exceptionally high value of 1332 mg/l is recorded at Mojo river. Both groundwater and surface water are hard water. On the piper diagram surface and ground water both clustered in the left part, suggesting that the water in the area is Calcium-Sodium-Magnesium-Bicarbonate type.

Bacteriological analyses of the boreholes in Mojo River reveal that the river is totally polluted by raw sewage. From 80-water sample collected from groundwater (borehole, dug well and spring) in the area, 40 % of the water sample indicate they are unfit for domestic use due to high concentration (above maximum allowable limit) of NO_3^-, F^-, Fe^{+2} and Total Coliform bacteria count.

As for surface water in the area, Mojo river water is totally unfit for domestic use, because of high organic pollutant (which is indicated by high BOD, COD, and low DO), high total coliform, suspended solid and high turbidity, high NO_3^- and phosphate. High value of Hardens also limits the use of groundwater for food processing and Textile industries. Surface water in the area is unfit for all industrial purpose due to high turbidity, color and odor.

The principal source causing pollution of Mojo River that drain through Mojo town comes from domestic and industrial waste generated in town and discharge in the river without treatment. The sampling points are concentrated in Mojo town and the pollution of groundwater is also resulted due to poor sanitation condition and the condition of borehole and dug wells in which direct runoff intrusion is possible.

Recommendation

Mojo River is used for variety of purposes by inhabitants along their course. The water consumed for domestic uses, live stocks and irrigation. However, the discharge of domestic and industrial waste highly polluted them so that their use is limited and the groundwater in the area also is affected by infiltration of polluted water. Therefore, immediate actions have to be taken by the concerned authorities to restore the quality of the river by preparing policy and legislation that should be implemented to control further discharge of waste to the river. In addition to these improving the sanitation condition of the major Towns is required to control further pollution of groundwater by sewage leakage.

i As pollution is a major problem of Mojo town, the factories in the town and its immediate surroundings should develop treatment plants with proper design and the majority of their industrial effluent should be free or in minimum concentration in terms of pollutants.

i concerning tanneries in the town, recycling of the chrome tanning solutions or precipitation of chrome using lime is recommended which would be cost-effective and that will have significant pollution prevention.

i Wastewater should be directed in such a way that the groundwater quality is not unnecessarily endangered. And since the level of urbanization in the basin worsens waste disposal problems, the well fields should be protected from future urban settlement in the area which may induce various urban wastes such as surface pollutants withdraw from various sources and leakage from septic tanks through permeable Medias that could easily reach the aquifer.

i Finally this research work is preliminary survey in which I tried to show the quality condition of the Mojo River Basin and groundwater, and the effect of river quality on the groundwater quality, on that basis I recommend further detail research work to be conducted with in the area by:

- ♦ further investigation of trace element and bacteriological analysis with high precision instruments in order to study the degree of industrial pollution and anthropogenic effect on surface and groundwater of the study area.
- ♦ monitoring the log-term trends in river water quality
- ♦ monitoring the log-term trends of groundwater quality in the area by
- ♦ upgrading groundwater data set (increasing sampling point, more borehole information and Geophysical investigation)
- ♦ determining the flow path and age (residence time) of groundwater by using isotopic studies
- ♦ groundwater flow modeling for characterizing and prediction of pollutant transport.

¶And in general human beings must learn to respect the resource base on which life ultimately depends and to see land and water as two sides of the same coin.

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