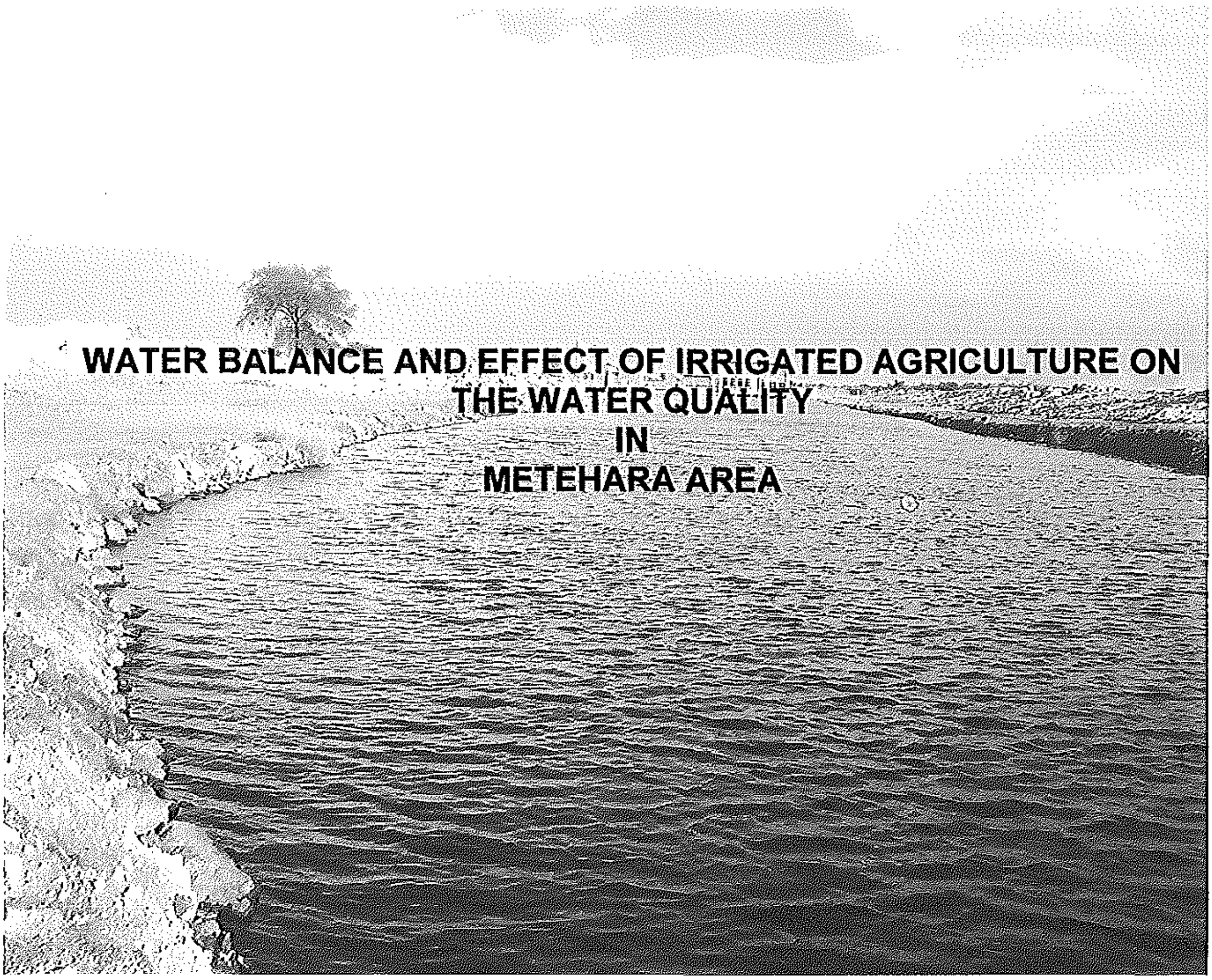
ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SCIENCES

WATER BALANCE AND EFFECT OF IRRIGATED AGRICULTURE ON THE WATER QUALITY IN METEHARA AREA



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

By

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ADDIS ABABA

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Aknowledgement

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Abstract

The study area, Metehara to Nura era, covers a total area of 777 km^2. In this area, mechanized farms of sugar cane and citrus fruits are found and more than 12,000 workers depend their lives on the plantations. Though the main source of water for domestic purposes is Awash River, there are some boreholes which serve to fulfill the needs of the society. One purpose of this work is to determine the groundwater potential for the area. Accordingly, water balance calculation for the area was carried out and groundwater recharge of the area was calculated to be 2 Mm^3 of water annually. The actual evapotranspiration estimation gave a value of 522 mm while the mean annual rainfall of the area is 593 mm. The runoff over the study area was determined and resulted value of 52 Million cubic meter of water was obtained.

Total dissolved solids (TDS) value shows an increasing trend in groundwaters towards the lake. Beseka Lake has the highest concentration of TDS showing that it is highly mineralized. Fluoride concentration in groundwaters shows variation where the highest values were observed on boreholes close to Fentale Mountain. The fluoride concentration of Beseka Lake also has high (as high as 32.7 mg/l). High nitrate concentrations (as high as 96.8 mg/l) were observed on boreholes located inside the farms (most probably due to the application of fertilizers) and also in places where there is an increased number of population and this increase in nitrate concentration in densely populated areas is probably the effect of septic tanks.

Chapter One
Introduction

1.1 Background

Water is the cradle of life. Without it, no living thing can survive in this world. This resource is used for many purposes like drinking, sanitation, irrigation, industrial uses etc. In order to satisfy these needs and continue the existence of modern civilization, we have to utilize it properly. By proper utilization it is meant that we need to have an integrated water management strategy. Water management deals with the proper use and utilization of both surface and subsurface waters to ensure the continuity of life. One aspect of this management principle is the proper and wise use of groundwaters which are contributing massively nowadays to fulfill various needs of the world. Pollution of the environment, especially water, has become the main problem of this world in the new millennium. Modern world is one source of pollution of the environment and groundwater in particular. The rapid growth of population besides the continued growth of arable land and use of fertilizer application has become a major source of pollution. This suggests that groundwater must be protected from many polluting sources (activities) and thus its quality has to be ensured. Ignoring this issue could be costly for us. Groundwater, as described earlier, is becoming the major source of water for different purposes but one problem of this resource is the location of groundwater resources that serve as a sustainable water source. So for this case, groundwater recharge condition of an area must be fully understood.

The metehara area consists of irrigated state farms that produce sugar and citrus fruits using Awash River. Different types of fertilizers and pesticides are used in the farms and combination of these may have an impact on the water resource of the area.

The main source of water for domestic purposes in the area is Awash River. But due to lack of sanitation, the people of the area are susceptible to water-born diseases. So, in this respect another adequate and sustainable water resource must be found. Groundwater can be another alternative source of water to the area but in order to determine this, its quantity (potential as well as recharge condition) as well as quality must be studied.

1.2 Previous works

Work on the study area have been carried out by many researchers, organizations etc. they mainly focus on the geology, hydrogeology, master plan study etc. Getahun Kebede carried out a regional hydrological study of the Nazareth area. Works carried by Vladmir Kazmin and Seifemichael Berhe (1987),DipOala(1972), Mohr(1983) concentrate on the study of the geology of the Nazareth area.

Works on the Flouride occurrence in the East African Rift system has been done by George Darting etal.(1996), B.Gizaw(1996) and the Ethiopian rift valley by Ashely and Burely(1994). Works on Lake Beseka was carried out by Ministry of water resources (1998).

1.3 Objectives

- One objective of this work is to determine the groundwater potential of the area (through calculation of water balance) and determine the amount of water recharging the groundwater system.
- Irrigated state farms are found in metehara area. In these farms, fertilizers and pesticides are applied to the crops so as to increase production. But their impact on the water quality with respect to human health is not assessed. Another objective of this work is to understand the effect of irrigated agriculture and the associated fertilizer and pesticide application on the water quality and point out recommendations.
- Determining the quality, resource and type of the groundwater of the region is also another objective of this work.
- The final objective of this work is to study (understand) the hydrogeology of the region using qualitative assessment of the rocks and also determine the groundwater flow direction

1.4 Methodology

The first work that has been done during the work of this paper was the collection of literature data (desk studies) like:

- Collection of meteorological data (rainfall. wind speed etc)

Meteorological data were collected from six stations (Metehara, Welenchiti, Abomsa, Nura era, Shola Gebeya) for the analysis of meteorological parameters of the study area.

- Collection of hydrological data (river discharge, lake area etc)

Hudrological data (river discharge) of Awash River at different localities was obtained and data related to Lake Beseka was also obtained

- Toposheets of scale 1:50,000 were used
- Hydrogeological map of Nazareth area was used
- Geological map of Nazareth area was also used etc

Then the area was delineated using toposheets of the scale 1:50,000. In delineating the boundary of the study area, the technique of watershed dividing points was followed. Then field investigations were carried out. During field work, different research activities were carried out like:

- Study of the geology and hydrogeology of the area.
- Water samples from different sources like borehole, lake, River etc were collected.
- In-situ tests like pH, TDS, EC was carried out on the water samples during the field trip.
- The exact location and elevation of water sampling points was registered using GPS (Global Positioning System).

The final method that has been applied in the completion of this work was

- Complete analysis and presentation of laboratory test results of the different water samples and relate these test result with agriculture.
- Analysis of the different meteorological data and hydrological data to calculate the amount of groundwater recharge of the area.

Chapter Two
General overview of the study area

2.1 Location and general outline

The study area is located in the axial part of the Main Ethiopian Rift; east Shoa zone of Oromiya national state at 195 km east of Addis Ababa. The area is bounded between latitude 8°35′ and 8°59′ North and 39°43′ and 39°57′ East longitude. The study area covers a total of 777 km^2.Highly mechanized sugar and citrus fruit plantations are found in the study area. These mechanized farms as well as the sugar factory gave a job opportunity for more than 12,000 workers. There are over 9 villages where the workers as well as their families live in. In the plantations, the factory and also the villages different activities are practiced and these have great impact on the quality of the water. In the study area, the groundwater is not mostly used for drinking purposes and also the potential of most dug wells is low. This initiated this research to be carried out and to point out some remedial measures.

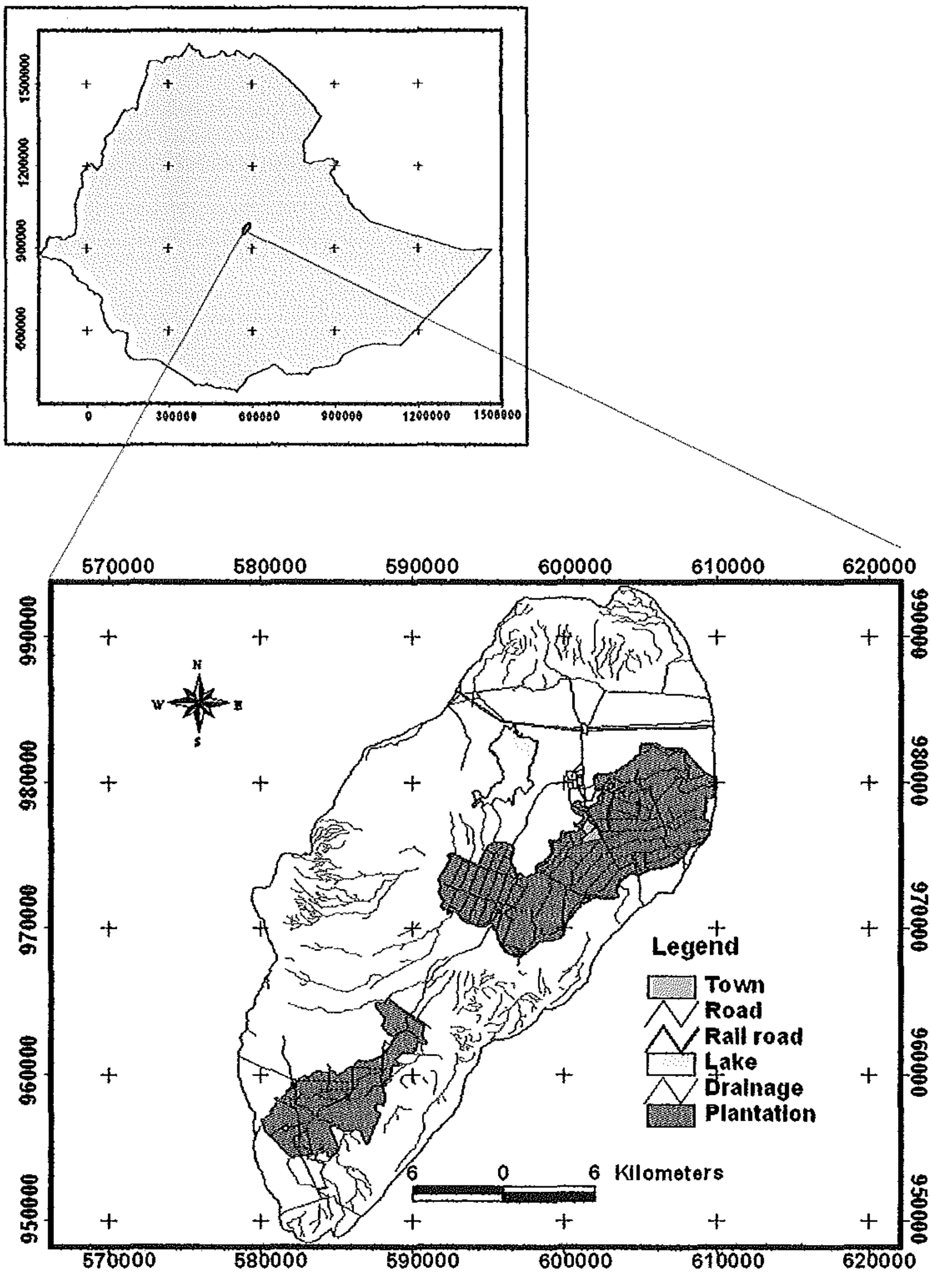


Fig 2.1 Location map of the study area
(delineated using topographic map of 1974 and note that now, the lake has increased its size to fill the other side of the road)

2.2 Physiography, Land use and Land cover

The major landform of the area consists of flat to undulating plains, hilly plain, volcanic cones, high gradient Mountain etc. Of these major landforms, flat to undulating topography occupy the major parts of the catchment. The high gradient mountain occurs in the northern part of the study area including the Fentale Mountain. The altitude of the area ranges from 930m to 2500 m above mean sea level. The land use, land cover of the area consists of different units. These include:

a) (Semi) Natural vegetation

Some of the major types of vegetations that are found in the study are include:

- Open as well as dense woodlands,
- Open bushy woodland,
- Grass land,
- Open shrub etc

Of these types of vegetations, open bushy woodland is the dominant one.

b) Water

The water units found in the study area are: Lake Beseka and Awash River.

c) Cultivated land

There are hardly any cultivated lands by individual persons. The major cultivated areas of the area are Metehara Sugar State, Nura Era citrus farm and Abadir plantation.

d) Settlement

There are many towns located in the study area namely Metehara, Addis Ketema, and Bole towns. Besides these, there are over nine villages around and inside merti (metehara) sugar factory and Abadir plantation.

Chapter Three
Geologic Setting

3.1. Regional Geology

The regional geology where the study area lies is made up of Oligo-Miocene Quaternary volcanics that are intensively dissected by extensional tectonics. The m litho-stratigraphic units are described below.

3.1.1. Alaji Basalts

A succession of up to 800 m thick predominantly aphyric flood basalts re unconformably on the eroded surface of the Mesozoic sediments represented limestone of the Upper Jurassic Gebredare formation and sandstone of Cretaceo Amba Aradam Formation. K-Ar age determinations place the basalts between 28 an myr (Kuntz etal. 1975; Moridelli etal.1975), suggesting correlation with the widespre Alaji Basalts of the Ethiopian plateau (Zanettin and Justin einestin 1973, 1974, 19 and the Adolei Basalts of central-eastern Afar (Barberi etal. 1975). The topm members of the succession are essentially of porphyritic varities , and near Asebe Te northeast of the Nazreth map area have been dated as 14my old (Kuntz etal.1975).Th belong apparently to the Jebel Sadale central type complex which structurally and in a correlates with the Tarmaber basalts on the opposite side of the rift (Zanettin and Jus Vestin op.cit). Similar central- type complex possibly exists in the Batu Mountains, so of the area.

3.1.2. Anchar Basalts and Arba Guracha Silicics

Along the eastern margin of the rift, Alaji basalts are conformably overlapped by a uni flood basalts and siliciceous rocks which is in turn partly covered with sligh uncomformity by silicics of the Nazareth group. In the Anchar area the unit represented by about 400 m of basalts with general intercalation of ignimbrites, the c at the base being 12.4 my old. To the south and northeast the basalts are latera replaced by welded and unwelded ash-flows valley and the Gurach valley in the vicir of Asebe Teferi the section is essentially silicics. The Anchar Basalts form the lower part of the rift volcanic succession.

3.1.3. Arba Gugu basalt

This unit, erupted from Arba Gugu shield volcano and is represented by successive lava flows up to 300 m thick, made up of mostly of porphyritic pyroxene and/or plagioclase basalts with an age of around 8.5 my. The flow can be traced along the upper margin of the rift escarpment to Dindin village and further north.

3.1.4. Chilalo and badda Trachytes

From the data obtained from Justinyisentin etal.(1975), Kuntz etal. (1975), two elliptical shield volcanoes on the eastern rift shoulder belong to numerous groups of trachyte volcanoes developed in the upper Pliocene on both sides of the rift. Chilalo volcano first erupted followed by trachytes while Badda evolved from basalts and trachy basalts to Trachytes. Lava flows of both volcanoes are contemporaneous with the young ignimbrites of Nazareth group and partly inter finger with them. The formation of these shield volcanoes coincide with the important stage of rifting around 4 to 4.5 myr. This rifting is supposed to correspond to the peak of the silicics volcanism in the rift (Morbidelli etal.1975) and preceded of the fissure erupted Bofa basalt.

3.1.5. Post-Ashangi Group volcanic

This sequence includes Nazareth and Wonji Group that is composed of a range of igneous rocks of different ages and occurrences.

3.1.6. Nazareth Group

The group is composed of a thick succession of ignimbrite, unwelded tuffs, ash flows, and rhyolites and Trachytes form the larger part of the rift floor and also outcrop in the rift escarpments and on the adjacent plateau margins. In the rift, the group attains thickness of up to 250m and possibly more, while on the rift shoulders only a few meters of ignimbrites are generally observed.

According to Morbidelli and Piccirillo (1973); Morbidelli etal.(1975); Brotzu etal.(1974-75), the ignimbrites of the rift floor were fissure eruptions. There is no direct data to corroborate this suggestion. However, the silicics centers such as Gara Gumbi (Gara Gumbi rhyolites) were active in the period between 7 and 5.5 myr (Christiansen etal.1975) so that central type explosive eruptions played a significant part in the formation of the Nazareth volcanics. Silicic centers were especially abundant during the latest stages of the Nazareth volcanism, as is evident from the wide distribution of rhyolitic domes cutting through older ignimbrite sheets (Older Alkaline and Peralkaline Rhyolite domes)

The lowermost ignimbritic flows of the Nazareth Group intercalated with the Chorora sediments are 9.5 my old (Kuntz et al.1975). An upper age limit of the group is older than 2.5 my, possibly 3 to 3.5 my-the age of the overlying Bofa basalts. Numerous K-Ar determinations on the Nazareth silicics (Morbidelli et al.1975; Mohr 1974) fall between 7 to 6 and 1.5 my, with a maximum between 5.5 and 3.5 my. According to Kazmin et-al.(1978), ages around 2 to 1.5 my long to a younger pleistostocene, the dino ignimbrites, unconformable on the Nazareth silicics. The time of formation of the Nazareth group is therefore between 9.5 and 3 to 4 my, which is close to the age established by Zanettin and Justinvisentin (1974) for the Balchi rhyolite.

Accumulation of the Nazareth Group was accompanied by formation of the shield volcanoes on the rift's eastern shoulder. The Arba Gugu shield volcano is synchronous with the early stages of the Nazareth volcanism, and chilalo and Badda volcanoes were formed during later stages.

3.1.7. Bofa Basalts

In the rift the silicics of the Nazareth Group are overlapped by a unit of fissure flood basalts which was named after its type locality in Bofa village. In the Awash Gorge near Kerayu Lodge the lower part of the Bofa Basalts is dated as 2.5 my, and they are overlapped by ignimbrites 1.5 my old. The Bofa Basalts may include much older flows, for example an age of 3.5 my was established by Mohr (1971) for basalts in the Nazareth vicinity which possibly belong to the same unit. The Bofa Basalts are not restricted to the central part of the rift as younger units, but are rather evenly distributed over the rift floor. They represent an episode of fissure eruption which immediately followed a major faulting episode.

3.1.8. Wonji Group

As pointed out by many authors (Mohr 1967a, b and others; Meyer et al.1975; Gibson 1970; Dankin and Gibson 1971) the latest volcanism in the Ethiopian Rift is related to its axial extensional zone, the Wonji Fault Belt. Although some volcanic manifestations such as eruptions 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 Berhe (1978) the Wonji Group includes all rift volcanics formed after the last major episode of rift faulting which followed accumulation of the of basalts. As observations in the Arba valley north of Abomsa village show, the oldest volcanics of the Wonji Group, the Dino Ignimbrites, overlap strongly faulted Bofa Basalts, but are not themselves affected by this faulting.

The following major units comprise the Wonji Group:

- Dino Ignimbrites
- Pantelleritic Volcano Centers
- Sub-Recent and Recent fissure basalts

The group also includes some minor units such as hylocalstites, explosion centers and rhyolite domes.

The Dino Ignimbrites

This unit covers a considerable portion of the rift floor and comprises a number of flows of compact fiamme ignimbrites in places intercalated with aphyric basalts and unwelded pyroclastics.

In the Awash Gorge this ignimbrite rests on the Bofa Basalts with a paleosol horizon at the base, and is dated as 1.5 my.

The Pantelleritic Volcano centers

This unit is aligned en enhelon along segments of the Wonji Fault Belt. The main products of eruption consist of peralkaline rhyolites and trachytes with some pumice, pitchstone and obsidian occurring mostly at post-caldera stages (Gibson 1970; Dakin and Gibson 1971; Cole 1969; Brotzu et al.1974-75; Thrall 1973).

A feature of the acidic volcanic centers is the formation of large calderas; in some cases the whole volcano collapsed, leaving behind a circular area of subsidence. Such a development was suggested for Gedemsa Caldera (Thrall 1973) and for Kone Caldera (Cole 1969). Fentale volcano is surrounded by a roughly circular area of subsidence measuring 50 by 36 kilometers which, while not readily distinguishable on the ground, is clearly seen in ERTS (Earth Resources Technology Satellite) satellite imagery.

Pleistocene-Sub-Recent and Recent fissure basalts

These are mainly concentrated along the Wonji Fault Belt, although some exceptions are known in the rift. The basalts differ in the degree of preservation of original flow surfaces, the youngest flows of the historical period being fresh aa lavas. Older basalts contemporaneous with early stages of development of the pantelleritic volcanoes were fissural while the youngest eruptions were of central type. Lines of well preserved volcanic cones follow fractures in the Wonji Fault Belt, which in many places cut across the pantelleritic volcano centers.

3.1.9. Lacustrine sediments

The lacustrine deposits are purely lake or swamp deposits or those of volcano-lacustrine type of the rift valley. The lacustrine sediments consisting of clay, silt, tuffs. travertine, diatomites with intercalation of pumices are widely distributed. They are Pleistocene to Holocene in age and they are deposited from extensive lakes during the Pleistocene pluvials. In Nazareth, Welenchiti, Wonji and koka the thickness of the lacustrine sediments varies from 30 to 40 meters.

