ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

ASSESSMENT OF WATER QUALITY IN THE SODERE - METEHARA AREA

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Abstract

Awash River basin is the major resource for both domestic and agricultural uses while groundwater at the majority of the study area, especially from deep boreholes seems unattractive for domestic and agricultural activities due to high concentration fluorides and sodium ions. Therefore, due attention should be given to Awash River, both in proper utilization and conservation of its quality. The core of this research work is concerned with assessment of the quality of the different water bodies with respect to domestic and agricultural uses and to study their temporal and spatial variability.

The interpretation of the chemical data and the Arial distribution of TDS and nitrate prevailed some sign of contamination. The major sources of the present contamination are due to intense agricultural activity in the area. This is highly manifested by high concentration of nitrate in groundwater of the area.

The over all agricultural as well as drinking water quality especially with respect to fluoride content, the groundwater is identified in a conditions which is not suitable for both agricultural and domestic uses. a land area of about 161.55ha of Metehara sugarcane plantation has been affected, in which 55.55ha of the land has been totally lost while the productivity of the remaining 106ha become very poor as a result of insufficient mechanical operation caused by high water table and high sodium salt deposit.

The drinking and agricultural quality of the different water bodies was assessed on the basis of the available data. Accordingly it was observed that the groundwater from deep well are not fit for drinking due to the presence of fluoride ions in the range beyond the admissible limit. The relative high concentration of F^- ions can be attributed to the presence of hot springs, fumaroles and the acidic rocks like ryholite, tracyte and obsidian.

CHAPTER ONE: - INTRODUCTION

1.1 Background

Natural water is one of the fundamental natural resource required for social, economic development, human uses and existence of healthy environmental and ecosystems. However, fresh water is a limited resource, which is currently, demanded at an increasing rate as a result of an increase in population growth and advancement of technology all over the world as a consequent the demand for fresh water for agricultural, industrial and domestic uses are at a rising rate. This emphasis the requirement of detailed research in the sector of water resources, specially in relation to their chemistry and their spatial and temporal variability, as well as proper implementation and protection of water resources from quality degradation. In addition the existence of good quality and adequate quantity of fresh water is an essential requirement to attain sustainable development of the area and the country (Ethiopia).

Therefore, this work focuses on hydrogeochemistry and spatial and temporal variability of the different water bodies in the area under consideration and is produced from the assessment of laboratory result review of previous works and available literatures such as the different volumes produced by Halrcrow 1989, during Awash Basin master plan study and different volumes produced by FAO, report on lake Beseka by Ministry of Water Resources and field observation and laboratory test results on water samples collected during field visit . The first three chapters are organized in away to give clear picture of the study area. These chapters gives an over view of general out line, Geology and tectonics, hydrogeology and climate of the area with relevance assessment on hydro geochemistry and their temporal and spatial variation as well as waters quality in relation to mainly for domestic and Agricultural uses.