3.1.10. Alluvial deposits

The alluvial deposits are of two types: those spread out in alluvial plains and those strips along rivers and streams. Alluvial plains are filled up grabens and large stretches of flat land in the rift valley and along the whole length of the western border of the country. These are troughs in the lowland where during the pluvial period streams deposited large amounts of sediments carried down from the highlands. The thin strips of alluvium along streams occur in most places both in the highlands and the lowlands. The alluvial sediments occur in Metehara and Abadir area in the rift proper. Their grain size ranges from silt to gravel.

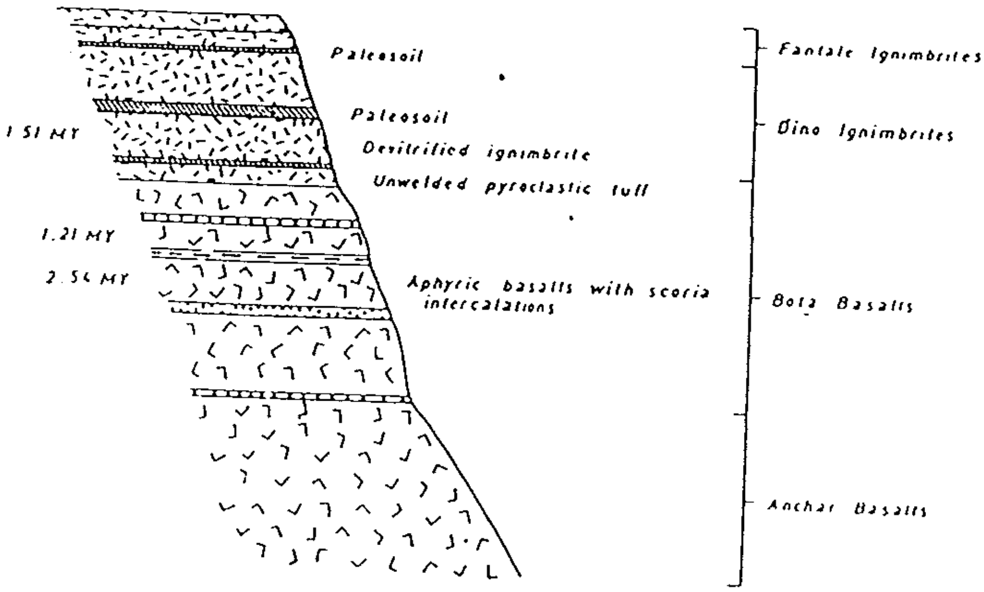


Fig 3.1 Section at Awash Gorge near Karayu Lodge
(After Kazmin and Seife, 1978)

3.2 Tectonics

The main Ethiopian Rift (MER) extends over 1000 km in a general north (NNE) direction and covers a total area of 150,000 km^2. This structural depres in the north from Hartale and extends in the south up to lake Langano. It's w but mostly it is 60 km in average and ranges up to 80 km. According to seve in the Eocene the regional up lifting occurred, as part of Afro-Arabian swell, gave rise to large scale faulting with clear western and eastern fault margin e of MER. There exist morphological differences between the eastern and th escarpments. The eastern is characterized by well defined lineaments thro length, while the western progressively die out in its south western extreme s the feature of rift escarpment is hard to define. The floor of the main Ethiop dissected by intense, fresh NNE-SSW trending faults known as Wonji fault faults are of normal type and are up thrown both northwest and southeast. H Graben structures are very common. The Wonji Fault belt forms a zone alo recent lavas and ignimbrites have erupted.

The Holocene lavas are also restricted to the Wonji Fault Belt and are associate calderas such as Fentale, Kone, Boset, and Gadamsa. They consist of bedded explosion tuff, recent pantelleritic and commenditic obsidian flows and domes a recent aphyric basalts.

3.3 Geology of the Study Area

The principal rock units of the study area are divided into two groups: sedimentary rocks of fluvo-lacustrine which are distributed at the southern part of the study area (Abadir farm area) and volcanic rocks which have different mineralogical composition and stratigraphic composition. Volcanic rocks mainly ignimbrites and basalts of different ages are widely distributed in the study area.

The major rock units which are found (which are outcropped) in the study area include:

3.3.1 Bofa basalts

This is the very oldest rock unit found in the study area. It is found on the south of Metehara sugar plantation and to the east of Abadir farm. This unit is highly affected by faults. This rock unit is mostly aphyric, locally vesicular and fresh with several flows separated by scoriaceous horizons.

3.3.2 Dino ignimbrites

This unit consists of compact fiamme ignimbrites intercalated with basalts and unwelded pyroclastics. This unit is found in the area between Nura era and Abadir farm. The thickness of the Dino ignimbrites which forms the oldest rock unit of the Wonji group is 30 meters. This unit is Pleistocene in age.

3.3.3 Pleistocene-Sub recent basalts

This rock unit is found extensively on the north and west of Abadir farm in the study area and is it is also one of the oldest rock units of the Wonji group. This rock unit is highly affected by minor faults.

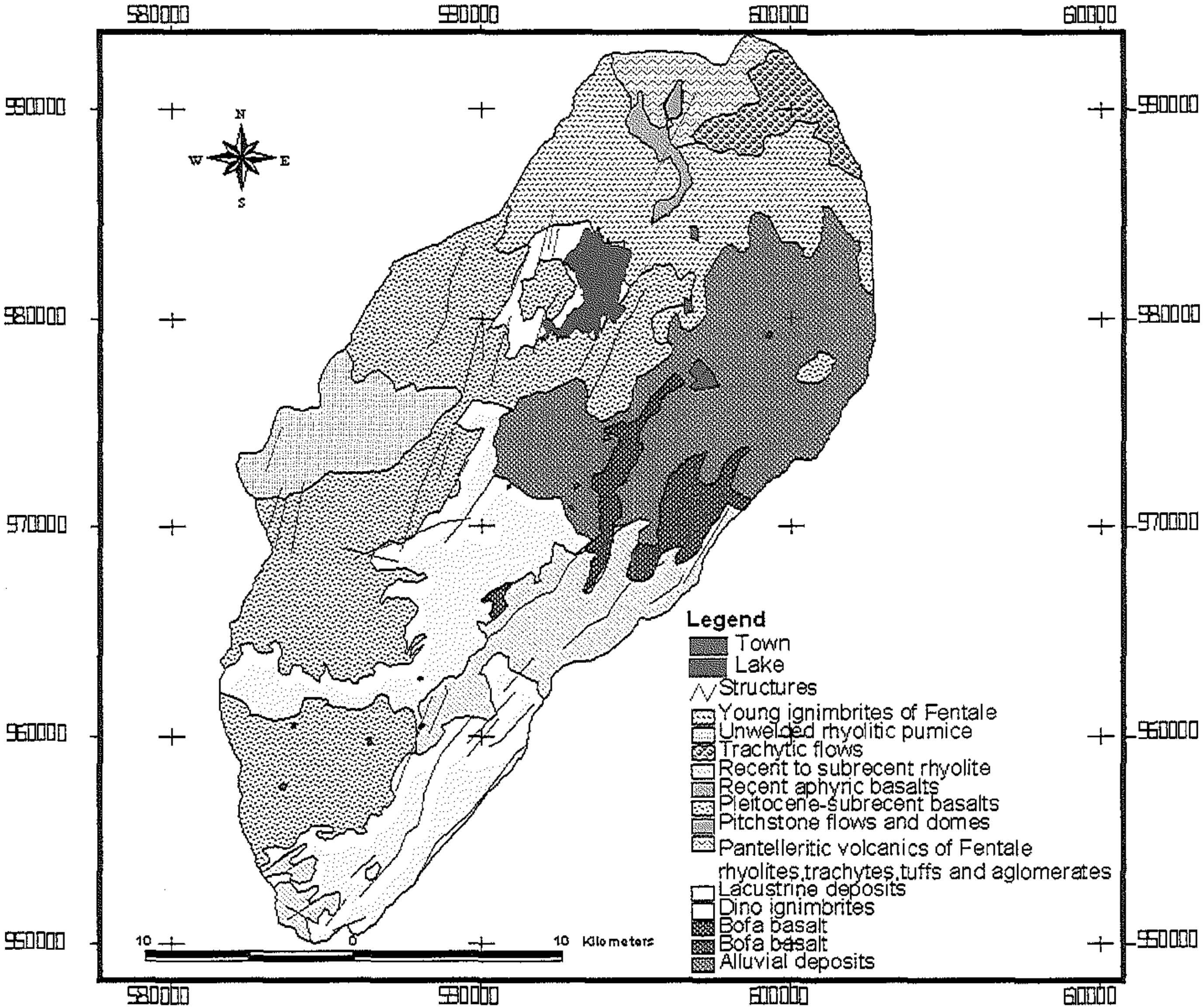


Fig 3.2 Geological Map of the area (modified from Geology of Nazareth, EIGS, 1978)

3.3.4 Trachytic flows and domes associated with Fentale, Tinish Fentale and Kone

This unit also covers a relatively smaller part of the study area. In the study area this unit is found locally around Fentale Mountain and also on some parts to the west of Fentale. This unit is Pleistocene in age. This unit is not affected much by different structures.

3.3.5 Pantelleritics volcanics of Fentale rhyolites, trachytes tuffs and agglomerates

This unit covers a small part of the study area and it is found locally on the northern side of Metehara town around Fentale Mountain. It is pleitocene in age.

3.3.6 Lacustrine sediments

As the name implies, this unit is found in the floor of Lake Beseka and also on the close vicinity of the lake. Lacustrine deposits are mainly fine to medium grained in texture.

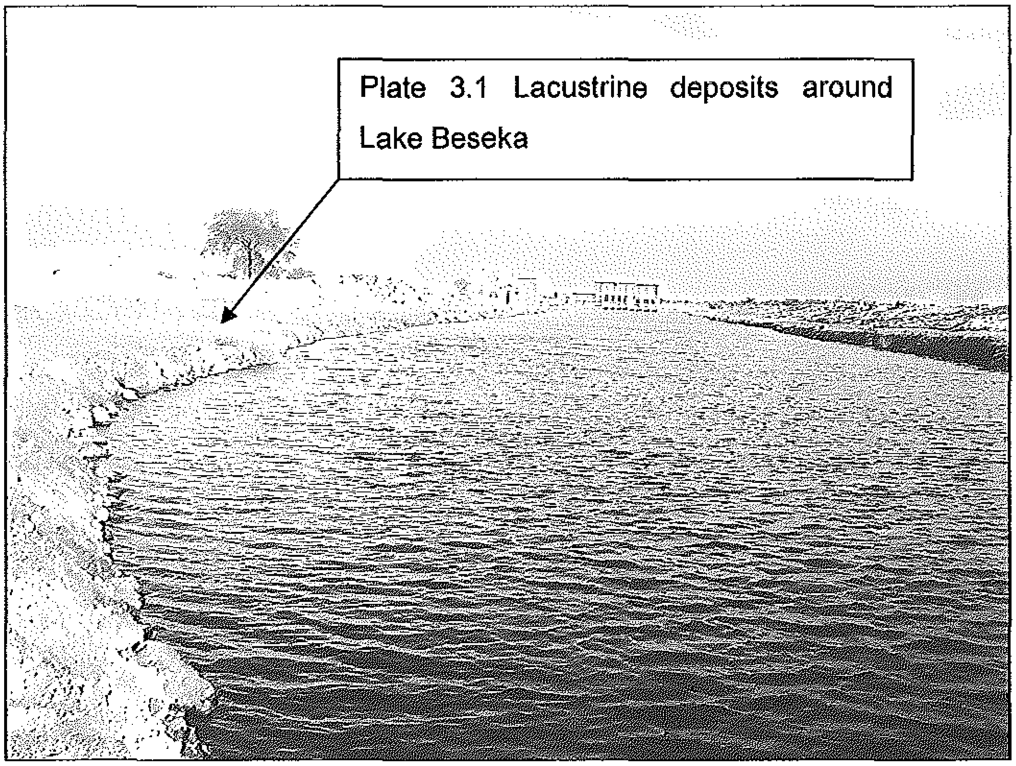


Plate 3.1 Lacustrine deposits around Lake Beseka

3.3.7 Recent to Subrecent rhyolite domes and flows

This unit is found extensively on the south western part of the area distinctly shown on the left and right sides of Bofa basalts and in some cases it is intercalated with the alluvial sediments found on the left and right banks of Awash River.

Plate 3.2 Weathered rhyolite

3.3.8 Unwelded rhyolitic pumice

This unit covers a small portion of the area and is outcropped on the south western part of the study area.

3.3.9 Pitchstone flows and domes

This unit is the least outcropped unit found in the study area and is found locally around Fentale Mountain.

3.3.10 Young Ignimbrites of Fentale

This unit covers larger portion of the study area and is pleitocene in age. As the name implies, this rock unit is one of the youngest rock units found in the study area (it is pleitocene in age). In the study area, this rock unit is found in Metehara town, extensively on the northern side of Metehara town close to mount Fentale, on the area between Addis Ketema town and Abadir farm to the south of Metehara town.This rock unit is dark grey in color with highly scoriaceous texture and is minorly affected by weathering.

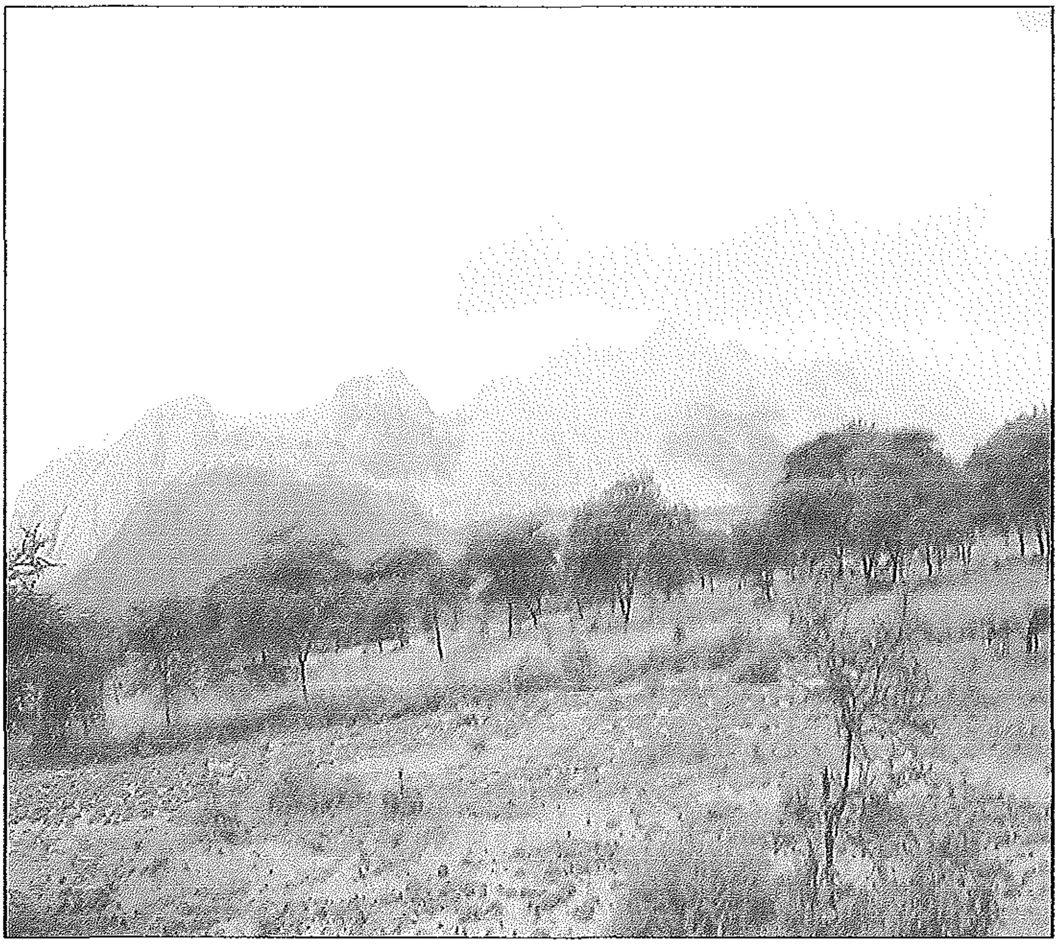


Plate 3.3 Fentale Mountain

3.3.11 Recent aphyric basalts

This is also one of the youngest rock units exposed in the study area and it is Holocene in age. This unit, unlike the previous units, covers a very small part of the study area. It is found locally on the northern side of lake Beseka (very close to the lake). This unit resulted from fissure eruptions and is highly vesicular with coarse texture.

3.3.12 Alluvial sediments

This unit is the also a younger unit found in the study area and is found around Addis Ketema town, inside Abadir farm, around Awash river and inside Merti sugar plantation.

The alluvial sediments are Holocene in age and their thickness is about 43 meters in Addis Ketema town (near Metehara) and Abadir area (farm). This unit provides a surface that is conducive to the growth of plants and hence is the backbone to the agricultural activities in the area.

Chapter Four

Hydrometeorology

4.1. Climate

The study area is characterized by semi arid climatic condition (kola) with minimum altitude of 930 meters above sea level. The maximum altitude on the mountains is 2500 maters above sea level. Using the data obtained from National Meteorological Services Agency (NMSA), various climatological elements of the study area were summarized and are stated below.

4.1.1 Temperature

Temperature is measured at 2 stations within the area and the mean monthly temperature is computed as the arithmetic average of the mean daily temperature of all the days in the month. According to the data obtained from National Meteorological Service Agency (NMSA), the study area has an average temperature of 25 °C with a minimum temperature of 21.7 °C and a maximum temperature of 28 °C. Maximum temperature values were recorded in the months of May and June and minimum temperature record was obtained in the month of January.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
21.7	23.7	25.3	26.1	27.2	28.1	22.7	22.4	26.8	24.2	22.2	25.4

Table 4.1 Mean Temperature of the area.

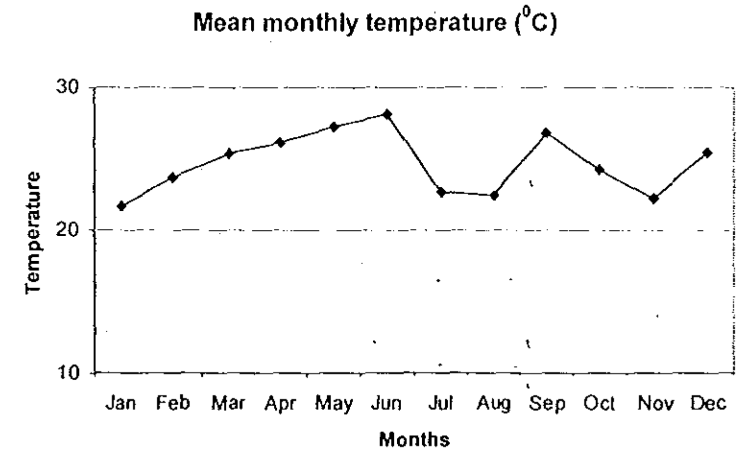


Fig.4.1 Mean annual temperature in (°C)

4.1.2 Wind speed

The mean monthly wind speed of the area measured at two meters above the ground varies from 1.4 m/s to 2.1 m/s with maximum values observed in the months of June, July and August and the minimum values were observed in the months of September, October and November.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.6	1.8	1.8	1.6	1.6	2.1	2.1	1.8	1.4	1.4	1.4	1.5

Table 4.2 Mean monthly wind speed

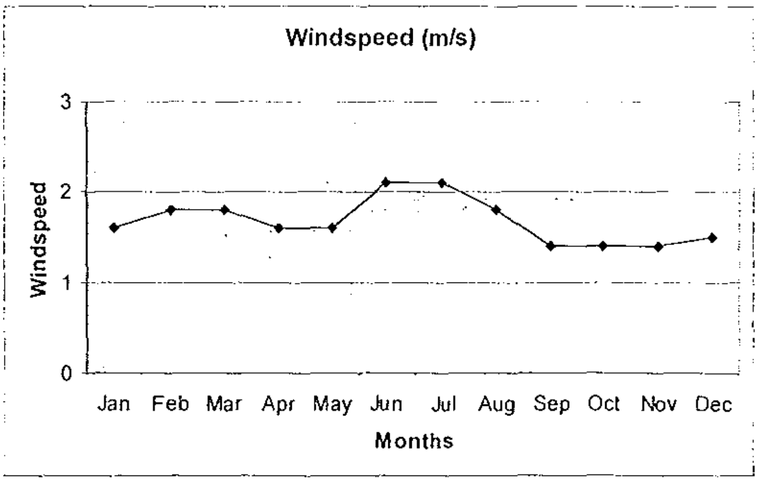


Fig.4.2 Mean annual wind speed (m/s)

4.1.3 Sunshine hours

For the data range 1986-2001 it was found that the values of mean annual sunshine hours in the study area range from 7.1 hours to 9.2 hours. From the data it can be observed that the highest values of sunshine hours were observed from October to June while relatively lower values were observed in the months of July, August, and September.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
8.8	8.8	8.5	8	9.2	8.1	7.1	7.3	7.7	8.7	9.1	9.2

Table 4.3 Mean Monthly sunshine hours

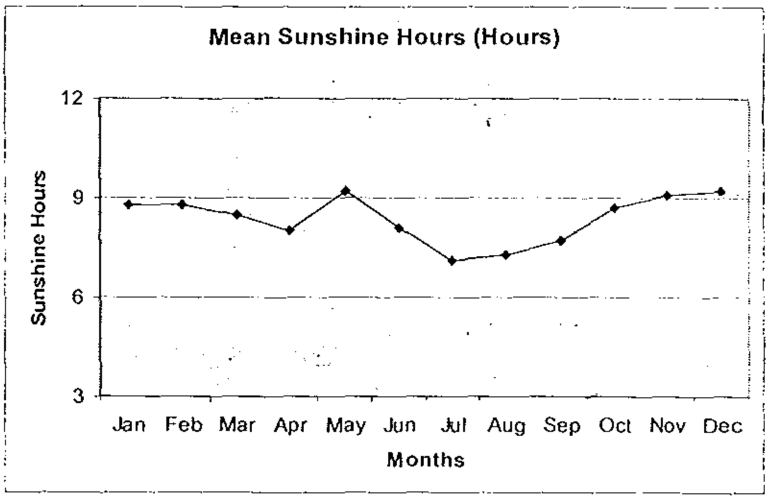


Fig 4.3 Mean annual sunshine hours

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 rainfall. The area has a maximum humidity value of 60.4 and a minimum value of 46.7%. The maximum humidity values were recorded in the months of July, August, and September while the minimum values were recorded in May and June.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
53.7	54.1	54.4	54.9	49	46.7	56.8	60.4	56.8	48.8	48.3	52.3

Table 4.4. Mean monthly Relative Humidity

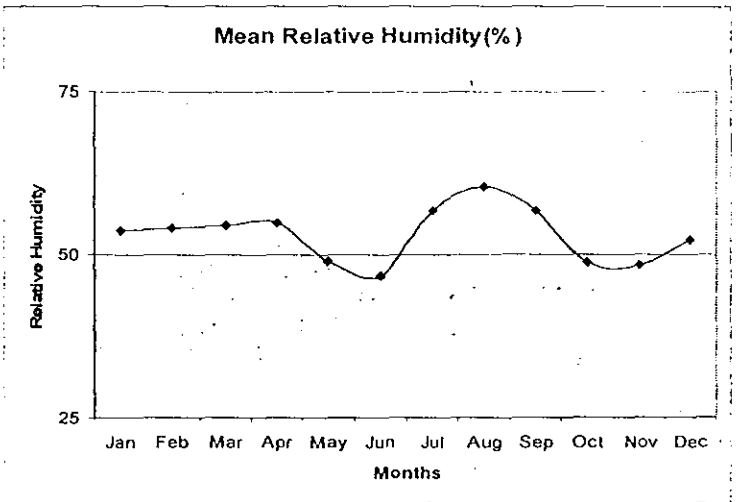


Fig. 4.4 Mean annual relative humidity

4.2 Hydrology

The most prominent hydrological features of the study area are intermittent streams, Awash River, lake Beseka and springs. Irrigation using Awash River is highly practiced in the area. In this section, we will treat some hydrological parameters one by one.

4.2.1 Rainfall

Rainfall is the most important form of precipitation. It consists of water droplets less than 0.5mm in diameter. The area under investigation is located between latitude 8°35′ and 8°59′ North and 39°43′ and 39°57′ East longitude. The spatial and temporal variation of rainfall in Ethiopia is strongly controlled by the inter-annual movement of the position of the Inter Tropical Zone (ITCZ). During its movement to the north and south of the equator, the ITCZ passes over Ethiopia twice a year and this migration causes the onset and withdrawal of winds from north and south. The ITCZ represents a low-pressure area of convergence between dry tropical Easterlies and moist Equatorial Westerlies along which equatorial wave disturbances take place.

When the ITCZ is located north of Ethiopia, the northeasterly winds from southwest reach to most parts of Ethiopia. During this time, the Trade winds from the north retreat. When the ITCZ is located in the south, the Trade Winds from north drifts the equatorial winds. This periodical anomaly of winds causes seasonal rainfall variability.

The big summer rains or Keremt rains occur when the ITCZ is found north of Ethiopia. During this period the whole country is under the influence of Equatorial Westerlies from South Atlantic Ocean and southerly wind from the Indian Ocean.

When the ITCZ moves to the south, the country will be under the influence of continental air currents from north and northeast. These winds originate from North Africa and west Asia and are cold and dry. In spring (March, April, May) the ITCZ lies in the southern part and a strong cyclonic cell (low pressure area) develops over Sudan. Winds from the Gulf of Aden and the Indian Ocean (anticyclone) blow across central and southern Ethiopia and form the relatively Belg rains.

The metehàra area which is located in the Eastern part of the country as well as the central and northern part of the country experience a nearly bi-modal (two peak) rainfall distribution. These are Belg rains (February to May) and Kiremt rains (June to

September). Mean annual rainfall gradually decreases towards the northeast and east (Tenalem and Tamiru, 2001).

According to the data obtained from National Meteorological services Agency (NMSA), the area obtains its highest rainfall in the months of June to September especially in the months of July and August. This can easily be shown on the Mean Monthly Rainfall (in millimeters) for the area over a time of 18 years.

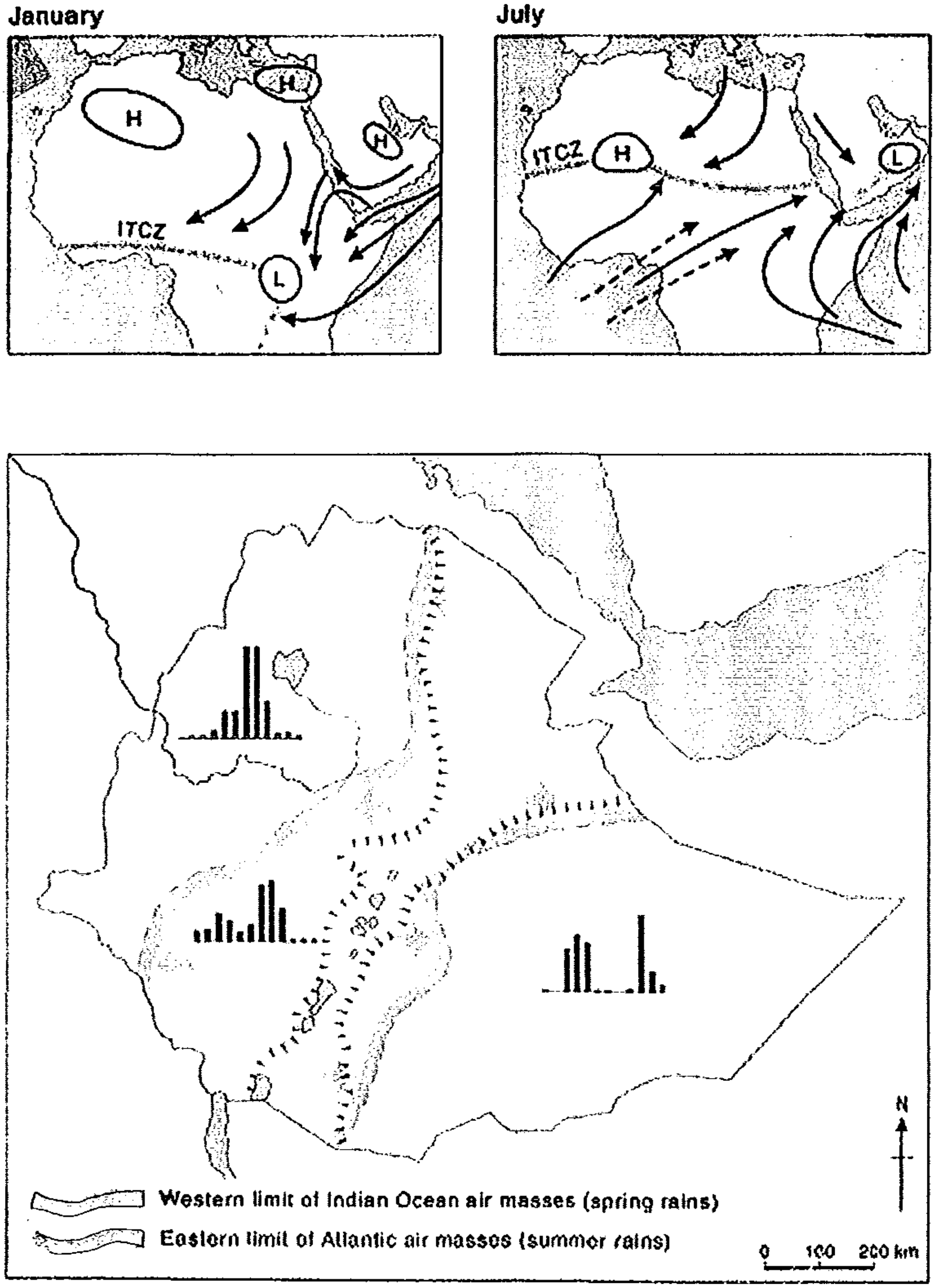


Fig 4.5 Spatial and temporal variation of rainfall in Ethiopia

Aerial depth of rainfall of the area was calculated using two approaches (methods): Arithmetic mean (average) method and the Isoheytal method.

a) Arithmetic mean (Average)

It is computed as the arithmetic mean of the amounts measured by the gauges within the area.

$$P_A = \frac{\sum_{i=1}^{n} P_i}{n} \qquad \text{.......... (4.1)}$$

P_A: average rainfall for the total area

P_i: measured precipitation at a given station and time

n : number of rain gauges

In the study area there are two rain gauges: one in Metehara town and the other in Nura Hera farm. Arithmetic mean computed using these two gauges gave a value of 539 mm of rainfall.

This method is unreliable when the topography is steep and the stations are widely spaced. In the study area, even though the area has a flat topography, the stations are widely spaced and due to that the value obtained by this method is unreliable.

b) Isoheytal method

Isohyets are lines of equal precipitation on the drainage map of the basin. The area and equivalent uniform depth (EUD) of precipitation are calculated and the weighted average precipitation is calculated based on the equivalent uniform depth of precipitation between adjacent isohyets and their areas.

$$P_A = \frac{P_{1.2}.a_{1.2} + P_{2.3}.a_{2.3} + \ldots + P_{n-1.n} \cdot a_{n-n.n}}{A_t} \qquad \text{.......... (4.2)}$$

$P_{1,2}$: rainfall between isohyets 1 and 2

$a_{1,2}$: area enclosed by successive isohyets of 1 and 2

A_t : total area

In using this method, rainfall data from five stations was used (Table 4.5).

station	Latitude	Longitude	Elevation	Mean Annual Rainfall
Metehara	8.520	39.540	930	501.456
Nura Era	8.500	39.540	1140	577.502
Welenchiti	8.400	39.260	1450	936.218
Abomsa	8.280	39.490	1800	924.183
Shola Gebeya	9.030	38.460	2500	948.976

Table 4.5 Annual mean value of rainfall at different stations

The obtained mean annual rainfall of the five stations ranges from 501mm at Metehara station located at 930 meters above sea level to 949 mm at Shola Gebeya station located at 2500 meters above sea level. In this respect, rainfall and elevation tend to have a positive relationship.

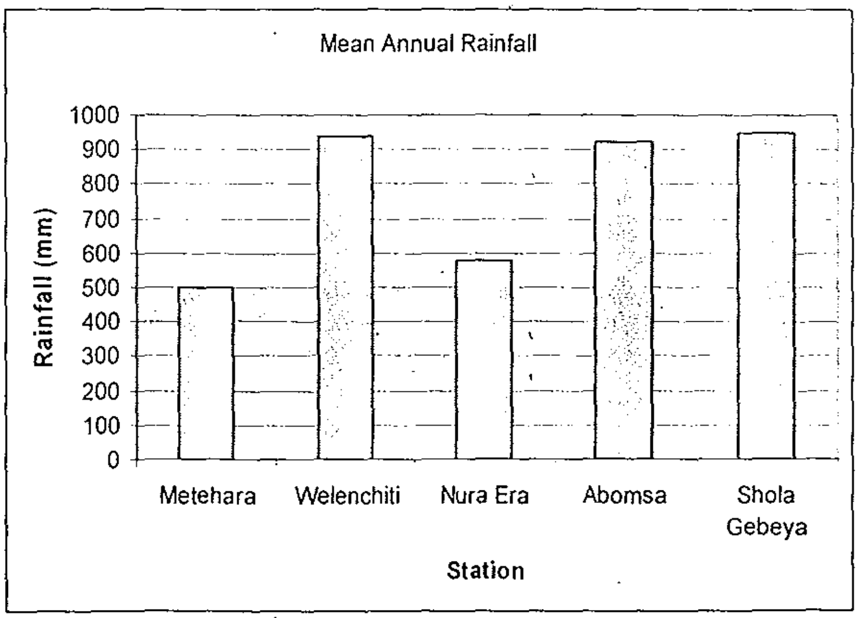


Fig.4.6 Annual mean rainfall at different stations

Using this method, aerial depth of precipitation was calculated and the weighted precipitation was found to be 593.26mm. (As shown in Table 4.6 and Fig.4.6)

A	B	C	D	E=BxD
Isoheyt (mm)	Estimated EUD	Net Area (Sq.Km)	Percent of Total Area	Weighted Precipitation
<550	530	186.1925	23.94	126.89
550-600	575	178.5491	22.96	132.01
600-650	625	385.7996	49.60	310.05
650-700	675	16.6336	2.14	14.44
700-750	725	9.1071	1.17	8.49
>750	760	1.4248	0.18	1.39
				593.26mm

Table 4.6 calculated aerial depth of rainfall using Isoheytal method.

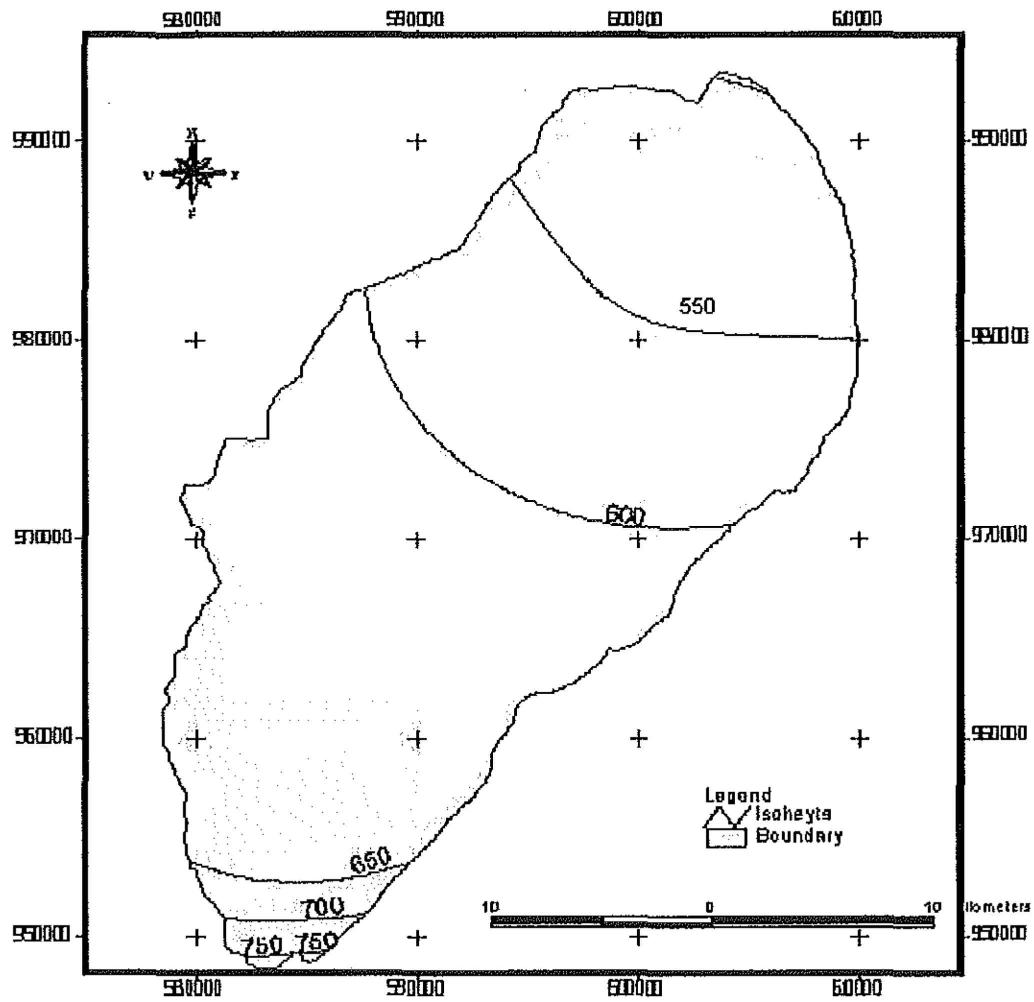


Fig 4.7 Isoheytal map of the area

This method offers a relatively accurate effective uniform depth of precipitation as it works for all types of terrains (flat or steep) and the stations don't necessarily have to be equally spaced.

4.2.2 Evaporation and evapotranspiration

Evaporation is the movement of water molecules to the atmosphere from free water surface; bare soil etc. Free water evaporation is only the mechanism for mass transfer of water to the atmosphere. Growing plants are continuously pumping water from the ground into the atmosphere through a process called transpiration (Hendricks & Hansen, 1962). It is the conversion of water molecules to vapor by evaporation (open water body) and transpiration (plants) away from the watershed surface to the atmosphere (Axon, 1982). Potential evapotranspiration is the water loss which will occur if at no time there is a deficit of water in the soil for the use of vegetation (Thornthwaite, 1944) while actual evapotranspiration is used to describe the amount of evapotranspiration that occurs under field conditions. Several methods have been developed to estimate evapotranspiration: using pan evaporation up to empirical formulas. In this particular paper, due to the lack of pan evaporation data, empirical formulas that use different meteorological data are used to calculate potential and actual evapotranspiration.

5.2.2.1 Potential Evapotranspiration

a) Thornthwaite method

Thornthwaite method is based upon the assumption that potential evapotranspiration is dependent only up on meteorological conditions and ignores the effect of vegetative density and maturity. The only necessary factors to calculate potential evapotranspiration using this method are mean monthly air temperature (T), Latitude, and month (Thornthwaite & Mather 1955; 1957). The last two factors yield average monthly sunlight.

An estimate of the potential evapotranspitarion, PET_m, calculated on a monthly basis is given by:

$$PET_m=16N_m(10T/I)^a \qquad (4.3)$$

Where m is the months 1,2,3,...,12 ,N_m is the monthly mean temperature in ^{o}C, I is the heat index for the year, given by :

$$I=\Sigma i_m=\Sigma(T/5)^{1.5} \qquad (4.4)$$

And:

$a=6.7x10^{-7}I^3-7.3x10^{-5}I^2+1.8x10^{-2}I+0.49$ (to 2 significant figures).

The day light factors (N_m) are obtained from a table by dividing the possible sunshine hours for the appropriate latitude by 12 (in our case 10^0N).

Potential evapotranspiration was calculated using this empirical formula. According to this, the weighted mean annual PET over the area is 1372mm.

b) Penman method

Penman (1956) & Blaney (1956) derived a theoretical equation for the estimation of free water evaporation and evapotranspiration. This equation uses climatic data, including vapor pressures, sunshine duration,. net radiation, wind speed, and mean temperature. The basic equation of penman to calculate potential evapotranspiration, PET_m, is

$$PET_m = \frac{(\Delta/\gamma)\ H_T+E_{at}}{(\Delta/\gamma)+1} \quad \text{..........} (4.5)$$

Where H_T is the available heat and is calculated as

$$H_T=0.75R_I-R_o \quad \text{..........} (4.6)$$

Where R_I is the incoming radiation and R_o is the outgoing radiation. R_I is a function of R_a, the solar radiation (fixed by latitude and season) modulated by a function of the ratio, n/N, of measured to maximum possible sunshine duration. And "n" is bright sunshine over the same period,h/day

$$E_{at}=0.35(1+u_2/100)(e_a-e_d) \quad \text{..........} (4.7)$$

Where u – mean windspeed at 2m above the surface, miles per day

e_a – saturated vapor pressure at air temperature T_a

e_d - mean vapor pressure of the air.

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

$$e_a(T_a)=6.11exp(17.3T_a/T_a+237.3) \quad \text{..........} (4.8)$$

With vapor pressure in mb and temperature in °C.

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

$$e_d=W_a e_a(T_a) \quad \text{(4.9)}$$

Where W_a is expressed as a ratio.

The emperical equation for the incoming radiation, R_I, takes the form

$$R_I(1-r)=0.75R_a.f_a(n/N) \quad \text{(4.10)}$$

r-is the albedo

$f_a(n/N)$ takes several forms. The study area, located south of $54^{1/2}$ °N (10 °N), $f_a(n/N)$ takes the form:

$$f_a(n/N)=(0.16+0.62n/N) \quad \text{(4.11)}$$

The emperical equation for the outgoing radiation takes the form:

$$R_o=\sigma T_a^4(0.47-0.75\sqrt{ed})(0.17+0.83n/N) \quad \text{(4.12)}$$

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

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

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

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

4.2.2.2 Actual evapotranspiration

As defined earlier, actual evapotranpiration is the amount of evapotranspiration that occurs under field conditions (Fetter, 1988). This actual evapotranspiration is one of the components that are vital in calculating the water balance of the area. Since the study area is located in the warm rift system, high actual evapotranspiration is of to be expected. Different methods have been tried to calculate actual evapotranspiration:

a) Turc method

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

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

Where

P=annual Precipitation

L=330+25T+0.05T

T=Mean annual air temperature (^oC)

In this method, the dominant factors in evapotranspiration are precipitation and temperature. Using this method, an actual evapotranspiration value of 522 mm was obtained for the study area.

b) Thornthwaite method (water balance method)

This method calculates actual evapotranspiration using precipitation and soil moisture deficit values. The majority of the water loss due to evapotranspiration takes place during the winter months while little loss is during the summer. Always actual evapotranspiration is less or equal to potential evapotranspiration. When the soil is saturated, it will hold no more water. In this conditions, actual evapotranspiration is equal to potential evapotranspiration (AET=PET) (Shaw, 1988). If there is no rain to replenish the water supply, the soil moisture gradually becomes depleted by the demand of vegetation to produce a soil moisture deficit (SMD). As soil moisture deficits increases, actual evapotranspiration becomes increasingly less than potential evapotranspiration. The values of soil moisture deficit and actual evapotranspiration vary with soil type and vegetation.

Thornthwaite and Mather (1957) introduced the concept of 'root constant' that defines the amount of soil moisture (mm depth) that can be extracted from a soil without difficulty by given vegetation. A soil moisture budget can be made on a monthly basis for various types of vegetation classified according to their root constants. Therefore, to evaluate actual evapotranspiration over an area, the proportions of different types of vegetation covering the basin must be known.

The dominant type of soil type in the study area is fine sandy loam and the dominant vegetations are shrubs, pasture grass, etc and combination of these two gives an available water capacity of the root zone of 150mm. inputs for this method are: Precipitation, Potential evapotranspiration, soil moisture values. The soil-water storage capacity of the region is represented by a single value S_{max} and an initial value of soil moisture by S_o (Dingman, 1994). If for a given month Pm > PETm, the value of the soil moisture at the end of that month, Sm, is found as

$$S_m = \min[((P_m - PET_m) + S_{m-1}), S_{max}] \text{ ------------------(4.15)}$$

If Pm < PETm a soil moisture deficit develops or increases. The soil moisture for this case is given as

$$S_m = S_{m-1}\exp\left[-\frac{PETm - Pm}{S\max}\right] \text{ -------------------------(4.16)}$$

The monthly actual evapotranspiration (AET) is then found as:

$$AET = PET \quad \text{if } P_m > PET_m \text{ -------------------------(4.17)}$$

$$AET = P_m + S_{m-1} - S_m \text{ otherwise ---------------------(4.18)}$$

Based on these categories and meteorological datas, the actual evapotranspiration of the basin is calculated using Thornthwaite and Mather soil water balance model (Table 4.7). Actual evapotranspiration calculated using this method gave a value of 537.6 mm.

Table 4.7 Long-term average monthly water balance at Metehara area for a soil with an available water capacity of 150mm. The soil is a fine sandy loam and the vegetation is made up of deep rooted crops (like shrubs) with a rooting depth of 1m.

	Jan	Feb	Mar	Apr	May	June	July	August	Sept	Oct	Nov	Dec	Year
P*	17	33.6	53.5	49.3	26.9	29.6	109.1	133.2	44.3	28.6	3.9	8.6	537.6
T	21.7	23.7	25.3	26.1	27.2	28.1	22.7	22.4	26.8	24.2	22.2	25.4	
j	9.23	10.55	11.64	12.2	13	14	9.8	9.6	12.7	11	9.55	11.71	
PET	73	97	119	132	151	167	84	81	144	104	79	121	1372
Correction factor	0.97	0.98	1.00	1.03	1.05	1.06	1.05	1.04	1.02	0.99	0.97	0.96	
Corrected PET	71	95	119	136	159	177	88	84	147	103	77	116	
P-PET	-54	-61	-66	-87	-132	-147	21.11	49.16	-103	-74	-73	-107	-833.73
Acc.pot WL	-411	-472	-538	-625	-757	-904			-103	-177	-250	-357	
SM	9	6	3.85	2.16	0.89	0.33	21.44	70.6	70	42.7	26.2	12.9	
ΔSM	-3.9	-3	-2.15	-1.7	-1.31	-0.56	21.11	49.16	-0.6	-27.3	-16.5	-13.3	
AET	20.9	36.6	55.6	51	28.2	30.2	88	84	44.9	55.9	20.4	21.9	537.6
D	50.1	58.4	63.4	85	130.8	146.8	0	0	102.1	47.1	56.6	94.1	834.4
S	0	0	0	0	0	0	0	0	0	0	0	0	0
RO	0	0	0	0	0	0	0	0	0	0	0	0	0

T=Mean monthly temperature, PET= Potential evapotranspiration, j=Heat Index, P=Mean monthly Precipitation, SM=Soil Moisture, ΔSM=Change in the soil moisture during the month, D=Soil moisture deficit, S=Soil moisture surplus, RO=Runoff (Note that this method was applied in this work so as to determine Actual evapotranspiration (AET)

Conclusion

Since we are using the rainfall value obtained using Isoheytal method (593 mm), we will use the actual evapotranspiration value obtained using Turc method because this method is a good estimation evapotranspiration in arid and semi-arid areas.