1.2 Location and General out line

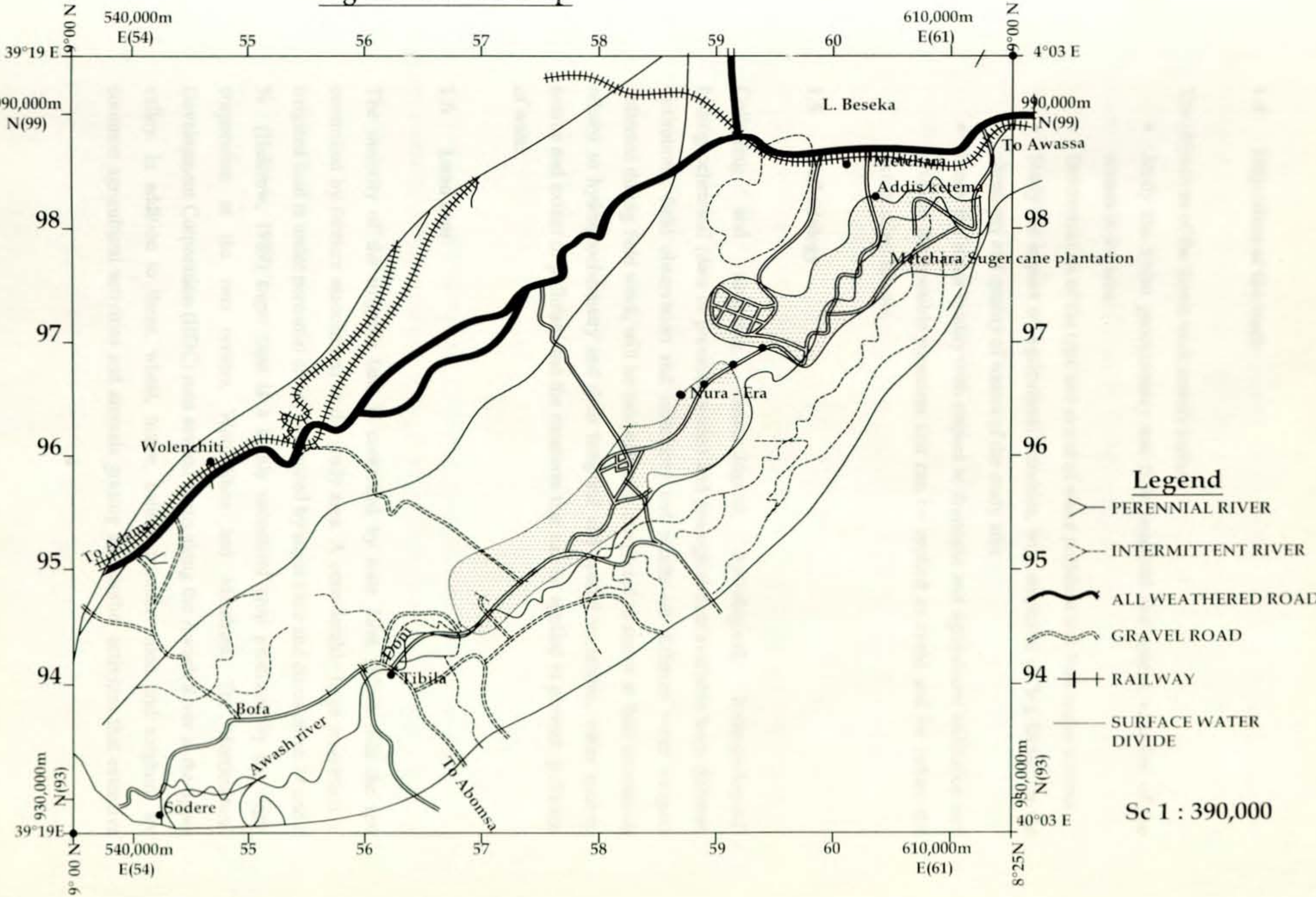
The study area is situated in the part of Main Ethiopia Rift, which is located in Eastern Shoa zone of Oromiya National Regional state .The area is bounded between latitude 8^0

25' and $9^0 00'$ N and $39^0 19'$ and $40^0 03'$E. The study area has nearly an elliptical shaped configuration with a total area of about 2925 km^2 that covered road from Nazareth to Harrer, together with Awash River and its tributaries included within the region between Sodere and Metehara localities. In general, the area is part of the upper Awash valley where a large proportion of irrigated land is under perennial crops, dominated by sugar cane and citrus.

1.3 Geomorphology

The geomorphology of the study area is characterized by landscapes, which is mainly represented by undulating plains that, faulted into plateau and scarp country, and aligned NE-SW direction. Consequently, it is locally difficult to traverse in a NW-SE direction across the scarps. Moreover the stated landscape with undulating plains is locally comprised scattered and isolated volcanic hills and mountains, constituted by volcanic cones and domes with surrounding lava fields. Often these landscapes are extensive and highly dissected and consequently, they pose difficulty to traverse. The altitude of the area lies in the ranges of 1200 m to 2540 m above mean sea level; with the higher altitude values are corresponding to the volcanic cones and domes of the area. The altitudes of the extensive undulating plains generally lie in the range of 1200 m to 1500 m above mean sea level.