Method	PET (mm)	P(mm)	AET (mm)
Turc	—	593	522
Penman	1921	593	—
Thornthwaite	1372	593	538

Table 4.8 Summarized values of PET and AET and Precipitation.

4.2.2.3 Evaporation from open water body

This section is treated separately as there is one open water body in the study area (Lake Beseka). Beseka Lake is an open water body that is found in the study area. Understanding the evaporation from this water body helps immensely in understanding the whole process of evaporation for the study area and also helps as a reference for future works targeting the lake, if any. Keeping this in mind, evaporation from this open water body was calculated using Penman formula (combination method) as discussed below.

a) Penman formula (combination method)

This formula calculates evaporation from open water body using standard meteorological observations. Penman formula calculating evaporation from open water body is derived using the following series of steps:

In a simplified energy balance equation:

$$H=E_o+Q \qquad (4.19)$$

Where H is the available heat, Eo is energy for evaporation and Q is energy for heating the air.

The values of Eo and Q can be calculated by

$$E_o=f(u)(e_s-e_d) \qquad (4.20)$$

And

$$Q=\gamma f_1(u)(T_s-T_a) \qquad (4.21)$$

γ is the hygrometric constant (0.27 mm of mercury/^oF) to keep units consistent. It is generally assumed that $f(u)= f_1(u)$. If the equation 5.20 is based on the air humidity using the air temperature T_a, then:

$$E_a=f(u)(e_a-e_d) \qquad (4.22)$$

Where e_a is the saturated vapor pressure at air temperature T_a, and thus (e_a-e_d) is the saturation deficit (e_d is the vapor pressure of the air).

If Δ represents the slope of the curve of saturated vapor pressure plotted against temperature, then:

$$\Delta = \frac{de}{dT} \cong \frac{e_s - e_d}{T_s - T_d} \cong \frac{e_a - e_d}{T_a - T_d} \quad \ldots\ldots (4.23)$$

Then from equation 5.21:

$Q = \gamma f(u)\,[(T_s - T_d) - (T_a - T_d)]$

$$= \gamma f(u) \left[\frac{(e_s - e_d)}{\Delta} - \frac{(e_a - e_d)}{\Delta} \right]$$

$$= \frac{\gamma E_o}{\Delta} - \frac{\gamma E_a}{\Delta}$$

Substituting for Q in the energy balance equation (equation 5.19),

$$E_o = H - \frac{\gamma E_o}{\Delta} + \frac{\gamma E_a}{\Delta}$$

$$\Delta E_o = \left[\frac{\Delta H}{\Delta + \gamma} \right] + \left[\frac{\gamma E_a}{\Delta + \gamma} \right]$$

$$= \frac{\Delta}{\gamma} H + E_a \Big/ \frac{\Delta}{\gamma} + 1 \quad \ldots\ldots (4.24)$$

Evaporation for Beseka Lake was calculated using Penman method (Combination method) and an evaporation value of 2174mm was obtained.

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T^c	21.7	23.7	25.3	26.1	27.2	28.1	22.7	22.4	26.8	24.2	22.2	25.4
Sunshine hours (n)	8.8	8.8	8	9.2	8.1	7.1	7.3	7.7	7.7	8.7	9.1	9.2
Wind speed (miles/day)	84.16	94.68	94.68	84.16	84.16	110.5	110.5	94.68	73.6	73.6	73.6	78.9
R_a	12.8	13.9	14.8	15.2	15	14.8	14.9	15	14.8	14.2	13.1	12.5
N	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
n/N	0.76	0.74	0.67	0.75	0.64	0.56	0.58	0.62	0.63	0.74	0.78	0.8
e_a	26	29.4	32.4	34	63.2	38.2	33.52	32.4	33.1	30.3	26.8	32.5
e_d	13.9	15.9	17.6	18.7	17.7	17.8	19	19.6	18.8	14.8	12.9	17
$e_a - e_d$	12.1	13.5	14.8	15.3	18.5	20.4	14.5	12.8	14.3	15.5	13.9	15.5
σT_a^4 (mm/day)	14.7	15.1	15.4	15.6	15.8	16	15.56	15.4	15.52	15.2	14.8	15.5
$R_I(1-r)$ (mm/day)	7.3	7.8	7.7	8.6	7.6	6.9	7.1	7.4	7.4	7.9	7.6	7.4
R_o (mm/day)	2.35	2.33	1.98	2.07	1.94	1.74	1.62	1.64	1.75	2.49	2.81	2.4
$H = R_I(1-r) - R_o$	4.95	5.47	5.72	6.53	5.66	5.16	5.48	5.76	5.65	5.41	4.79	5
E_a	5.68	6.84	7.49	7.18	8.69	11.46	8.14	6.48	6.19	6.7	6.01	7
Δ/γ	2.39	2.63	2.8	2.9	3	3.11	2.89	2.8	2.85	2.68	2.46	2.82
E_o	160.3	163.8	191.27	201	199	200.7	190.96	184.5	179.5	178.5	154.2	171.1
E_{at}	7.8	9.2	10	9.86	11.9	15	10.7	8.7	8.7	9.4	8.4	9.7
H_T	3.1	3.5	3.8	4.4	3.8	3.4	3.7	3.9	3.8	3.4	2.9	3.2
PE	4.68	5.42	5.84	6.18	6.17	6.57	5.81	5.2	5.1	5	4.5	4.9
PE* Number of days of the month	139.5	142.8	167.4	174	179.8	186	170.5	161.2	158.1	155	135	151.9

Table 4.9 Calculation of potential evapotranspiration and evaporation from open water body using Penman formula (combination method).

4.2.3 Runoff and Base flow

Runoff is a component of stream water which is generated from precipitation as flowing water in a basin. Runoff occurs when the rate of precipitation exceeds the rate of infiltration into a soil. Topography, vegetation, geology, and climate are the controlling factors of runoff over an area (Fetter, 1994).

The runoff component for the water balance of the area was determined using Chow's (1988) runoff coefficient method. This is given by:

$$C = \frac{R}{\sum_{M=1}^{M=12} P} \qquad \text{.......(4.25)}$$

Where C=runoff coefficient

R=Depth of runoff

P=Monthly Precipitation

Zenaw Tessema (1997) determined a runoff coefficient of 0.15 for Lake Beseka and its surroundings. But this value does not actually represent the entire study area as there are some forests (citrus plantations etc) like plantations and according to Richard (1998), these have a runoff coefficient of 0.1. So for the study area, an average runoff coefficient of 0.12 is suggested for this work.

Accordingly, runoff is given by:

R=(AxP)xC

The rainfall depth of the study area was calculated to be 593mm and the entire area of the study area is 777km^2 of which 40 km^2 is covered by Lake Beseka. So, for this calculation an effective area of 737 km^2 was used.

Using the above approach, the runoff over the study area was determined and resulted value of 52 Million cubic meter of water.

The base flow component contribution of Awash river to the runoff of the study area was calculated by assessing the data obtained from the ministry of water resources from metehara gauging station (period, 1986-1996), and also from Nura era gauging station (period, 1986-1996) and according to this data, there is no base flow component within the study area; this was analyzed by taking the difference between the upstream and down stream discharge values obtained from the gauging stations. The fact that there is no base flow contribution to the runoff can be attributed to the high evapotranspiration rate which is more than rainfall intensity in most months within the study area.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	-11.9	-29.2	-12.6	-31.0	-89.8	-38.8	-25.7	-26.2	-29.3	-24.4	-23.4	-24.5
1988	-25.8	-23.5	-23.4	0.6	-15.3	-15.8	-40.1	X	0.3	-15.5	-16.1	-16.5
1989	-18.5	-18.3	-20.2	-15.6	-16.2	-26.4	4.7	-22.1	-74.3	-15.9	-11.3	-13.1
1990	-4.7	34.6	-47.7	-12.0	-12.4	X	X	X	X	-15.2	-70.6	-12.8
1991	-14.1	-14.0	-25.1	-12.5	-15.1	-11.3	-39.5	13.6	-89.4	-26.0	-19.8	-10.5
1992	-8.2	16.4	-8.4	-29.8	-14.0	-35.7	-56.8	-10.3	0.1	27.5	-7.9	-6.9
1993	4.5	4.9	-2.4	-55.0	24.2	-14.8	-12.6	X	X	19.6	2.5	-1.1
1994	-14.7	-7.9	-15.3	-18.1	-3.4	-71.4	-61.3	-23.9	-6.1	X	-26.9	-30.2
1995	-31.6	-6.1	-25.1	8.1	-33.6	-42.9	-58.1	-68.2	-59.3	-73.4	-64.1	-63.8
1996	-6.1	-5.5	-37.9	-18.7	-32.3	-45.6	-82.9	59.6	123.7	-54.4	-60.3	-51.0
Average	**-13.1**	**-4.9**	**-21.8**	**-18.4**	**-20.8**	**-33.6**	**-41.4**	**-11.1**	**-16.8**	**-19.7**	**-29.8**	**-23.0**

Table 4.10 Discharge difference between Metehara and Nura era

As can be seen in Table 4.10, the discharge of Awash River in the study area (except in some months) gives a negative value. One other reason why the discharge decreases is due to the irrigation activity carried out with in the state farms as water is taken from the river to be used for irrigation purposes.

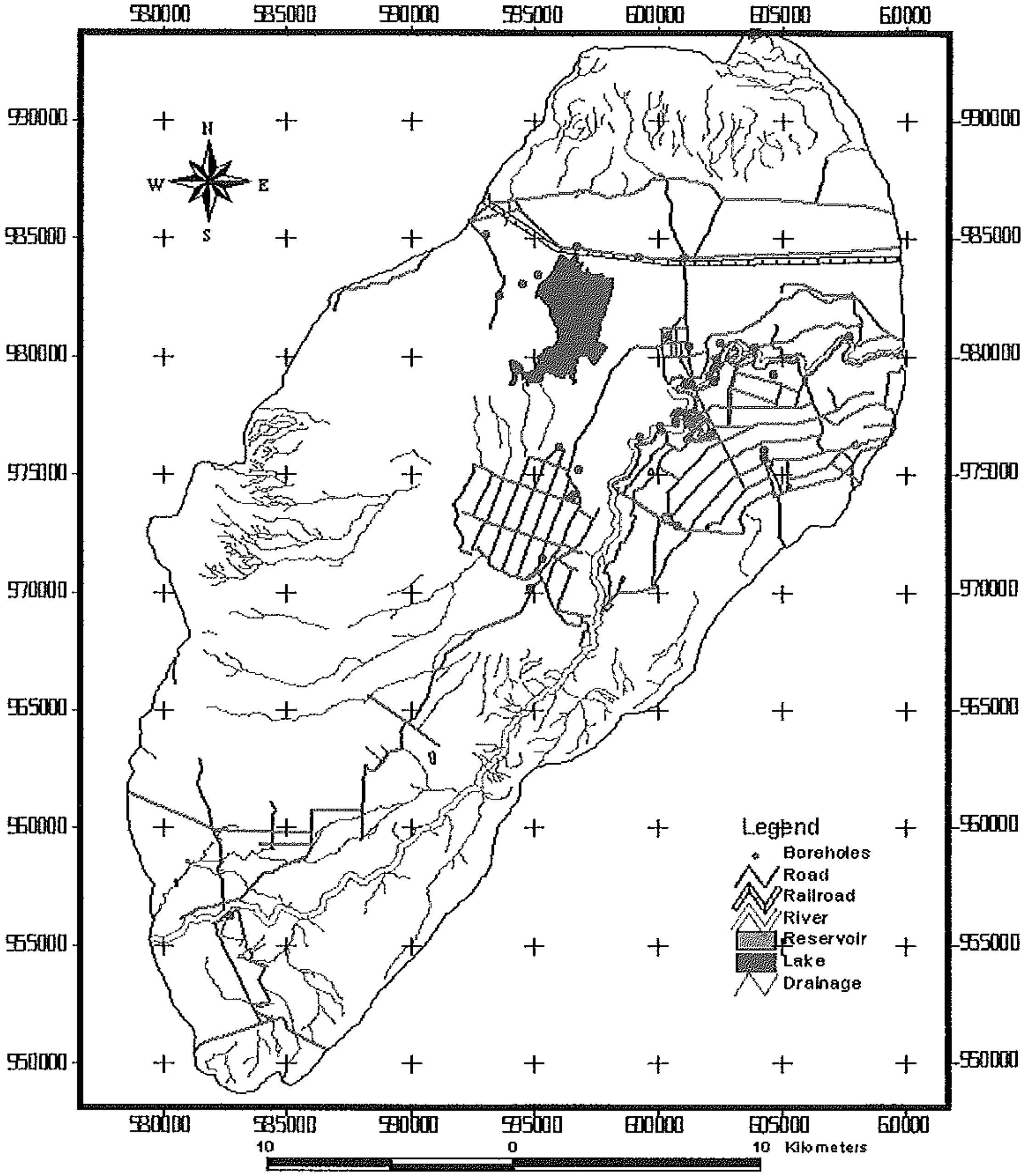


Fig 4.8 Drainage map of the area

4.3 Water balance

The water balance represents the hydrological gains and losses of a given system (reservoir, column of soil, aquifer, river basin, etc) over a specific period of time. The water balance is sometimes referred to as water budget. Hydrologic budget is a quantitative evaluation of the total water gained or lost from a given hydrological system during a specific period of time. It considers all water, whether surface or groundwater, entering, leaving, or stored within the system. Water balance applies to an aerially restricted place (the boundary of the system has to be known) and requires evaluation of in and out flowing amount of water within the area under consideration.

All components of the hydrologic system are interrelated; changing one component has its influence on others. Generally water balance has the following form:

Inflow=Outflow±Change in storage

For example the general form of the water balance of a given river basin or catchment can be given by:

$$P+I+A_r+Q_i=R+E_t+D+Q_o+W\pm\Delta S \quad (4.26)$$

Where:

P=Precipitation

I=Infiltration from surface water

A_r=Artificial recharge

Q_i=groundwater outflow

R=Surface runoff

E_t=Evapotranspiration

D=drainage (including upward seepage)

Q_o=groundwater outflow

W=Withdrawal

$\pm\Delta S$=Change in storage

Water balances are mainly used to determine the groundwater recharge, that is, the water reaching the groundwater table. Groundwater recharge estimations have important role for water resource management. This recharge amount reaching to the groundwater table depends directly or indirectly on many factors such as temperature, humidity, precipitation etc.

Assuming that there is no groundwater inflow as well as outflow and also with the absence of artificial recharge, the estimation of water reaching the groundwater table can be calculated by:

$$R=P-Q-Et \qquad (4.27)$$

Where R is the estimated recharge to the groundwater (Mm^3), P is the precipitation (Mm^3), Q corresponds to runoff (Mm^3) and E_t is the actual evapotranspiration (Mm^3)

Parameter	Amount
Total area (Km^2)	777
Lake Beseka area (Km^2)	40
Land surface (Km^2)	737
E_t depth (mm)	522
E_t (Mm^3)	406
Precipitation depth (mm)	593
Precipitation (Mm^3)	460
Groundwater inflow	0
Groundwater outflow	0
Artificial recharge	0
Runoff (Mm^3)	52

Table 4.11: Datasets for water budget calculation

The groundwater of the area calculated using this approach gave an annual value of 2 Mm^3 (0.002574 mm). This very low value of recharge occurs due to the fact that in the study area there is high rate of evapotranspiration and relatively low amount of rainfall and this low amount of rainfall is manifested on low groundwater potentials of the dug wells and as observed during field work, there are many boreholes which produced a low yield as a consequence were abandoned. Caution must be taken in understanding this way of calculating groundwater potential as it is under limitations like the inavailability of some parameters.

Chapter Five
Hydrogeology

5.1 Hydrogeology

The ground water potential of an area depends primarily on the type of rock(s) that are present in the area and also the presence of different structures (like faults, joints etc) contributes immensely to this end. In the study area, volcanic rocks of different origins as well as fluvo-lacustrine deposits are found. The volcanic rocks include materials having wide range of hydrologic properties. This property is due to differences in mineralogy, chemistry, texture, structure, etc. and hence, their ability to store and transmit water varies accordingly (Fisher R.V and H.U, 1984 and William's,H., Turner, F.J, and Giblet C.M.,1985; Cited in :Tamiru Alemayehu,1994). The most important features governing the ground water flow and storage in volcanic rocks are the following:

- ✓ Vertical permeability due to primary and secondary fractures
- ✓ Horizontal permeability due to horizons containing openings due to lava flows and gas expansion during solidification.
- ✓ Occurrences of impervious horizons and dikes.

All fractured and porous volcanic rocks do not always serve for ground water circulation; on this regard, the main controlling factors are:

- ✓ Type , frequency and distribution of the fractures
- ✓ Degree of the fractures and pore interconnection
- ✓ Thickness of the lava flow
- ✓ Occurrence of cementing material and their hydraulic characteristics
- ✓ Constitution of the soil cover
- ✓ The depth of the lave flow-because at depth volcanic rocks may have low permeability due to the pressure exerted by the overlying units

Ground water circulation and storage in the volcanic rocks also depends on the type of porosity and permeability formed during and after the rock formation. All rock structures possessing a primary porosity and may not have necessarily permeability; that is, without the original interconnection, the primary permeability, but the later connection, by means of weathering of fractures may result a secondary permeability (Tamiru Alemayehu,1994).

Primary porosities are not only constituted by interstitial spaces but also by primary fractures. The secondary porosities are dominated by fractures. In the study area, fractures and faults prevail giving way to the development of secondary porosity.

Weathering and tectonic fractures form secondary fractures based on the nature of the movement and the type of stresses acting on the rock bodies, major tectonic fractures are of displacement, tensile and shear types. The fractures extend from the upper part of the lava flow to hundreds of meters of depth. If faults are filled with massive fault breccias, these may act as underground dams and the general permeability of the rock body will be reduced. Faults with low magnitude of displacement may act as underground conduits for the regional and local ground water flow. In volcanic terrains, enlargement of the ground water flow paths are relatively not significant so that ground water tend to reduce the size of the empty spaces by the depositions of weathering products on the faces of interstices and fractures. Further weathering processes often cause the formation of impervious clay layers. For all these reasons, the porosity and permeability of the volcanic rock bodies tend to decrease with time. Some of this decrease is owing to compaction, but the filling of pores with secondary minerals is probably the most important cause of the decrease (Davis and Dewiest, 1996).The decrease of the permeability may not be linear. In fact fresh rocks may have a good primary permeability due to open fractures and connected.

As the weathering processes continue and additional forces of compaction are applied almost all permeability due to primary porosity will be destroyed. The most important causes, which lead to reduction of the porosity and permeability, are due to the combined effects of weathering and compaction. As stated earlier, volcanic rocks have a wide range of hydrologic properties. The porosity of unfractured volcanic rocks bodies varies from less than 1 percent in dense basalt to more than 85 percent in pumice. Typically rocks within dikes and sills will have less than 5 percent porosity; dense massive flow rock will have values ranging from 10 to 50 percent. Although porosity may be quite high, the permeability is largely a function of other primary and secondary structures within the rock. Joints caused by lava tubes, vesicles that intersect, tree molds, fractures caused by buckling of partly congealed lava, and voids left between successive flows are some of the fractures that give recent andesite and basalt its high permeability. In addition to the features causing permeability, the porosity may be increased locally in the rock by weathering. Buried soils are a common feature of thick sequences of volcanic rock.

From groundwater potential point of view, three broad aquifer classes are found in Ethiopia. These are:

1. Extensive aquifers with intergranular permeability (Unconsolidated sediments; alluvium,elluvium, colluvium, lacustrine sediments and poorly)
2. Extensive aquifers with fracture permeability (volcanic rocks: basalts, rhyolites, trachytes, ignimbrites).
3. Extensive aquifers with fracture and/or karstic permeability (consolidated sediments and metamorphosed carbonates: Limestone, sandstone, shale, marl, evaporate, marbles)

The aquifers of the study area fall under the first two classes. Depending on Permeability, four types of lithologic units are found in the study area. These are:

- High permeable rocks
- Moderate Permeable rocks
- Low Permeable rocks
- Very Low Permeable rocks

In the next section, these units are described individually.

5.1.1 High Permeable rocks

Recent aphyric basalts, young ignimbrites of Fentale, Bofa basalts, Alluvium deposits, pleitocene to sub recent basalts fall under this group. In this section we will treat each unit one by one.

→ Young ignimbrites of Fentale

As discussed in the previous section, this rock unit covers large part of the study area. This ignimbrite is grayish green, fresh, columnarly jointed with blisters and crevasses.

These joints, blisters and crevasses act as groundwater conduits for the recharge from Fentale Mountain.

➔ **Recent aphyric basalts**

Recent basalts aquifers have close to the highest transmissivity known. Although transmissivity of recent basalt is high, ground water may be very difficult to develop from aquifers. This is owing to the fact that ground water drains freely to points of discharge and the depth to the groundwater may be excessive or water may even be locally absent. The Recent aphyric basalts which are found in the study area are highly vesicular basalts with interconnected pore spaces. Presence of interconnected pore-spaces is vital in order for rock units to store and transmit ground water and this is clearly observed in the recent aphyric basalts of the study area. The pore spaces in this unit are interconnected and due to this, the rock unit stores and transmits appreciable quantity of ground water and thus is considered to have high permeability.

➔ **Bofa Basalts**

As discussed earlier, this unit is highly affected by faults and joints and these structures serve as a channel for ground water storage. Therefore, the Bofa basalts in general are expected to have high permeability.

➔ **Alluvium**

Unaltered pyroclastics, like alluvium, have porosities and permeabilities directly related to fragment size, sorting, and degree of combination. This unit found in Metehara, Abadir farm and around Awash River, grades from sandy clay to sand and gravel beds downward. The sand and gravel beds have high water storing and transmitting capacity. So it is grouped as a high permeable formation. Poor sorting and abundance of fine material will cause this deposit to have low permeability but moderate to high porosities.

➔ **Pleitocene to sub recent basalts**

This unit found on the south eastern side of the study area is affected by faults and fractures and is one of the high permeable units (zones) of the area.

5.1.2 Moderate permeable rocks

The Dino ignimbrites found in the study area fall under this category. Even though this rock unit is affected by many faults and joints, it is a moderately permeable and sometimes the permeability can be low. This was observed during field investigation (a borehole drilled in Bole town before Nura era farm was found to have no yield).

5.1.3 Low permeable rocks

➔ Unwelded rhyolitic pumice and unwelded tuffs is the only low permeable unit found in the area and this is because it is not affected by structures and is not a highly weathered unit.

5.1.4 Very Low Permeable Rocks

➔ **Pantelleritic volcanics of Fentale rhyolites, trachytes and tuffs**

Rhyolites are silica rich and are viscous and erupted in thick, dense flows. These are found around Fentale Mountain and also rhyolite dome flows near Nura era farm and these rock units are found to be highly impermeable and hence are sites of a very low ground water potential. According to Davis and De Weist (1966), welded tuffs have medium to low porosities and very low permeability and this was observed in the study area.

➔ **Trachytic flows and domes associated with Fentale, Tinish Fentale and Kone; Pitchstone flows and domes; Recent to sub recent rhyolites**

Due to the mineralogical composition of these rocks and the fact that most of them are not affected by different structures, makes them highly impermeable.

➔ **Lacustrine sediments**

These consist of clay, silt etc. Eventhough these minerals have high porosity, their permeability is low owing to their low effective porosity.