Fig 1.1 Location Map



1.4 Objectives of the work

The objectives of the thesis work mainly include

- Study the hydro geochemistry and their temporal and spatial variation of the waters in the area.
- Determination of the type and extent of water pollutant and their major sources.
- Study the impact of Agricultural activities, with emphasis on big farms, on the chemistry and quality of waters of the study area
- Study the water quality with respect to domestic and agricultural utilization and propose the possible measures that can be applied to avoid and /or reduce the extent of pollutants.

1.5 Methodology

Collecting and assessing, meteorological, hydrological, hydrogeological, hydrogeochemical (data of previous works) and geological data available from different institutions, field observation and laboratory test results on different water samples collected during field work, will be analyzed and interpreted to arrive at final conclusion related to hydrogeochemistry and their temporal and spatial variations, water quality, source and extent of pollutant and the measures that can be applied to prevent pollution of water.

1.6 Land uses

The majority of the irrigable land is controlled by state farm (82%) with the rest controlled by farmers associations in the study area. A considerable large proportion of irrigated land is under perennial crops, dominated by sugar cane and citrus crops 74 and 8 % (Halcrow, 1989) sugar cane is a highly successful crop produced by the sugar corporation at the two centers, Wonji-Shoa and Metahara. The Horticultural Development Corporation (HDC) runs several farms along the Awash River in the upper valley. In addition to these, wheat, maize, cotton, tomato, onion and sorghum are common agricultural activities and animals grazing are another activities that extensive took place in the area, especially along the main road to Harrer. Almost all farm use fertilizers with different types vary somewhat from farm to farm. The main product applied is area (46% N) and on many farms is the only fertilizer applied. Phosphate in the form of triple super phosphate (approx. 18% P) and diammonimum phosphate (approx21% N and 23 % P) is applied on most crops in the upper valley, excepting sugar cane. Banana also receives phosphate fertilizers. Special fertilizers are applied as ammonium sulphate nitrate since the sulfur is required wide spread iron deficiency and a dilute solution of ferrous sulphate is applied repeatedly to the cane leaves during each crop cycle. Insecticides and fungicides are applied to most crops (Hal crow, 1989), listed in table 8.1

1.7 Previous works

Several works have been performed in the study area. These works are mainly focus on geology, geothermal, fluoride problems and master plan study of the region. Among the works carried out in the region some of them are regional hydrological study of Nazareth area by Getahun Kebede (1987) that includes the study area. Other important works that focus on the geology of the area were carried out by DipOala (1972), Mohr (1987), Kazmin and Seife (1987). Fluoride occurrence in the East African rift system has been described by Geotrg Darting et al (1996) B. Gizaw (1996) and of the Ethiopian rift by Ashley and Burley (1999).

None of these works has been conducted with the view to study the impact of big farms on the quality of the groundwater in the region, while the present work mainly focus on the quality and its temporal and spatial variability of the different water bodies and the impact of irrigation on the water quality. The work of Ministry of Water Resource (1998) on the rise of Beseka Lake and its remedial measures to overcome the impact it imposed on the infrastructures and water quality can be taken as one of the detail work carried in the stud area.