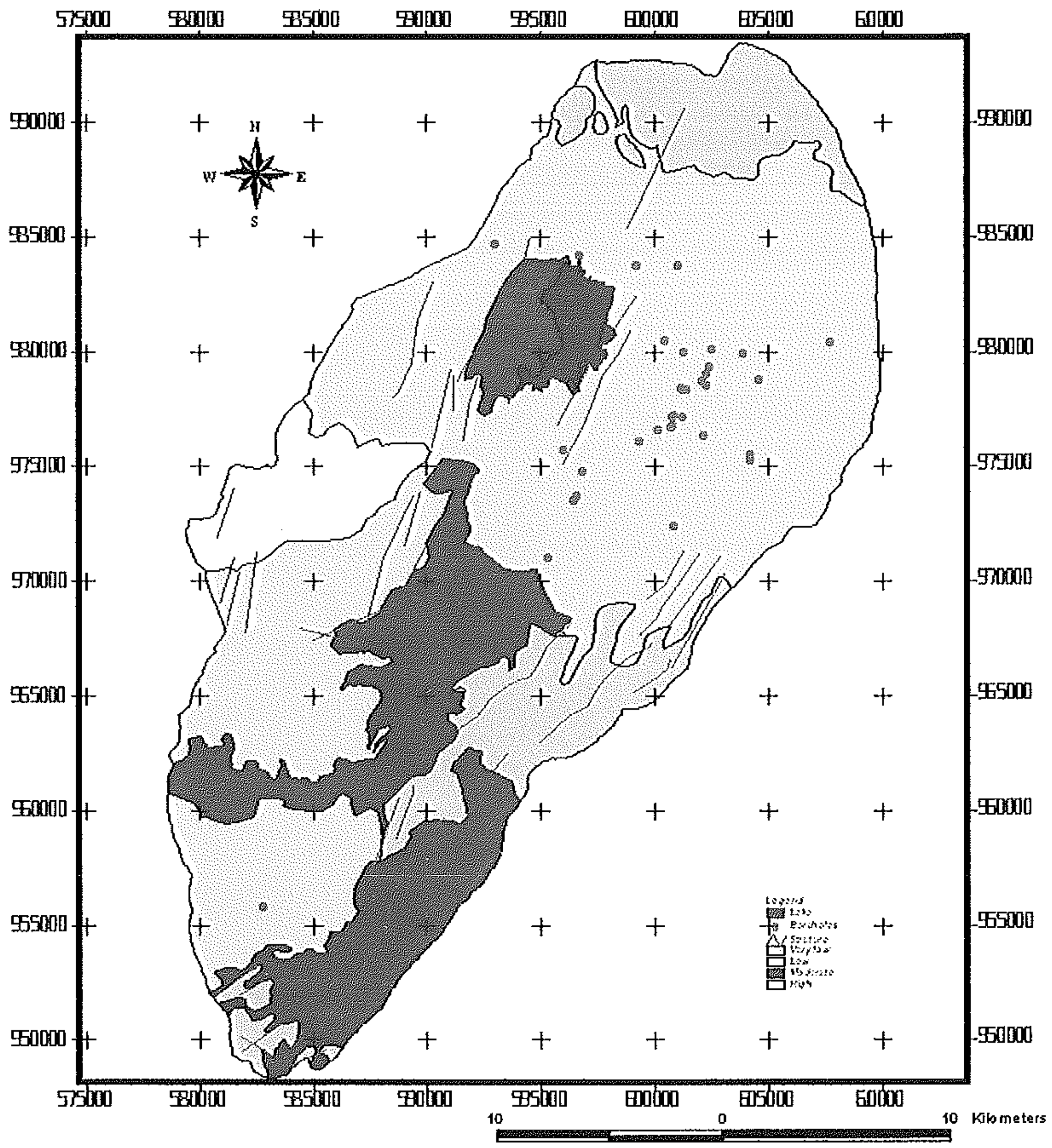


Fig. 5.1 Hydrogeological (Permeability) map of the area (modified from Hydrogeology of Nazareth, EIGS, 1985)

5.2 Groundwater Movement and Recharge

Groundwater movement in an area is controlled mostly by topography and to a lesser degree by geology. Most of the faults of the study area act as conduits to ground water movement while some act as barriers. But generally the flow of ground water is from the highland areas to the lowland areas (topographically controlled). According to the report published by Ministry of water resources (1998), the main concentrated flow in the study area is in Abadir farm area. It has groundwater flow direction southwest northeast.

The concentrated flow at Abadir farm area and Tone springs are separated by a groundwater divide that runs in parallel direction to the flow. The concentrated flow at Abadir farm area drains all the groundwater flowing to this area and infiltrated excess irrigation water in northeast direction parallel to Lake Beseka.

When we look at the ground water recharge on a regional basis, we find that part of the high rainfall on the western and eastern high lands contributes varying amount of recharge to the groundwater depending on the soil, rock and topographic conditions in those regions while large portion of the rainfall goes as quick runoff to the lowlands. On its way down the escarpment, some of the quick runoff is lost as recharge to the ground water where streams cross fault zones. The regional main fractures with linear alignments are important features for groundwater migration from high to low concentration areas.

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

Chapter Six
Hydrochemistry

General

Natural water consists of dissolved minerals, dissolved oxygen, suspended particulate material etc. The chemical composition of natural water is derived from different sources of solutes, including gases and aerosols from the atmosphere, weathering and erosion of rocks and soil, solution or precipitation, reactions occurring below the land surface and cultural effects resulting from human activities (Hem,1989). Natural surface waters and groundwaters carry both dissolved and suspended particles. The amounts of the latter present in groundwater before it is brought to the land surface generally are small. Water quality is defined by physical, chemical, and biological characteristics. The significant physical characteristics include temperature (generally measured in $^{\circ}C$) and total dissolved solids, dissolved or in suspension, which can modify the appearance, hydrogen ion activity (pH), specific electrical conductance (EC), hardness, redox potential (Eh) etc of the water. Water chemistry studies require the identification and determination of different constituents, such as major ions, bicarbonate, carbonate, sulphate, chloride, nitrite (nitrate), calcium, magnesium, sodium, and minor and trace elements such as iron, boron and selenium. Dissolved gases may also influence or modify chemical characteristics; they are: CO_2, O_2, H_2S, Ammonia, and methane.

The biological characteristics are determined by living organisms, mainly pathogens which can cause illness both to the water user and the consumer of food irrigated with contaminated water. The water characteristics which cause damage to the user should be studied inorder to minimize the adverse effects and enable the water to be used. In the next section, some of the basic physical and chemical characteristics of water are discussed.

In the next section, some of the hydrochemical parameters of the water samples of the area are treated individually.

6.1 Hydrogen-ion activity (pH)

The activity (effective concentration) of hydrogen ions can be expressed in logarithmic units. pH represents the negative base 10 log of hydrogen activity in moles per liter. Whether a particular water is said to be "acidic" or "alkaline (basic)" depends on the effective concentration (activity) of hydrogen ions (H^+). At 25^0C, pH value of above seven is considered as an alkaline (basic) solution while a pH value of less than seven indicates an acid solution. A pH value of seven is taken as a neutral solution. The measurement of pH provides values of concentrations of H^+ and OH^- in solution. These species contribute to acidity or alkalinity. River water in areas not influenced by pollution generally has pH in the range of 6.5 to 8.5. In the study area, Awash River water sample collected before the irrigated farm of Nura era gave a pH value of 7.86 which consolidates this assumption. Where photosynthesis by aquatic organisms takes up dissolved carbon dioxide during daylight and the organisms release CO_2 by respiration at night, pH fluctuations may occur and the maximum pH value may reach as high as 9. In carbonate dominated systems (high concentration of CO_3^{-2}, HCO_3^- etc) alkalinity of the solution is expected. Acid waters may occur naturally as a result of solution of volcanic gases or gaseous emanations in geothermal areas. Most natural waters contain substantial amounts of dissolved carbondioxide species (CO_3^{-2}, HCO_3^-) which are the principal sources of alkalinity. Undissociated dissolved carbondioxide contributes to acidity rather than alkalinity. At normal groundwater pH values of 6.5 to 8.5, the dominant inorganic carbon species in groundwater is bicarbonate ($HCO3^-$). At pH values greater than 9, the inorganic carbon species carbonate ($CO3^{-2}$) is dominant.

The pH of the water samples obtained from boreholes in the locality varies from 7 to 9.2 and in these waters, bicarbonate ($HCO3^-$) is dominant. pH of Lake Beseka was found to be above 9 showing a high degree of alkalinity. Awash River in general has a pH of 7 to 8.So in general; the waters of the study area have an alkaline pH.

6.2 Electrical Conductance (EC)

Electrical conductance, or conductivity, is the ability of a substance to conduct an electric current. Specific electrical conductance is the conductance of a body of unit length and unit cross section at a specified temperature. Conductance is expressed as mhos or micro siemens (it is the reciprocal of resistance). The presence of charged ionic species in water makes it conductive and this increases with the increment of ion concentrations. In other words, EC is a measure of the total concentration of ionic concentration in nature. The electrical conductance of some localities within the study area as obtained from the water samples analyzed is the following:

Locality	Sample Type	EC (µs/cm)
Awash Before Nura era	River	403
Beseka lake (close to the road)	Lake	6730
Spring near Beseka lake	Spring	1069
Beseka lake (middle)	Lake	6170
Abadir farm	Bore well	2320
Merti barak	Bore well	1698
Algae town	Bore well	2100
Metehara sugar plantation	Bore well	1981

Table 6. 1 The EC of the different water bodies of the study area.

As can be seen from the table, Beseka Lake is rich in ionic species followed by the groundwaters of the area. This is because there is high rate of open water evaporation (2174 mm) which increases the ionic species (concentration) of the lake.

6.3 Total dissolved solids (TDS)

The total dissolved solids comprise dissociated and undissociated substances, but not suspended material, colloids, or dissolved gases. This value is commonly determined by evaporation of a sample to dryness, and 1-2 hours drying at 180^{0}C. The residue on evaporation is not quite the same as the solution content: the hydrogen carbonate ions are precipitated as carbonates and sulfate as gypsum; small amounts of magnesium, chloride, nitrate and boron as well as organic substances can escape. The sum of the dissolved constituents like the conductance can be used for the control of chemical analyses of individual substances.

TDS of natural water range from less than 10ppm of dissolved solids for rain and snow, to more than 300,000 ppm for some brine. Water types are divided into many categories depending on their TDS value as shown in table 6.2.

Water Type	TDS in ppm
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

TDS is a function of EC. EC and TDS are related by

TDS=k.EC where k is a constant that ranges from 0.6 to 0.8.

The TDS of the water samples collected from the study area are summarized below.

Locality	Sample Type	TDS (mg/l)
Awash Before Nura era	River	196
Beseka lake (close to the road)	Lake	3588
Spring near Beseka lake	Spring	817
Beseka lake (middle)	Lake	6921
Abadir farm	Bore well	1150
Merti barak	Bore well	832
Algae town	Bore well	1040
Metehara sugar plantation (merti)	Bore well	1625
Metehara town	Bore well	1090

Table 6.3 TDS values at different localities within the study area.

From the above table we can see that Beseka Lake is rich in dissolved solids followed by bore wells from different localities. This shows that the lake is highly mineralized. This can be due to the fact that the lake is a closed water body and there is a high rate of evaporation. With the continuing rate of evaporation, the TDS of the lake increases and also the EC. The reason for the increased amount of TDS of the groundwater of the study area than the river is that groundwater has got interactions with different rocks beneath the surface and with longer residence time, the water will be rich in ions and hence its TDS increases. The TDS of some boreholes in close vicinity of Lake Beseka also have high values (as high as 4646 mg/l) and this can be due to the interaction of lake water and groundwater. In terms of TDS, Awash river and some boreholes inside the study area fall under "Fresh" water category while Lake Beseka and some boreholes have "Brackish" water.

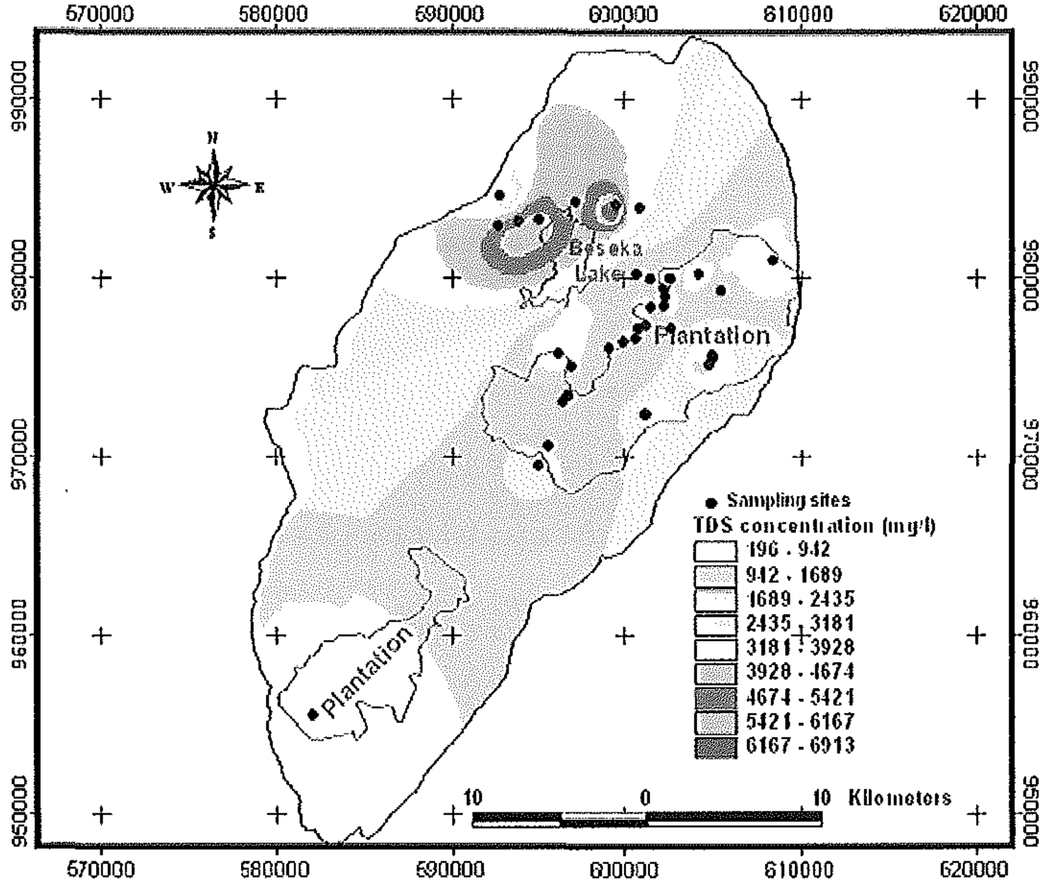


Fig 6.1 TDS distribution map of the area

As can be seen from the map, TDS increases towards Beseka Lake. This is because the direction of groundwater flow is towards the lake and the water reaching the lake will be highly enriched in minerals during its course.

6.4 Hardness

Hardness represents the soap consuming capacity of water. The effect results from cations that form insoluble compounds with soap. Most of the effect observed with soap results from the presence of calcium and magnesium, thus hardness is generally expressed in terms of these constituents. Hardness is expressed in terms of calcium carbonate ($CaCO_3$), and it may be divided into two types: Carbonate and non-carbonate. Carbonate hardness includes that portion of the calcium (Ca) and magnesium (Mg) ions that combines with bicarbonates and the small amount of carbonate present. This is called temporary hardness because it can be removed by boiling, which precipitates calcium and magnesium carbonate and sulfate minerals. Non carbonate hardness is the difference between total hardness and carbonate hardness. It is called by those amounts of calcium and magnesium that combine normally with sulphate, chloride and nitrate ions, plus the slight hardness contributed by minor constituents such as Iron. Non-Carbonate hardness cannot be removed by boiling.

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 the water bodies of some localities within the study area was analyzed and is shown in table 6.

Locality	Sample Type	Hardness (mg/l)
Awash Before Nura era	River	104
Beseka lake (close to the road)	Lake	-
Spring near Beseka lake	Spring	238
Beseka lake (middle)	Lake	-
Abadir farm	Bore well	212
Merti barak	Bore well	326
Algae town	Bore well	176
Metehara sugar plantation	Bore well	-

Table 6. 5 The Hardness of the different water bodies of the study area.

From the above table we can see that the groundwaters of the study area fall under the category "Hard" to "Very Hard" water while that of the Awash River fall under moderately hard.

6.5. Redox Potential (Eh)

The redox potential, Eh, is a numerical index of the intensity of oxidizing or reducing conditions within a system. Positive potentials indicate that the system is relatively oxidizing, and negative potentials indicate that it is relatively reducing. Eh is a function of depth and the presence of oxygen demanding wastes; that is, with depth and presence of large quantity of oxygen demanding wastes the value of Eh decreases. In groundwater systems, the Eh is generally less oxidizing than in surface water systems because of the lack of a source of molecular oxygen below the water table and the presence of reducing solids (principally organic matter and sulfide minerals) in the aquifer. However, a sample of groundwater removed from association with these solids and exposed to the atmospheric air with its high concentration of oxygen will equilibrate with the air and become more oxidizing, there by raising the redox potential.

This is because with depth, the concentration of oxygen decreases. Therefore, surface waters (rivers and lakes) are bound to have higher values of Eh than subsurface waters. The Eh value obtained during insitu filed testing of the water samples of both surface and subsurface waters gave a negative value. For groundwaters, this shows the location of the water table at great depth while for surface water bodies; it shows that they are polluted.

Locality	Sample Type	Eh
Awash Before Nura era	River	-79.5
Beseka lake (close to the road)	Lake	-122.8
Spring near Beseka lake	Spring	-43.2
Abadir farm	Bore well	-37.4
Merti barak (farm)	Bore well	-9.65
Algae town	Bore well	-27.6

Table 6. 6 The redox potential of different water bodies of the study area.

6.6 Major ion constituents

The major dissolved cations observed from the analysis of water samples of the study area generally are: Calcium(Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), and Potassium (K^{+}) and the major anions are Bicarbonate (HCO_3^-) sulfate(SO_4^{2-}), Chloride (Cl^-), Fluoride(F^-),Nitrate(NO_3^-), and those contributing to alkalinity, most generally assumed to be bicarbonate (HCO_3^-) and Carbonate (CO_3^{2-}). The silicon present usually is monoionic and is reported interms of an equivalent concentration of oxide, Silica (SiO_2).

Major ions	Minor and trace constituents
Ca^{2+},Mg^{2+}, Na^{+},K^{+}	Fe,Mn,Al,Ba,Cd
HCO3/CO3, SO4	Cr,Pb, Zn, As, Se, P, F, I, B, NH4+,
Cl^-, NO3, H4sio4	Co, Cu, Pb, Hg

Table 6.7 Typical groundwater and surface water dissolved constituents

6.6.1 Cations

The major cation constituting the groundwater of the area is sodium ion whose values range between 173 to 770 mg/l. This is because sodium is a major constituent volcanic rock like the rocks of the study area in which it chiefly occurs in plagioclase, the soda-lime feldspar with the sodium rich end member albite, $NaAlSi_3O_8$. Furthermore, once sodium enters into groundwater bodies, its removal by precipitation of primary minerals is rare unless the sodium chloride (NaCl) saturation is reached. Potassium ion was analyzed to have values between 10 and 28.8mg/l. Calcium was identified also (occurring in ranges between 1.3 and 427 mg/l and Magnesium was found to be in the range between 0.5 and 442 mg/l (some unusual high values may be due to analytical error). The calcium concentration of the groundwater increases at Abadir farm, Metehara sugar estate, and eastern side of Lake Beseka perhaps owing to mixing and dilution of groundwaters by irrigation waters. Human activity and infiltration of Awash River, which has higher concentration of calcium than the groundwater, may be another reason for this increment of calcium content. The above mentioned areas are composed of fluvo-lacustrine and application of irrigation water from Awash River, fertilizers and human settlement are mainly responsible for higher calcium content and also according to R.P Asheley et al (1985), one possible reason for higher concentration of calcium in the boreholes of the farm is addition of CaO on the field. Some trace elements like chromium are also found in the water samples with an amount less than 0.006 mg/l and manganese occurs in a maximum amount of 0.03 mg/l.

The major cations analyzed from water samples collected from Awash River are sodium and calcium but mostly sodium whose values range 31 to 38 mg/l while the major cation found in the lake Beseka is sodium whose values lie between 1850 to 1880 mg/l showing again that the lake is highly mineralized and this can be due to excess evaporation.

6.6.2 Anions

The major anions of the groundwaters of the area are bicarbonate having values that ranges from 490 to 1256 mg/l. The second most abundant anion present in the groundwater samples of the area is sulfate having concentration values of between 2.5 to 1800 mg/l. This sulfate is mostly observed in samples obtained inside the farms. The third most abundant anion is chloride having values of 20 to 383 mg/l. The reason for this abundance of chloride can be attributed to the salinity of the soil due to irrigation activity.

Fluoride was also found in the groundwater samples, (between 0.15 to 26 mg/l). This value of relatively higher value of fluoride can be due to the depletion of calcium in waters which leads to higher concentration of fluoride in waters. High concentration of fluoride was observed in the surroundings of the lake (as high as 32.7 mg/l) and also on boreholes close to Fentale Mountain and this is because high concentrations of fluoride exist as a result of the passage of groundwater through the recent volcanics. Ion exchange strongly affects the groundwater and waters with high sodium bicarbonate and fluoride contents are common (Halcrow, 1989).

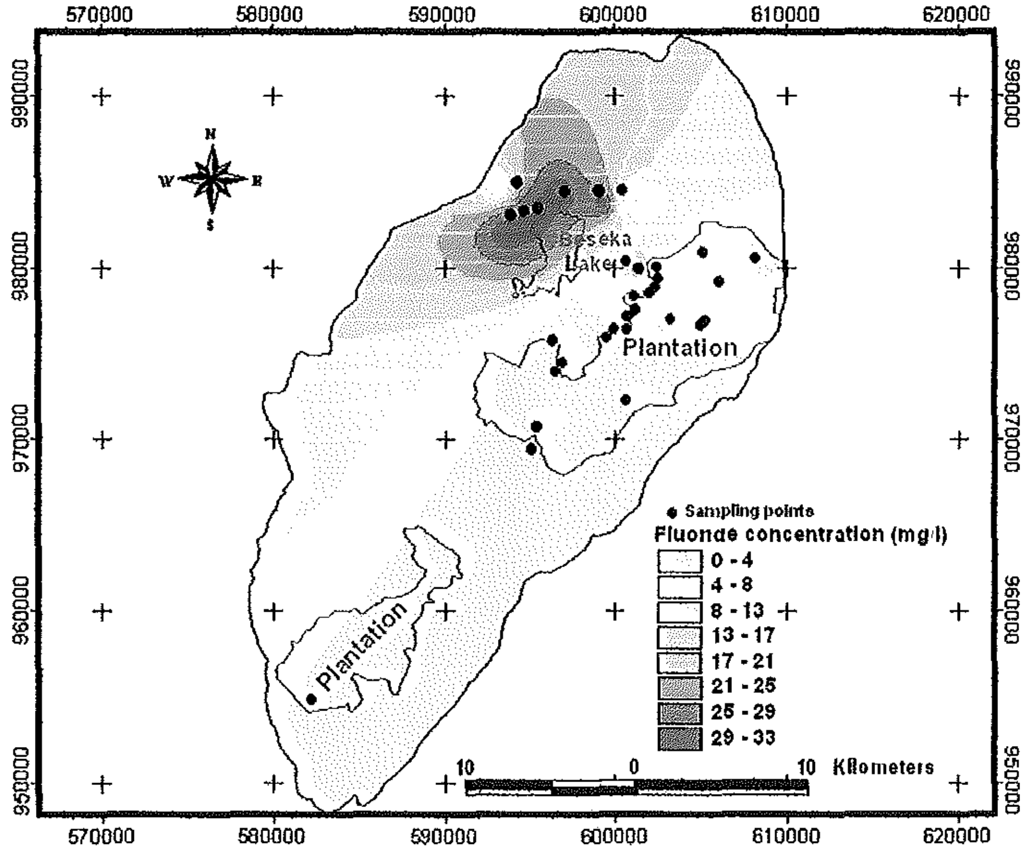


Fig 6.2 Fluoride distribution map of the area

As can be seen from the map, fluoride concentration increases towards Beseka Lake and close to Fentale Mountain. As stated earlier, this is because high concentrations of fluoride exist as a result of the passage of groundwater through the recent volcanics. Boreholes inside the farms have relatively lower values of fluoride while those found close to Beseka Lake and Fentale Mountain have high concentration of fluoride.

Nitrate ions were analyzed to be found in the ground water samples (between 2.8 to 96.8 mg/l in concentration). The highest value of nitrate concentration was found from the water sample collected from a borehole inside Metehara sugar plantation (merti). This could be attributed to agricultural activities as well as septic systems (to be discussed in the next chapter).

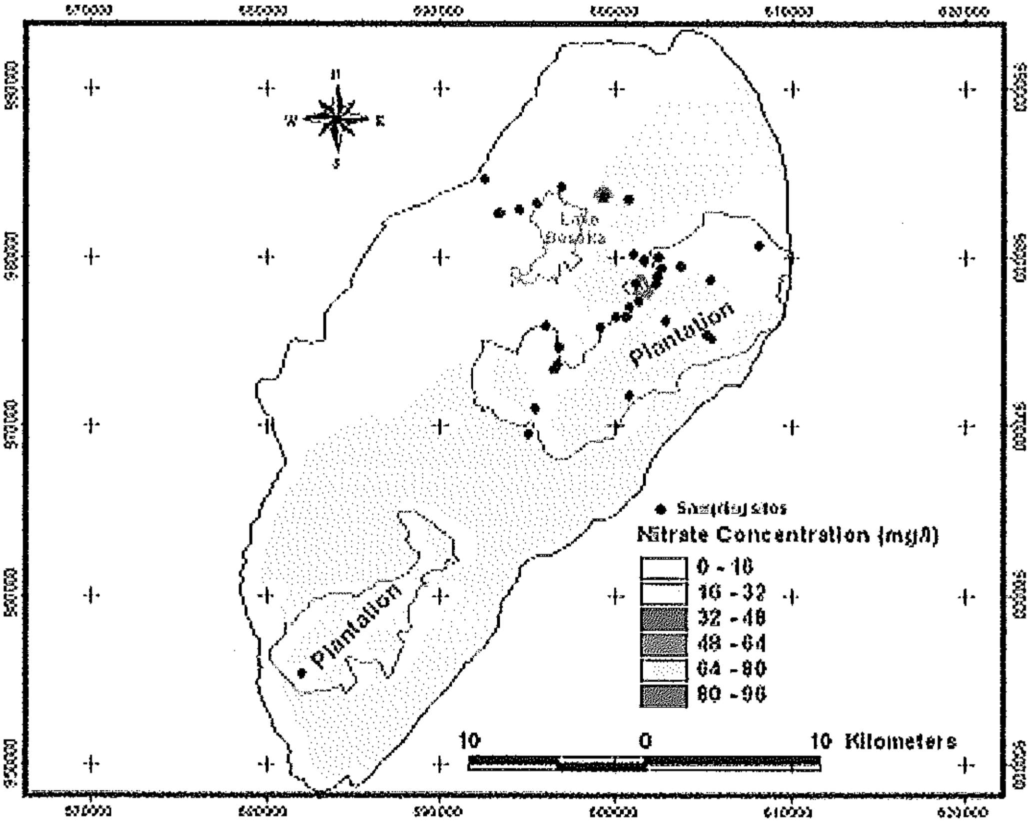


Fig 6.3 Nitrate distribution map of the area

The major anions of water samples obtained from Beseka Lake are dominantly bicarbonate (1958-1989 mg/l) and chloride (586-589 mg/l) while the major anion of Awash River is bicarbonate (182-199 mg/l).

From these values we can see that the dominant cation in all types of water is sodium (though in different amounts) and the dominant anion is bicarbonate and from this we can say that there is an interaction between the water systems of the region especially between the lake and groundwaters in its close vicinity.

Though also in small amounts, there are also some cations and anions in the groundwater samples as shown in table 6.8.

Type	E	N	T°C	EC	pH	CO_2	HCO_3	CO_3	Cl^-	SO_4	F^-	NO_3	Na^+	K^+	Ca^{2+}	Mg^{2+}	HBO_2	SiO_2	PO_4	TDS
BH	591755	994100	43.3	1797	8.31		817		128	74	4.71	2	408	25	3	2.4	2.6	69	0.23	1535.94
BH	601100	983750		2090	8.4		976	192	187	325	2.9		770	15.8	3.2	0.97		70		2542.87
BH	600500	980450		1800	9.2		380	336	113	87.5	8.9		550	6.6	1.3	1.7		80		1565.3
BH	601300	979990		3200			1256	220	15	240	26									1757
BH	604671	978815	27.6	1968	7.7	26	739		170	161	6.9	18	378	11	43	23	3.67	79	0.17	1632.74
BH	603974	979946	27	795	7.35		444			17	2.8				77	15		71		626.8
BH	602550	980125		1481	8.2		780	9	63	66	10.6	0.19	348	7	8	8				1299.79
BH	602450	979325		1200	8		512		80.8	72			156.4	9.2	75.4	21.4		88.5		1017.48
BH	602300	979025		919	-		-				1.78									689.3
BH	602300	978550	27	1220	7.2		642		50	125	15.3				57	23				912.3
BH	601264	978343	28	1310	7.2		474		130	198	2.7				99	33				936.7
BH	601260	977184	31.3	1915	7.56	32	639		206	141	3.29	17	296	18	33	38	3.67	81	0.12	1476.08
BH	600900	977225	29.5	680	-		364		8	2.5	2.8				52	15				444.3
BH	600811	977134	28.1	1057	7.53	31	622		23	29	5.87	10	178	8	42	16	1.74	86	0.12	1021.73
BH	600824	976777	31.7	1811	7.48	39	540		197	122	3.94	25	284	16	55	23	5.05	90	0.12	1361.11
BH	600780	976696	26.9	1353	7.78	19	478		98	104	2.99	45	173	17	65	28	1.32	93	0.12	1302.07
BH	602184	976322	29.4	1603	7.64	25	547		159	141	2.79	11	303	12	30	13	2.16	81	0.12	1302.07
BH	600170	976615	28.1	1090	7		524		18	63	6.8				74	22				707.8
BH	599381	976124	28.8	1168	7.77	20	673		37	38	3.94	3	206	14	30	24	1.68	86	0.12	1116.74
BH	604300	975550			8		366		383	1547	2		663	38	427	56		97		3579
BH	604300	975250		6700	7.05		390		1655	1800	2.6				274	442		83		4646.6
BH	600870	972395	30.6	2781	7.64	28	656		344	403	2.52	30	455	22	50	85	4.93	77	0.23	2109.68
BH	596648	973717	30.9	2591	7.77	20	643		298	313	4.35	13	485	26	33	28	4.81	75	0.12	1923.28
BH	595365	971003	35.2	2006	7.86	13	519		212	246	5	15	388	22	18	23	2.7	80	0.12	1530.82
BH	594872	969739	33.3	2875	7.79	14	414		358	529	3.7	32	505	32	38	36	4.03	80	0.12	2031.85
BH	593032	984700			8.75		848	30	141	82	6.3	3	440	41	14	0.5				1593.2
BH	596854	974763	315	2100	8.03		490		20	253		37.4	269	29				85.2	0.767	1040
BH	596530	973542	32.5	2320	7.9		572		25.5	271.6	0.15	12.32	286	25.2				286	0.873	1150
BH	602140	978705	28.9	1698	8.1		628		20	161	20	17.6	173	18				84.3		832
BH	601450	978322	29.4	1981	7.35		682		176.3	144.2	9.1	96.8	465.3	10	33.6	8		128.1		1625.1
River	607750	980413	26.7	366	7.26	19	199		14	9	1.59	1	38	6	30	6	1.86	25		331.45
River	601189	978394	25.3	349	7.15	23	188		13	9	1.54	2	36	6	29	5	0.96	25		323.49
River	596072	975731	24.8	347	7.99	5	182		12	14	1.56	2	35	6	26	6	0.96	25	0.12	310.64
River	582812	955815	27.1	196	7.86		148		15	14.4		30.8	31.4	8.8				41.1	0.035	196
Lake	596777	984188	27.4	7218	9.51		578	672	578	512	32.7	6	1860	59	3	1	13.7	122	3.7	4441.1
Lake	593657	982110	28.2	7394	9.52		1958	690	596	524	32.2	5	1870	62	2.2	0.4	15	121		5875.8
Lake	594572	982626	27.9	7404	9.51		1995	684	589	535	32.4	4	1890	58	2.2	0.4	17	122		5929
Lake	595180	982993	27.9	7384	9.5		1989	678	589	498	32.5	4	1850	55	2.2	0.4	15	119		5832.1
Lake	599267	983752	25.9	6170	9.37		3218	540	525.3	525.8	31.4	35	1960	67.6	1.3	17				6921.3

Table 6.8 Result of chemical analysis of water samples from Metehara area.

6.7 Presentation of chemical data

Tables of data are the most common forms in which the results of an analysis of water chemistry are reported. The data can be expressed in milligrams per liter, milliequivalent per liter, millimole per liter, or parts per million. The data may also be presented in graphical form. The most common graphical representation methods are piper trilinear diagram, stiff diagram, shoeller semi-logarithmic diagram, Bar graphs and radial diagrams. In this work, piper trilinear diagram was used. In the next section analysis using this method is shown:

6.7.1 Piper Trillinear diagram

The composition the dominant ions can be displayed graphically by several methods with one of the more useful summary presentations being piper trillinear diagram. On this diagram, the relative concentration of the major ion in percent Meq/l are plotted on cation and anion triangles, and then there locations are projected to a point on quadrilateral representing both cation and anions This diagram constitutes a useful tool in water analysis interpretation. The piper diagram is used for testing groups of water analysis to determine a whether particular water may be a simple mixture of others for which analyses are available or whether it is affected solution or precipitation of a single salt. A trillinear diagram can show the percentage composition of three ions. By grouping Na^+ and K^+ together, the major catons can be displayed on one trillinear diagram. Like wise, if CO_3^{2-} and HCO_3^{2-} are grouped, there are also three groups of the major anions. Analyses are plotted on the basis of the percent of each cation (or anion).

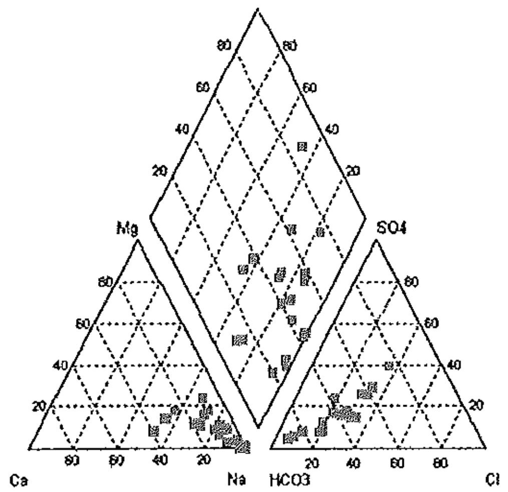


Fig 6.4 Piper diagram for borehole samples of the study area

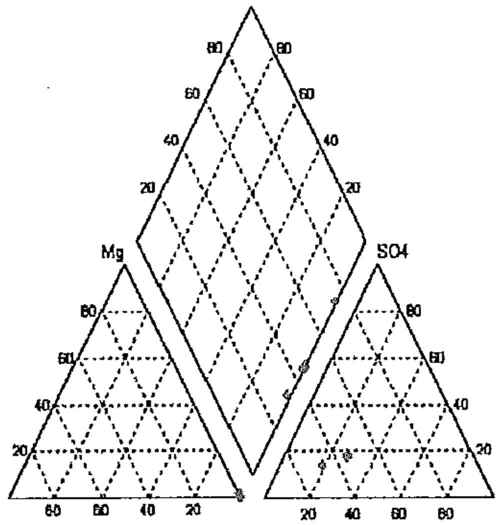


Fig 6.5 Piper diagram for Lake Beseka samples

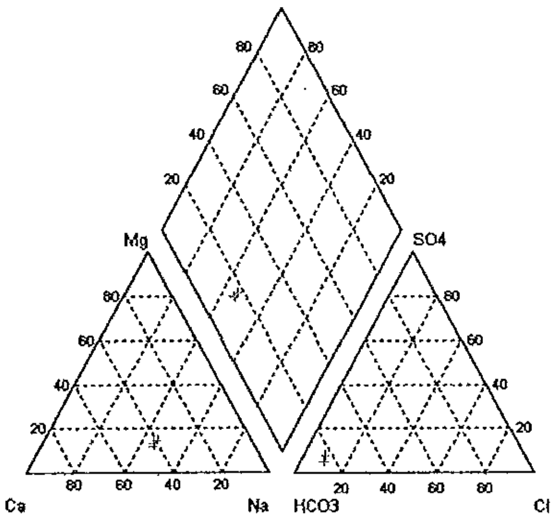


Fig 6.6 Piper diagram for Awash River samples within the study area

6.8 Water types

Knowing the major ion composition of water is used to classify the water into various types based on the dominant cations and anions. For this purpose water samples from different sources (like lake, river, and groundwater) were taken and these samples were analyzed using piper trillinear diagram.

The major water types of the study area are:

1. Sodium Bicarbonate type and at times associated with chlorine and sulfate

The sulfate water types were observed on boreholes inside the farms and this can be due to the use of pesticides in the farms.

2. Calcium Bicarbonate type (sometimes associated with sulfate) - found in the northern side of Lake Beseka close to Fentale Mountain.
3. Sodium Calcium bicarbonate

The groundwater sample collected from different locations within the study area (almost all of them) gave a value that has high concentration of sodium cation and high concentration of bicarbonate anion with some ions in small amount. So the water type of the area is termed as sodium bicarbonate type. This is clearly shown on the piper diagram. As can be seen from the piper diagram, Lake Beseka has almost the same composition as those of samples obtained from boreholes close to it and this shows a possibility of lake water- groundwater interaction.

Chapter Seven

Impact of Irrigated agriculture on water quality

General

In developing countries, groundwater is often the best or the only source of cheap, potable water. It is attractive as a supply option because:

- It is often conveniently available close to where the water is required,
- It has excellent natural quality, which is generally adequate for potable supply with little or no treatment,
- The capital costs of development are relatively low. In addition, development in stages to keep pace with rising demand is usually more easily achieved for groundwater than for surface water.

As consequence, millions of people both in urban and rural areas depend on groundwater for domestic supplies, often drawn from shallow aquifers which can be highly vulnerable to pollution. One source of pollution of groundwater resources is agriculture. Agriculture is the major source of income to the economy of a country. In these agricultural activities various chemicals like fertilizers, pesticides etc are added to the soil and when these chemicals are incorporated with irrigated water they become a major threat to the groundwater resources. One assumption is that greater fertilization gives better yields; the application of fertilizers has increased during the past few years. This has increased the natural content of nitrogen in soils available for leaching.

In general, areas with a greater potential for nitrate leaching are associated with the intensive agricultural areas (vegetable, flower and citrus crops) with intensive irrigation, heavy fertilization and sandy soils. Besides fertilizers, pesticides are also the other sources of contaminants to the groundwater resource.

The most common contaminants from agricultural practices include:

a) Sediments- contribute to the transport of plant nutrients which are bound to soil particles and greatly increase the costs of water treatment.

b) Nutrients- are present in chemical fertilizers, manure and other organic fertilizers such as compost or plant residue and these nutrients can be transported from agricultural lands to surface and groundwater.
c) Pesticides-also pose a serious threat to the groundwater resources as they are highly poisonous.
d) Disease causing micro-organisms present in manures and animal carcasses etc.

Awash River is one of the most utilized rivers of Ethiopia. This river is dominantly used for irrigation purposes. Using this river, various plantations are established throughout its course, few examples are those found in Metehara, Wonji and Tendaho. So in this respect this river plays an important role in ensuring food security of the country as well as becoming an important force in the countries economy. But irrigation using this river (generally agricultural activities) has got its own drawbacks. One aspect of this drawback is its impact on the water quality especially groundwater. The most important problem associated with agricultural activities is the presence of nutrients in groundwater, especially nitrate. Phosphorous and potassium do not generally pose problems, because pizometric levels are generally deep and potassium and phosphorous are transported slowly in soils or are completely retained.

7.1. Major sources of pollution to the groundwater resource of the area

7.1.1. Fertilizers (nutrients)

The need to improve crop yield in order to cope with ever increasing population number, has initiated the utilization of some plant nutrients. Accordingly, the so-called fertilizers are added to the soil. But these fertilizers by themselves have created a problem- a problem of pollution of the groundwater resources.

A variety of conventional fertilizers are used in Awash Basin where the type and rate of application vary from farm to farm and region to region. The main product applied is Urea (46% N) and on many farms is the only fertilizer applied. Phosphate in the form of triple-phosphate (approximately 21% N, 23% P) is applied on most crops in the upper valley, excepting sugar cane (Halcrow, 1989).

Special fertilizers are applied to sugar cane at metehara. Nitrogen is applied as ammonium-sulphate-nitrate since the sulphur is used to acidify the soil. Soil alkalinity there causes widespread iron deficiency and a dilute solution of ferrous sulphate is repeatedly applied to the cane leaves during each crop cycle (Halcrow, 1989).

The concentration of nitrate in groundwater due to leaching from nitrogen fertilizer application depends on:

- Amount and frequency of fertilizer application
- The thickness and permeability of unsaturated zone
- Crop type
- The volume of the groundwater available or aquifer storage.

In the study area more than 10,000 quintals of fertilizer is used in the estate farms. This fertilizer incorporated with water used for irrigation recharges the groundwater system. One major component of the fertilizer is nitrogen or nitrate (46% in Urea).

The water pumped from wells perforated at different depths within the zone of saturation of some basins indicates that higher nitrate concentrations occur in wells perforated near the top of the saturated zone, and the lower concentration occur in wells perforated near the bottom of the zone of saturation. This may be explained by the fact that vertical velocities are slight, so that vertical mixing of nitrate water resulting from accumulation of percolating nitrated water in the upper saturated zone is slow. Where the zone of saturation is relatively thin, mixing takes place more completely and nitrates appear to be more uniformly mixed with depth. Some vertical mixing of nitrates takes place locally in the zone of saturation as a result of fluctuations of water tables produced by pumping of individual wells. It is probable, however, that these effects are secondary to regional fluctuations in the water table.

The high values of nitrate concentrations in groundwater samples were found in the localities where the farms (plantations) are located. Relatively lower values of nitrate concentrations were observed on groundwater samples obtained outside the farms and on places where there are decreased number of populations (like boreholes close to Fentale). This indicates that the major source of nitrate in the groundwaters of these areas is the fertilizers used in the farms. The nitrate concentration of Awash River and

Beseka Lake is fairly low due to the fact that there is no application of fertilizers and also the scarcity of population near these waters. Nitrogen and phosphorus from fertilizers, promote algae growth and premature aging of lakes, streams, and estuaries (a process called eutrophication). Currently this problem was not observed within the study area but is a potentail threat to the surface water resource in the future.

Table 7.1 Rates of fertilizer and pesticide use on state Farms of the Awash Valley by crop and region in 1988 (in q/ha and Kg or l/ha respectively)

Crop	Fertilizer (all types)			Mixed Pesticides		
	Upper	Middle	Lower	Upper	Middle	Lower
Perennial crops						
Banana	*	1000	260		13	13
Citrus (orange)	940	330	*	56	22	*
Grape	500	*	*	43	*	*
Guava	450	*	*	10	*	*
Sugarcane	560	*	*	9	*	*
Winter crops						
Haricot been-green	250	*	*	30	*	*
Haricot been-seed	220	*	*	25	*	*
Melon	450	*	*	34	*	*
Okra	300	*	*	12	*	*
Onion	550	*	*	30	*	*
Tomato	520	*	*	50	*	*
Sorghum (grain)	150	*	*	4	*	*
Maize	200	*	*	10	*	*
Tobacco (cured leaf)	310	330	*	6	7	*
Summer Crops						
Cotton	250	100	170	26	28	29
Maize	200	*	*	20	*	*
Tobacco (Cured leaf)	310	330	*	6	*	*
Tomato	520	*	*	50	*	*

Note: * indicates that the crop is not grown in the area, or values are not available.

Source: Halcrow, 1989

7.1.2. Pesticides

The term "pesticide" is a composite term that includes all chemicals that are used to kill or control pests. In agriculture, this includes herbicides (weeds), insecticides (insects). fungicides (fungi), nematocides (nematodes), and rodenticides (vertebrate poisons). An increasing number of pesticide compounds are being incorporated to the groundwater supplies through agricultural activities in the world. There has, however, been little research into the mechanism by which such pollution occurs and routes via which pesticides move from the land surface into aquifers. All these pesticide compounds pose a significant environmental hazard since they are designed to be toxic and persistent The natural processes which govern the fate ad transport of pesticides can be grouped into the following broad categories: sorption, leaching, volatilization, degradation and plant uptake. Pesticide compounds may degrade in the soil by microbial or chemical processes to produce metabolites and ultimately simple compounds such as ammonia and carbondioxide. Most pesticide compounds have water solubilities in excess of 10 mg/l, and this is not a limiting factor in leaching from soils. Pesticide transport in the soil and subsurface environment may vary depending on the type of pesticide and upon conditions in the soil and aquifer, for example, moisture content, pH, dissolved oxygen etc.

The use of pesticides has extensive potential for contaminating groundwater as well as surface water. Pesticides applied to the soil may migrate through the soil to the water table. Pesticides in use to day are usually biodegradable to some extent. However, their break down products (metabolites) can also be found in groundwater (Fetter, 1993).

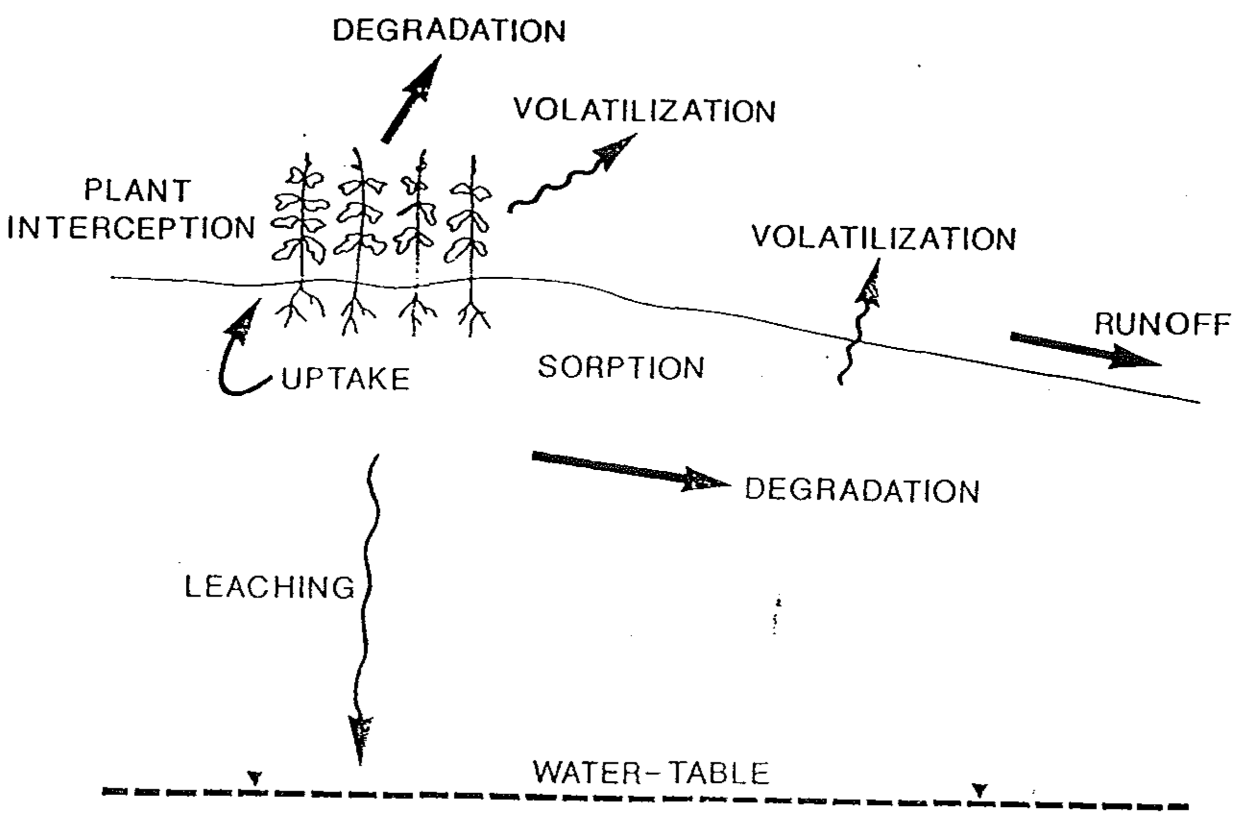


Fig 7.1 Processes determining the fate of pesticides

Halcrow (1989) noted that there is no detailed data on the level of pesticides used throughout the Awash Basin and the concentrations of these that amass in the Awash River or canal. From pesticides known in use in the Awash Basin till 1988, it is stated that none of the pesticides are persistent and that all are believed to be persistent and that all are believed to be biodegradable. But the pesticides used are to some degree, or other, toxic. In line with this, it is reputed that toxicity to people, fish, and animals drinking canal water immediately after spraying is common. And during field investigation, this was observed and an immediate impact of it like stomach ache was observed.

As described earlier, in the study area these impacts of agricultural pesticides in the groundwater quality haven't been assessed due to the lack of data. And it is recommended that in the future, detailed research on pesticides should be carried out so as to know their implications on the groundwater quality.

Aldnix 48%	Medopar
Azodrin(DDT) 10/10	Mencozev 80%
Anthio	Mitc 20% Ec-ULv
Anetellic	Nuvacron 40, SEW
Acarin	Perfection
Basudin 600EC	Parathion 50%
Cymbush	Quel tox
Curacron	Ripcord
Cidial 85 AS	Roger 40 ULV
Codal 400 EC	Roundup
Dursban 40 ULV	Ronstar/Divron
Dimecron 100 SCW	Santara
Ditane M-45	Sunicon 50 EC
Dursban 24ULV	Safsan
Ekathin 24ULV	Thiodan 25 ULV
Exactin WF	Thiodan 35% EC
Ethion 50ES	Thionex 25 ULV
Endrin 1.6 ULV	Tiezene 80
Fertilion combi	Torbidan
Gusathion	Tamaron UltracideUlvair
Koicide 101	Combi 500
Hosathion	Volt Custahaciòn
Metasystox R 50	

Table 7.2 List of Pesticides used in Awash valley

Sources: Original source is Awash Agricultural Corporation data abstracted from table 3 and 7 in Halcrow 1989, Annex J.

Biochemical Degradation

- Field dissipation half-life: the time it takes for half the pesticide to disappear

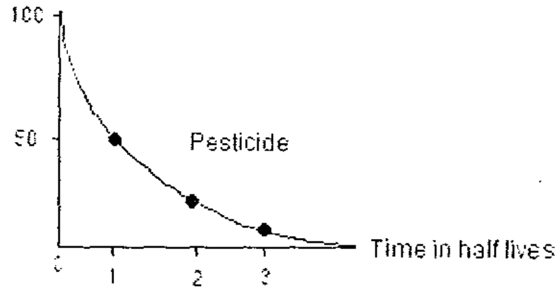


Fig 7.2 Biochemical degradation process of pesticides

7.1.3 Septic tanks

Groundwater contamination has occurred where there have been high densities of septic systems. Studies have shown that the groundwater has been contaminated by high amounts of organic contaminants from septic systems. Problems with septic systems are worsening when communities that rely on subsurface disposal systems also depend on private wells for drinking water.

There are many considerations to be made before installing a septic tank system. In order for it to function properly, it is important for the surrounding soil to have certain characteristics, the most important of which has to do with permeability. The water carrying capacity of the soil must be measured before a system can be approved for building and must be known before a proper system can be designed. Usually a percolation test is performed to determine the adequacy of the soil to support a septic system.

Another critical design consideration has to do with the height of the water table. The leach field must have a certain separation from the water table to prevent contamination from occurring. Likewise layers of impermeable "soil' must be a certain depth below the leach field. This was not considered during the construction of septic systems in the study area.

High population number with the associated high amount of wastes (increased number of improperly designed septic tanks) makes the contribution of nitrate to the groundwater substantial. That is the reason why high amounts of nitrate concentrations are observed from the groundwater samples where there is increased number of population; for example, a sample collected from a borehole around Metehara mosque was found to contain high amounts of nitrate. The logical reason to this is that since there is no agricultural activity in the close vicinity of the area, it can only be attributed to the large number of population.

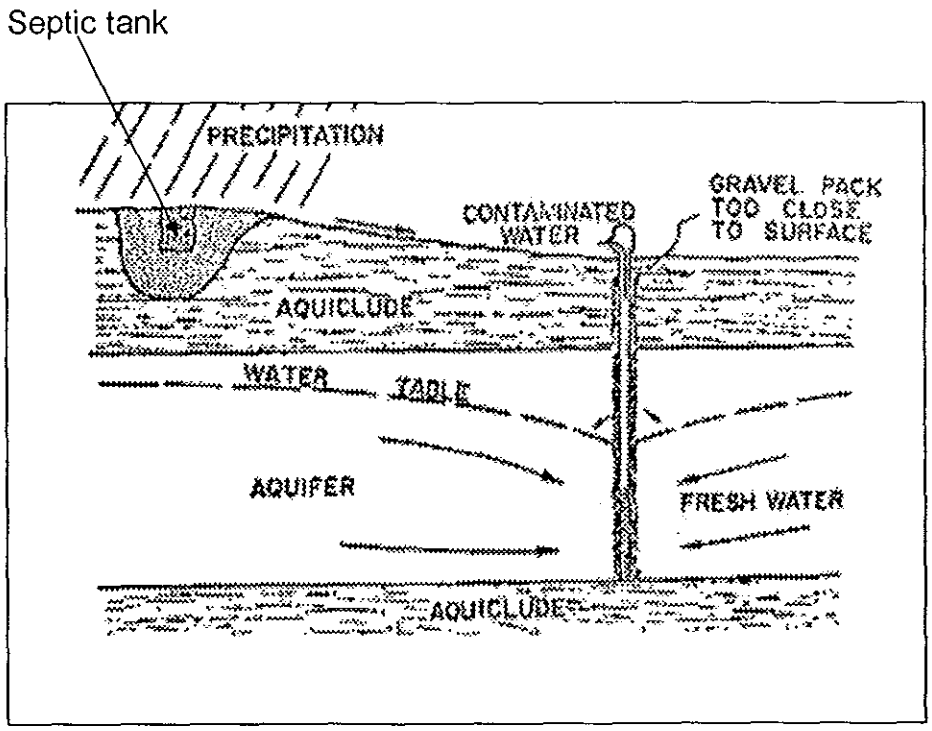


Fig. 7.3 Septic system

Agricultural activity	Impacts	
	Surface water	Groundwater
Fertilizing	Runoff of nutrients, especially phosphorous, leading to eutrophication causing taste and odor in public water supply, excess algae growth leading to deoxygenation of water and fish kills.	Leaching of nitrate to groundwater; excessive levels are a threat to public health.
Manure spreading	Carried out as a fertilizer activity; spreading on frozen ground results in high levels of receiving waters by pathogens, metals, phosphorous and nitrogen leading to eutrophication and potential contamination.	Contamination of groundwater, especially by nitrogen
Pesticides	Runoff of pesticides leads to contamination of surface and biota; dysfunction of ecological system in surface waters by loss of top predators due to growth inhibition and reproductive failure; public health impacts from eating contaminated fish. Pesticides are carried as dust by wind over very long distances and contaminate aquatic systems 1000s of miles away (e.g. tropical/subtropical pesticides found in Arctic mammals).	Some pesticides may leach into groundwater causing human health problems from contaminated wells.
Irrigation	Runoff of salts leading to salinization of surface waters; runoff of fertilizers and pesticides to surface waters with ecological damage; bioaccumulation in edible fish species, etc. High levels of trace elements such as selenium can occur with serious ecological damage and potential human health impacts	Enrichment of groundwater with salts, nutrients (especially nitrate)
Clear Cutting	Erosion of land, leading to high levels of turbidity in rivers, siltation of bottom habitat, etc. Disruption and change of hydrologic regime, often with loss of perennial streams; causes public health problems due to loss of potable water.	Disruption of hydrologic regime, often with increased surface runoff and decreased groundwater recharge; affects surface water by decreasing flow in dry periods and concentrating nutrients and contaminants in surface water.

Table 7.3. Impacts of agricultural activities on the ground and surface waters

7.2 Groundwater quality for domestic purposes

The concentration of nitrate in potable water that does not result in any significant risk to the health of the consumer over a life time of consumption (World Health Organization (WHO) guideline value) is 45 mg/l. Above this, ill effects of nitrate can be caused and this includes:

a. Methaemoglobinaemia (blue baby disease)

A well-documented human health risk from nitrate contamination is infant methemoglobinemia, a condition where nitrates are converted into nitrites in the digestive system, impairing the ability of infants' blood to carry oxygen.

b. The risk of gastric cancer
c. Gastric tumors
d. In cattle and sheep, nitrate is a particular hazard because the rumen of these animals provides an environment conducive to its reduction to nitrate.

As stated earlier, groundwaters of some localities within the project area especially those within the sugar plantations as well as those localities with increased number of population cannot and must not be used for drinking as their concentration of nitrate exceeds the guideline value set by WHO for a safe drinking water. The nitrate concentration of Beseka Lake and that of Awash river is relatively low and from the perspective of nitrate concentration, it can be used for drinking purpose.

The fluoride concentration of most groundwaters in the study area is above the WHO recommended concentration (1 mg/l). Concentrations above this can cause fluorosis. The fluoride concentration of the groundwaters of the area range between 0.15 to 26 mg/l and most values lie above the WHO recommended concentration and therefore the groundwaters of the study area should not be used for drinking purposes with respect to fluoride concentration.

The WHO drinking water standards 1963 are given below.

Characteristics	Limit of general acceptability(mg/l)	Allowable limit (mg/l)
Total solids	500	1500
Chloride	200	600
Iron	0.3	1
Manganese	0.1	0.5
Copper	1	1.5
Zinc	5	15
Calcium	75	200
Magnesium	50	150
Nitrate	45	-
pH	7-8	Min.0.5 Max.9.2

Table 7.4 WHO drinking water standards

The concentrations of some components above which ill-effects may arise are:

Fluoride	1.0-1.7 depends on climate (fluorosis)
Nitrate	100 (Methaemoglobinaemia)
Iron	0.1
Chloride	200(Taste)
Sulfate	250(Gastrointestinal irritation)
Zinc	5 (Taste)

The pH of the waters of the study area fall on the WHO permissible limit except that of Beseka Lake which is highly alkaline. Due to this, except the water from lake Beseka, the rest of the water obtained from boreholes, hand dug wells, and also from Awash river can be used for drinking purposes (with respect to pH).

As discussed in the previous chapters, the TDS of the waters of the study area have relatively high values good instances are boreholes inside the farms (Metehara as well as Nura era) as well as the Beseka Lake. The highest values of TDS were observed for Beseka Lake. In terms of TDS values, the water obtained from boreholes inside the farms as well as that of the lake should not be used for drinking purposes as they have high value of TDS (they are highly mineralized) which is above the allowable limit set by WHO while the water in Awash has a very good TDS value and can be used for drinking purposes.

The adverse effect of too much chloride in water in drinking waters is on its taste. Most persons can detect chlorides in water at 200 mg/l or greater concentrations. Again due to the high mineralized nature of the water in the lake, the water can not be used for drinking purposes in terms of chloride concentration while the water obtained from most boreholes can be used for drinking purposes though in some localities there is a high amount of chloride concentration due to unknown reasons (possibly due to the impact of pesticides). The water of Awash River is the safest (best) water in terms of chloride concentration for drinking purposes.

Sulfate concentration is also another anion that we have to consider in order to decide whether particular water is suitable for drinking purpose. The sulfate concentration of Awash River is very low and this makes it very suitable for drinking where as the sulfate concentration in the boreholes gives a relatively higher values especially those samples obtained from within the farms have a sulfate concentration above the WHO value of safe drinking water standards. This can be due to agricultural activities (Fertilizer and Pesticide application) inside the farms. The sulfate concentration of Beseka Lake is also high and this can be attributed to lake water and groundwater interaction.

7.3 Irrigation water quality

The suitability of water for irrigation is largely dependent upon the amount and type of dissolved mineral constituents, and the effect these constituents have up on the particular type of soil and plant species. Whether a particular quality of water is suitable for irrigation, however, also depends to a considerable extent upon such factors such as soil type, drainage, climate and irrigation practices.

The usual water-quality factors to be considered in evaluating or classifying water for irrigation use are: specific conductance (which reflects TDS), Sodium percentage and sodium adsorption ratio etc. In the next section, sodium adsorption ratio is discussed.

The sodium adsorption ratio is the sodium concentration divided by the square root of one-half of the combined calcium and magnesium concentrations (all expressed in meq/l).

$$SAR = \frac{Na}{\sqrt{\frac{(ca+Mg)}{2}}} \quad \text{.......... (7.1)}$$

In the mid-1950's the salinity laboratory of the United States department of agriculture proposed a classification system for irrigation water quality that relates specific conductance (electrical conductivity) and the sodium adsorption ratio. This diagram is used to determine whether particular water may be used for irrigation or not (shown in fig 7.4)

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

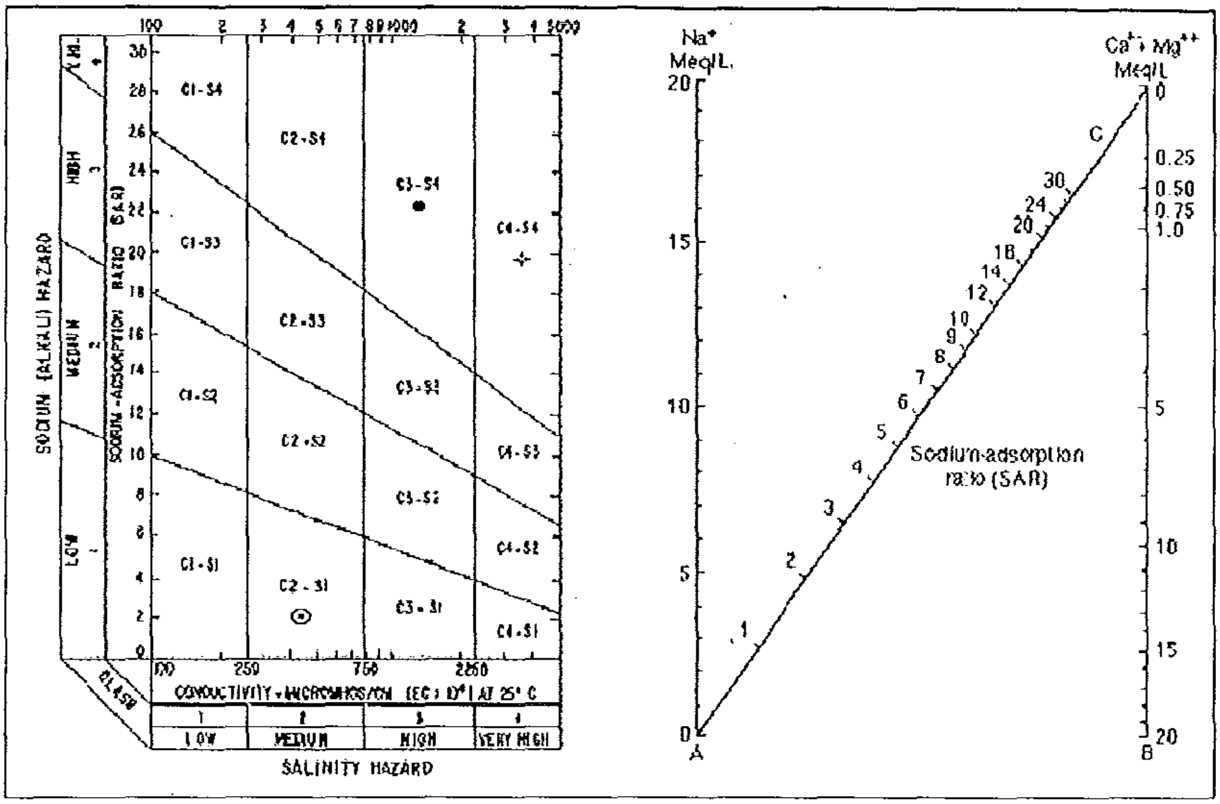
$$\text{Sodium percentage} = \frac{(Na+K)\,100}{Na+K+Ca+Mg} \quad \text{.......... (7.2)}$$

The percent sodium of the water from the boreholes ranges from 56 meq/l to 86 meq/l while that of Lake Beseka is approximately 99 meq/l. Awash River has an average percent sodium value of 48 meq/l.

Water class	Percent Sodium	Specific conductance µs/cm	Boron (mg/l)		
			Sensitive crops	Semi tolerant crops	Tolerant crops
Excellent	<20	<250	<0.33	<0.67	<1.00
Good	20-40	250-750	0.33-0.67	0.57-1.33	1.00-2.00
Permissible	40-60	750-2000	0.67-1.00	1.33-2.00	2.00-3.00
Doubtful	60-80	2000-3000	1.00-1.25	2.00-2.50	3.00-3.75
Unsuitable	>80	>3000	>1.25	>2.50	>3.75

Table 7.5 Quality classification of water for irrigation (after Wilcox) cited in Todd (1980).

According to the above classification, the water of Lake Beseka falls under the category "unsuitable" meaning that the water cannot be used for irrigation purposes while the water obtained from some boreholes can be classified as good water for irrigation but most of the water from the boreholes fall under the category "permissible". The water from Awash River falls under the water class "good" and is suitable for irrigation.



⊙ Represents SAR values of Awash River
✹ Represents SAR values of boreholes
✧ Represents SAR values of Beseka Lake

Fig 7.4 Diagram for the classification of Irrigation waters.

With respect to SAR and Ec, Awash River was calculated to have a low SAR value and a relatively low EC. Using the diagram for the classification of irrigation waters, it was observed that Awash River falls under the category C2-S1 (moderate conductivity and low salinity). Moderate salt tolerance (like sugar cane, papaya etc) can be grown using this type of water for irrigation and in most cases without special practices for salinity control.

The water samples obtained from boreholes was calculated to have a SAR value ranging between 4.09 to 96.79 meq/l. These waters (most of them) fall under the category C3-S4- high salinity water though there are also very high saline waters. This water cannot be used for irrigation purposes on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

The water samples collected from Beseka Lake was calculated to have a very high SAR value (as high as 307 meq/) and a high value of EC is associated with it. The water from the lake is very high salinity water (C4-S4) and is not suitable for irrigation under normal conditions, but may be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

Chapter Eight
Conclusion and Recommendation

The study area is found in the elevation range of 930-2500 meters above sea level. The principal rock units of the study area are divided into two groups: sedimentary rocks of fluvo-lacustrine which are distributed at the southern part of the study area (Abadir farm area) and volcanic rocks which have different mineralogical composition and stratigraphic composition. Volcanic rocks mainly ignimbrites and basalts of different ages are widely distributed in the study area.

The mean annual rainfall of the area is 593 mm. The total amount of evapotranspiration of the area is calculated to be 522 mm. The runoff over the study area was determined and resulted value of 52 Million cubic meter of water was calculated. The groundwater recharge of the area is estimated to be 2 Mm^3 of water annually. This very low value in relative to other areas was obtained because of the high rate of evapotranspiration and the relatively low amount of rainfall in the area.

Agricultural activities like irrigation, fertilizer application, pesticide application etc are carried out in the area. Fertilizer application has got some impact on the groundwater resource. Analysis of the groundwater samples collected at different sites within the study area for anomalous nitrate concentration (which is the major component of fertilizers) was carried out and it was found out that the nitrate concentrations of some boreholes inside the study area (like inside Abadir farm, Merti farm, Metehara town etc) is relatively higher concentration (as high as 96.8 mg/l), in some places above the WHO permissible limit for safe drinking water (>45 mg/l). This increase in nitrate inside the farms was attributed to the application of fertilizer as nitrate is the major component of fertilizers applied in the study area. For this problem, decreasing the rate of fertilizer application and if not, abandoning the wells found inside the farms can be a solution. Another option can be collecting the water used in the farms in an isolated container so that people and animal may not use it for drinking purposes. In areas outside the farms, high nitrate concentration in the waters is credited for increased number of population and with it the associated pollution from septic systems. Constructing septic tanks on localities where the soil is relatively impermeable is recommended. Another solution can be the construction of a well designed easily repairable septic systems and properly using them. The nitrate concentration of the surface waters (Awash River and Beseka Lake) of the area was found to be low.

Another impact of agricultural activity was manifested on high concentration of sulfate on the groundwaters and this was observed on boreholes found inside the farms (as high as 1800 mg/l) and it is assumed that this high amount of sulfate in the groundwaters is probably from the application of pesticides.

The impact of pesticides on the water quality was not studied due to the lack of data and the absence of efficient laboratory in the country to assess water samples for pesticide chemicals. It is recommended that in the future, detailed research on pesticides should be carried out so as to know their implications on the groundwater quality and also their impact on human health.

The TDS of the groundwaters shows an increasing trend from the highland areas to lowland areas and also inside the farms (From 444.3 mg/l to 4646 mg/l). High values of TDS were observed on boreholes close to Lake Beseka. The TDS of Beseka Lake is high (the lake is highly mineralized) and its values fall above the WHO permissible limit for safe drinking water (>1500 mg/l). The TDS of Awash River is relatively low (from 196 mg/l to 331 mg/l).

The fluoride concentration in Beseka Lake (up to 32.7 mg/l) and almost all boreholes (up to 26 mg/l) of the study area is high and should not be used for drinking purposes as their concentration fall above the WHO limit for safe drinking water. The fluoride concentration of Awash River is fairly low (approximately 1 to 1.54 mg/l) and this makes it suitable for drinking purposes.

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ANNEX 1. Summary of Monthly Humidity at Metehra station (%)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	51.3	54.7	54.3	54.7	X	53.0	54.7	48.7	54.7	45.0	43.7	X
1987	51.0	44.7	57.7	56.0	55.7	46.3	45.0	59.0	50.3	44.0	43.3	47.3
1988	57.7	55.3	44.3	50.7	39.7	42.0	57.7	62.0	59.7	49.3	48.3	49.0
1989	36.3	45.3	47.3	54.7	34.3	38.3	51.3	47.7	48.7	35.3	37.7	59.0
1990	54.3	72.0	67.0	60.7	46.7	41.7	58.7	59.0	61.0	46.7	46.3	46.3
1991	50.3	57.7	54.0	54.7	56.7	40.7	58.7	64.3	58.0	47.7	47.0	51.3
1992	60.3	67.7	53.0	64.3	X	X	X	X	X	X	X	52.0
1993	62.3	68.3	48.3	60.0	59.0	43.7	55.7	56.3	55.3	54.7	48.3	48.7
1994	46.3	43.3	46.7	50.3	48.3	49.7	X	65.3	50.7	32.3	44.3	40.0
1995	50.0	54.0	64.3	58.3	51.0	47.0	59.3	62.7	60.0	49.7	51.3	61.0
1996	58.3	47.7	60.3	62.3	62.0	60.0	64.7	64.3	58.3	51.3	53.7	50.7
1997	59.3	52.0	54.3	60.7	51.0	58.0	64.0	61.3	55.0	68.0	66.3	57.7
1998	62.0	71.0	64.3	53.0	X	X	54.3	61.7	59.7	58.0	48.0	52.0
1999	49.0	40.0	58.3	48.3	47.7	45.7	63.3	63.0	58.3	62.3	50.7	50.7
2000	47.0	47.0	44.0	47.0	45.7	44.0	58.7	62.7	64.3	X	59.0	58.7
2001	58.3	58.0	59.3	51.7	52.0	46.3	59.0	64.0	55.7	46.0	43.7	50.7
2002	56.7	46.7	54.3	49.7	42.3	43.0	46.0	58.0	55.0	44.0	41.7	61.3
2003	56.7	48.3	46.7	52.0	42.3	47.3	58.0	66.0	61.0	46.7	47.0	52.7

ANNEX 2. Mean monthly Temperature at Metehara station (°C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	20.35	26	26	27.15	28.15	27.9	26.1	26.65	26.55	24.75	23.45	22.35
1987	21.95	24.3	26.45	25.4	26.2	29.9	29.3	26.8	27.95	26.25	22.9	22.85
1988	23.85	26.3	26.75	27.7	28.2	29.7	26.4	25.6	26.05	24.95	20.85	21.25
1989	21.4	23.3	25.6	24.9	25.9	27.85	26.25	26.2	26.35	24.7	23.45	23.95
1990	22.95	24.2	24.25	24.8	28.9	30.15	26.05	26.3	26.75	24.6	23.7	21.5
1991	24.5	25.2	27.05	26.4	27.1	29.2	26.35	25.55	26.7	24.75	22.3	22.3
1992	23.65	24.45	27.8	27.8	27.85	29.05	26.55	25.4	25.45	24.75	23.4	165.9
1993	21.8	22.6	25.2	26.6	26.5	29.35	26.7	26.7	27.4	26.1	23.5	21.9
1994	21.65	23.9	27.7	28.65	28.1	26.95	25.85	25.6	25.4	24.45	22.65	21.55
1995	X	25.4	25.5	28.3	28.35	29.4	27.2	26.25	26.25	25.65	23.1	24.8
1996	24.65	24.7	27.25	X	27	28.05	26.25	26.25	27.05	24.85	22.65	21.4
1997	23.65	22.45	27.2	26.8	28.15	28.45	26.6	26.85	28.05	25.15	24.45	22.4
1998	24.1	26.25	27	28.65	29.15	30.65	27.85	25.75	27.05	25.35	22.45	20.5
1999	23.05	24.65	25.85	27.5	28.35	28.95	25.4	25.6	26.65	24.75	21.95	21.25
2000	21.95	22.65	25.8	27.5	28.75	29.85	26.5	25.6	26.7	24.3	23.35	21.95
2001	21.75	23.8	26.3	27.05	29.45	29.35	26.5	25.7	26.75	26.35	23.3	23
2002	23.75	24.8	27.3	28.1	29.4	30.05	29.2	26.8	27.25	26.5	23.9	24.7
2003	23.65	25.95	27.4	28.15	28.65	29	26.2	25.6	26.3	25.75	24.55	22.6

ANNEX 3. Monthly Total Rainfall in mm at Nura era station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	54.5	36	32.3	2	60.9	85.4	103.1	58.8	6.1	0	X
1987	0	11.3	57.1	47.5	134.6	3.2	45.8	210.7	9.7	3.8	0	0
1988	13.3	23.2	4.5	45.3	0	23.1	127.7	194.2	42.4	11	0	4.7
1989	0	46	89.8	160.3	1.4	57.1	114.6	173.9	59.1	8.9	0	16.2
1990	1.4	302.8	73	107.8	2.3	2.7	200.1	117.8	36.4	X	0.5	0
1991	0	47.2	130	17.3	17	17.8	209.5	137.7	53.1	11.6	0	0
1992	45.2	6.7	X	59.2	14.2	27.5	147.2	204.9	42.5	35.3	10	18
1993	118.4	20.6	0	100.5	41.2	9.6	117.5	125.4	46.1	34.8	0	6
1994	0	0	77.5	28.1	58.1	73.3	210.5	131	43.1	12.5	20.5	12.1
1995	0	31.2	40.7	103.8	14.1	52.3	74.2	157.8	40.6	0	0	0
1996	158.7	0	111.7	99.2	82.1	42.8	109.5	143.7	66.3	12.2	30.8	0
1997	21.2	0	14.6	6	0	0	41	37.5	27.2	164.4	X	X
1998	X	X	X	X	X	X	X	X	X	X	X	X
1999	X	X	31.3	0	14.8	39	14.8	153	24.7	140.5	4.4	0
2000	0	0	0	30.7	31.5	14.8	31.6	180.7	64.5	79.6	2.8	13.6
2001	0.3	26.5	131.8	22.3	28.3	31.6	8.3	102.8	83.4	0.8	0	0
2002	25.7	0	71.9	24.7	18.4	8.3	82.4	133	17.3	2.4	0	34.8
2003	27.8	33.4	47	23.6	1.6	82.4	X	240.9	70.2	0	3.7	35

ANNEX 4. Monthly Total Rainfall in mm at metehara station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0.0	41.6	43.2	25.9	13.0	51.8	64.3	67.1	36.5	4.0	0.0	7.0
1987	0.0	24.1	71.2	78.0	74.8	0.0	53.6	110.4	8.0	2.8	0.0	0.0
1988	13.6	29.6	11.3	23.7	7.8	11.3	156.5	136.1	104.3	18.0	0.0	11.9
1989	0.0	28.0	104.8	101.3	7.5	82.1	48.7	92.7	28.2	5.6	0.0	12.7
1990	0.5	220.8	58.1	62.9	1.8	0.9	146.4	76.9	82.4	2.1	0.0	0.0
1991	0.0	54.3	56.1	46.7	53.3	15.4	137.0	132.0	49.6	11.7	0.0	0.0
1992	25.8	50.3	0.0	75.8	16.8	62.4	90.0	157.6	62.2	49.6	5.7	2.3
1993	43.8	59.5	0.0	139.6	57.3	23.7	101.4	103.7	41.6	21.9	0.0	56.9
1994	0.0	0.0	6.5	21.4	55.4	38.6	248.4	131.6	39.6	0.1	12.7	1.9
1995	0.0	43.5	81.9	44.0	10.5	28.5	47.3	144.1	57.7	0.5	0.0	0.0
1996	27.6	0.0	97.3	35.1	80.5	26.5	205.1	100.5	52.6	1.6	7.5	0.0
1997	29.7	0.0	12.6	44.3	11.5	35.1	139.7	53.8	20.4	112.4	14.6	0.0
1998	0.8	18.1	76.6	34.2	14.9	4.7	78.2	135.6	54.0	78.0	0.0	0.0
1999	0.0	0.0	73.6	6.2	15.9	16.7	136.1	151.2	16.4	76.2	2.2	0.0
2000	0.0	0.0	1.8	20.7	36.9	29.6	135.9	152.7	46.8	47.3	11.9	9.4
2001	0.0	13.6	92.7	20.4	12.7	20.2	154.8	82.8	15.3	7.1	0.0	1.6
2002	2.4	0.0	73.3	19.3	9.3	10.2	43.0	80.8	16.8	0.0	0.0	21.2
2003	4.6	17.5	33.6	13.7	0.0	29.5	118.9	186.0	31.0	0.0	3.2	15.7

ANNEX 5. Monthly Total Rainfall in mm at Welenchiti station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	169	92.7	104.4	X	80.9	155.8	95.1	154.1	8	0	0
1987	0	37.7	220.4	132.3	272.6	1	91	165.6	24.7	9.7	0	0
1988	15	17.2	5.6	30.5	6.5	29.8	185.3	206.2	186.9	16.9	0	0
1989	0	189.6	149.5	286	0	83.4	185.9	244.2	119.2	1.4	0	14
1990	X	332.8	91.7	95.3	14.4	0	243.5	200.6	141.9	9.3	0	0
1991	2.7	90	137	16.9	7.1	23.8	223.1	184.3	44.4	X	X	X
1992	X	X	X	101.5	0	42.5	130.8	356.8	90.7	17.5	3.4	8.1
1993	47.1	50.7	0	114.3	31	42.2	210.9	139.6	140.8	19.6	0	0
1994	0	2.1	27.4	23.7	26	66.3	304.5	185.9	77.5	2.8	36.9	13.4
1995	0	57.4	163.4	95.7	12.9	46.1	156.1	310.2	135.5	12.1	0	3.5
1996	52.1	0	180	91.5	168.8	86.1	200.7	150.6	73.6	42.5	0	0
1997	29.8	0	38.2	23.2	44.7	145.7	255.3	131.1	88.6	117.8	51.4	0
1998	41.6	40.6	X	33.5	47	48.1	154.4	336.6	197.2	179	0	0
1999	11.1	0	104.1	0	0	39.1	246.5	232.9	52	167.4	3.6	0
2000	0	0	15.5	18.4	47.9	58.4	249.2	249.5	110.9	96.3	30.5	6.1
2001	0	0	128	20	65.9	76.5	X	X	X	X	10	0
2002	0	0	48.9	61.4	10	18.7	166.2	231.8	36	0	0	97.7
2003	32.5	32.1	119.6	152.6	0	61.2	393.2	321.7	7.5	X	0	X

ANNEX 6. Monthly Total Rainfall in mm at Abomsa station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0.0	71.1	108.7	93.0	42.4	X	121.3	80.5	86.4	X	0.0	14.
1987	0.0	18.7	287.5	113.3	141.6	X	15.0	222.5	34.3	29.8	0.0	0.
1988	33.8	67.2	3.1	93.6	12.1	79.0	182.8	211.4	179.5	58.6	0.0	6.
1989	0.0	50.2	61.4	119.2	28.4	90.3	136.7	192.4	120.8	49.1	10.6	33.
1990	7.4	347.4	186.1	183.5	40.8	22.0	220.8	115.8	106.9	8.3	3.1	4.
1991	2.0	69.6	100.2	45.3	58.3	69.8	171.0	185.1	46.1	21.0	1.1	5.
1992	46.6	49.5	5.6	146.3	45.2	50.2	142.0	166.7	197.7	158.7	19.7	39.
1993	189.9	38.3	0.0	202.2	82.8	19.7	118.3	128.0	92.8	120.0	4.7	8.
1994	0.0	0.0	31.0	62.8	142.6	117.1	290.0	132.7	76.3	19.0	126.0	7.
1995	0.0	19.9	147.8	112.3	64.2	31.3	106.6	172.0	85.7	13.0	0.0	6.
1996	66.5	3.4	144.0	80.1	143.4	121.1	107.9	214.3	135.9	22.5	8.7	0.
1997	27.5	7.3	71.5	106.0	15.4	70.6	243.7	140.2	99.5	234.4	110.0	0.
1998	108.8	32.4	130.3	38.4	71.3	51.7	108.6	175.6	193.8	86.6	1.7	0.
1999	15.8	1.3	162.4	4.6	21.8	82.4	275.9	204.0	144.8	229.6	0.0	0.
2000	4.8	0.0	10.5	88.1	67.1	13.3	119.4	200.6	65.9	116.8	45.8	25.
2001	3.6	24.5	170.2	36.3	121.7	56.2	210.3	199.9	81.9	17.8	2.9	20.
2002	37.8	0.0	100.8	37.2	18.0	48.8	65.6	145.3	52.3	0.0	X	X
2003	14.2	5.9	74.4	62.2	0.0	49.9	217.9	129.8	85.3	16.4	7.0	62.

ANNEX 7. Monthly Total Rainfall in mm at Shola Gebeya station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0	131.6	99.3	106.3	64.3	46.3	366.2	458.1	254.9	0	0	0
1987	0	49	129.2	55.4	163	113.3	90.1	285.6	10.5	159	X	X
1988	0	20.6	26.2	75.1	X	18.7	96.8	319.9	119.3	21.7	0	0
1989	0	19.6	11.8	138.3	4.5	73.6	235.7	363.5	145.8	28.1	0	13.8
1990	4.7	120.7	22.6	72.4	5.5	9	192.2	206.1	115.2	0.6	0	0
1991	0	10.3	83.1	25.2	18.8	68	221.3	271.9	100.2	11	0	9.4
1992	25.4	33.6	2.2	51	18.3	35.9	219.8	279.8	129.3	48.8	0	0.5
1993	8.2	53.1	0	83.6	72.2	37.1	323.3	208.1	113.5	24	0	0
1994	0	0	35	60.5	51.5	89.9	268.1	204.1	124.3	0	15.1	0
1995	0	5.5	53.8	100	26.3	21.5	227.7	302.3	61	0.3	0	3
1996	22.4	0	102.4	40.9	108.5	168.5	297.1	315.1	53.9	1.4	X	0
1997	28.3	0	45.9	114.8	11.4	101.7	214.1	213	35.8	128.5	39.2	0.2
1998	8.5	9.5	42.9	47.1	49.4	26.4	330.4	372.6	134.8	61.4	0	0
1999	1.4	0	22.4	2.7	3.7	130.7	373.5	430.9	80.8	48.2	6.2	0.6
2000	0	0	17.4	56	25.3	18.2	240.4	281.2	113.5	26.7	20	8.4
2001	0	5.7	93.8	25.3	50.6	52.2	391.1	229.6	64.1	4	0.3	1
2002	8.5	7.4	78.5	32.2	36.2	23.1	183.2	314.6	88.6	0.8	0	16.9
2003	16.7	10.5	48	84.9	0.5	107.8	326.8	265.6	105.7	0	6.2	9.6

ANNEX 8. Mean monthly discharge at Metehara station (m/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	21.4635	19.0594	33.1874	59.9081	29.7001	21.7936	12.9588	49.4678	29.2344	6.68475	6.6238	5.32814
1988	23.8191	7.09353	5.9924	45.2388	3.29296	2.79073	38.1671	X	91.3977	40.9308	5.42508	6.4734
1989	6.57011	18.4542	8.25074	22.0918	16.2531	16.9796	77.4335	65.5401	121.546	46.3639	24.0148	23.61
1990	21.0139	103.428	28.4262	37.9848	17.8198	X	X	X	X	73.1845	23.6789	15.6692
1991	13.0604	24.8634	30.386	37.4911	24.0025	19.5056	55.8664	129.778	138.993	35.8976	35.3081	31.7075
1992	57.2788	70.6163	22.6058	29.5871	21.4189	13.7071	22.5104	54.8836	114.712	94.2403	14.1237	20.8898
1993	75.3367	53.6533	25.0851	28.6373	67.9678	28.106	69.2137	144.63	163.55	83.3701	27.6649	29.0625
1994	23.7258	22.4174	20.094	20.4837	21.7196	20.4085	73.2717	61.958	60.2077	40.8431	22.3309	19.1281
1995	13.8698	21.7958	69.5302	56.1686	22.3713	33.0515	63.2379	76.3126	48.9582	17.7755	15.9881	15.7741
1996	39.4304	22.4634	56.7107	29:4591	23.7092	30.3803	38.3449	204.107	231.92	36.8199	19.8341	28.5951

ANNEX 9. Monthly mean Discharge at Nura Era (m/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	33.389	48.2507	45.7951	90.9195	119.534	60.5599	38.6415	75.6841	58.5592	31.0523	30.0277	29.8713
1988	49.6203	30.6008	29.3541	44.6129	18.551	18.6367	78.2331	94.1614	91.134	56.4085	21.5295	22.9772
1989	25.0779	36.7784	28.4711	37.708	32.45	43.3887	72.7507	87.6338	195.798	62.2857	35.2788	36.6675
1990	25.6754	68.8737	76.1423	50.0056	30.2486	41.2897	56.3503	80.7795	147.422	88.3988	94.2699	28.4784
1991	27.1339	38.8344	55.4568	50.0221	39.1326	30.8472	95.3932	116.193	228.344	61.8822	55.1243	42.1646
1992	65.4667	54.2491	30.9833	59.3846	35.4299	49.4515	79.3139	65.2152	114.589	66.7267	22.0256	27.7762
1993	70.829	48.7629	27.491	83.6552	43.7538	42.9362	81.7768	X	X	63.7623	25.1585	30.2014
1994	38.4481	30.3031	35.4299	38.6	25.1688	91.7621	134.593	85.9053	66.3555	X	49.2387	49.372
1995	45.5009	27.9383	94.6198	48.1153	55.9759	75.9805	121.384	144.468	108.249	91.1803	80.1242	79.5906
1996	45.5009	27.9383	94.6198	48.1153	55.9759	75.9805	121.295	144.468	108.249	91.1803	80.1242	79.5906

ANNEX 10. Run-off Coefficients

a. Richard's Run-off Coefficient

Types of catchment	Value of (C)
Rocky and impermeable	0.80 to 1.00
Slightly permeable, bare	0.60 to 0.80
Slightly permeable, cultivated or covered by vegetation	0.40 to 0.60
Cultivated absorbent soil	0.30 to 0.40
Sandy absorbent soil	0.20 to 0.30
Heavy forest	0.10 to 0.20

b. Barlow's Run-off Coefficient

Class	Type of catchment	Run-off coefficient
A	Flat, cultivated black cotton soil	0.1
B	Flat, partly cultivated, various soil	0.15
C	Average	0.20
D	Hills and plains with little cultivation	0.35
E	Very hilly and steep, with hardly any cultivation	0.45

ANNEX 11.Monthly mean wind speed at Nura era station at 2 mts in m/s

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	1.6	1.7	1.4	1.7	2	3.2	2.9	2.5	1.9	1.8	1.7	1.7
1987	1.7	1.7	1.6	1.5	1.8	2.6	3.1	2.6	1.7	1.4	1.4	1.4
1988	1.5	1.5	1.8	1.8	2.3	3.3	3.6	2.2	1.7	1.6	1.7	1.5
1989	1.5	1.7	1.6	1.2	1.6	2.4	3.1	2.2	1.7	1.5	1.8	1.6
1990	1.8	1.2	1.1	1	1.8	2.9	3.2	2.9	2.2	1.9	1.7	1.6
1991	1.7	1.7	1.7	1.8	2.1	3.1	3.8	2.7	2	1.7	1.6	1.6
1992	1.7	1.8	2.1	2	1.9	3	3.3	2.7	1.8	1.5	1.5	1.7
1993	1.8	1.6	1.6	1.6	1.7	3.1	3.7	3	2.4	1.7	1.6	1.5
1994	1.6	1.8	1.9	1.9	2.1	3.7	3.1	2.5	1.7	1.6	1.5	1.5
1995	1.5	1.6	1.6	1.5	2	2.7	3.2	2.8	1.9	1.7	1.4	1.6
1996	1.4	1.5	1.7	1.5	1.6	3.1	3.1	2.7	1.9	1.6	1.5	1.5
1997	1.6	1.8	1.8	1.9	1.9	2.6	2.8	2.1	1.7	1.3	X	X
1999	X	X	1.4	1.6	2.3	2.4	3	2.3	1.8	1.3	1.4	1.3
2000	1.4	1.5	1.7	1.6	1.8	3.1	2.5	2	1.2	1	1.3	1.3
2001	1.4	1.4	1.3	1.4	2.2	3.1	2.8	2.7	1.5	1.5	1.4	1.4
2002	1.5	1.5	1.3	1.5	1.8	2.8		2.4	1.6	1.5	1.5	1.4
2003	1.3	1.6	1.8	1.7	1.4	2	X	X	X	X	X	X

ANNEX 12. Monthly mean sunshine hours at Metehara station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	10.2	8.8	9.1	7.5	9.2	6.7	7.7	7.8	8.5	8.6	10.2	9.5
1987	9.6	9.1	7.5	8.9	8.2	8.3	8.9	7	8.7	9.1	9.7	9.7
1988	8.9	9.4	9.4	X	9.6	8.4	4.9	X	7.4	8	10.5	9.8
1989	8.7	8.6	8.4	7.2	9.8	9.3	6.4	8.6	4.9	8.7	9.6	X
1990	9.4	6.4	8.3	8.6	9.9	9.5	7.4	6.9	7.8	9.2	9.8	9.7
1991	9.3	8.8	8.1	8.7	8.1	8.6	7	6.8	8.3	8.9	9.4	8.7
1992	6.8	X	9.3	8.4	9.2	8.6	7.1	5.6	7.6	8.8	8.9	8.6
1993	7.2	7.1	10.1	8.2	9.3	9.3	7.5	8.2	7.1	8.6	10	10
1994	10.2	9.7	8.8	8.4	9.2	8.1	7.1	7.4	8.1	9.6	8.5	9.7
1995	10.1	9.3	7.8	8.7	9.8	9.4	9.6	X	8.4	9.2	10.3	9.5
1996	9.2	10.4	8.4	9.1	X	X	X	X	8.1	9.5	9.4	10.1
1997	8.3	10.7	9.1	7.6	9.7	8.4	8.1	8	8.2	7.9	8.2	9.4
1998	6.9	X	8.5	9.9	9.4	9.5	7	7.3	7.7	8.7	10.3	10.5
1999	9.6	10.8	8.3	10.5	X	7.9	7.3	8.2	8.4	8.1	9.3	10.1
2000	10.2	10.3	9.9	8.4	X	9.9	X	X	X	X	10.4	9.7
2001	8.9	9.8	7.4	9.3	9.1	8.9	X	6.6	X	8.6	10.5	X

ANNEX 13. Monthly mean sunshine hours at Nura era station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	9.2	8.1	8	6.5	9.2	3.3	6.8	7.5	8.3	X	9.7	8.5
1987	9.4	8.7	6.5	8.5	7.4	5.8	8.8	6.8	7.8	8.5	8.7	9.2
1988	7.6	8.7	9.1	7.4	10.2	8.7	4.7	X	7	8.4	10.5	X
1989	8.8	8.3	8.3	7	10.2	8.9	6.2	7.9	7.5	9.1	0.6	6.6
1990	9.5	6.5	7.7	8.1	9.7	9.2	6.9	7.8	7.5	9.2	9.8	9.2
1991	9	8.6	8.3	9.1	8.6	8.9	X	7	X	9.1	9.2	8.6
1992	6.7	6.3	9.1	8.9	9.3	8.8	7	5.9	7.6	8.3	8.9	8.6
1993	7	7.3	10.4	0.1	9	9.2	7.7	8.3	7.3	8.3	10	9.9
1994	10.3	9.7	8.7	9.2	X	X	X	X	X	X	X	X
1995	X	X	X	X	X	X	X	X	X	X	X	X
1996	X	X	X	X	X	X	X	X	X	X	X	X
1997	X	X	X	X	X	X	X	X	X	X	X	X
1998	X	X	X	X	X	X	X	X	X	X	X	X
1999	X	X	X	X	X	X	X	X	X	X	X	X
2000	X	9.7	9.4	8.4	9.4	5.4	6.7	7	7.5	8.3	9.5	9.5
2001	8.8	9.5	6.5	X	X	X	X	X	X	X	X	X

* X=no data