CHAPTER TWO: CLIMATE AND HYDROLOGY

2.1 Climate

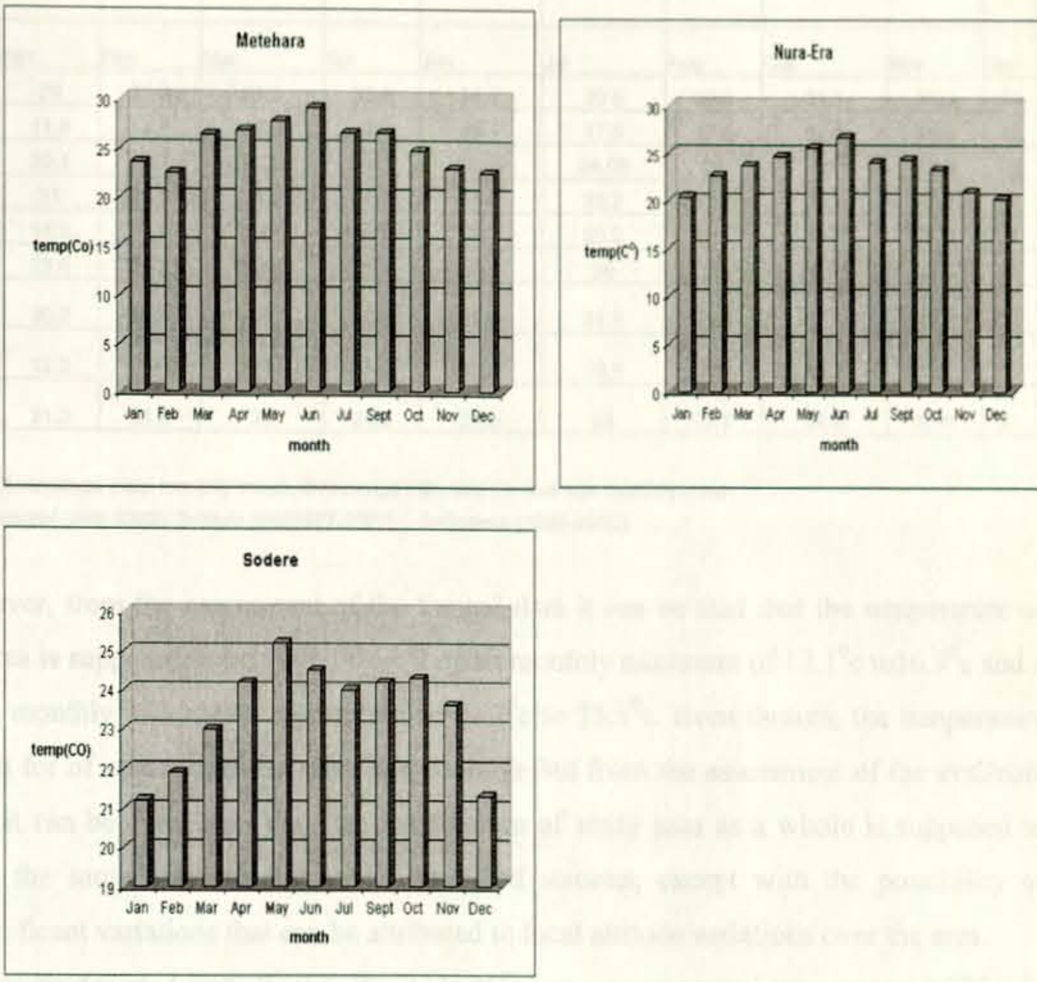
According to the assessment of some of climatological data (5 to 18 years) at Sodere, Nura-Era and Metehara areas, which were obtained from National Meteorological Services Agency (NMSA) and some data compiled from awash master plane volume IV, produced by Sir William Halcrow, 1989, the climatologically elements of the different localities of the study area are independently treated as outlined below.

2.1.1 Temperature

The temperatures of the study area shows an increasing trends from the up stream side to the down steam side (Metehara) with exception to Sodere station which exhibits occasionally a higher mean monthly temperature values than the corresponding months, at the next station (Nura - Era), probably due to the effect of the presence of hot thermal spring with a temperature of about 50 ^{0}c.

Metehara area has a temperature that range from an average monthly minimum temperature of 17.6^{0}c to an average of monthly maximum temperature of 33.5^{0}c. In general the mean monthly minimum and maximum temperatures at Metehara lie in the ranges of 12.5^{0}c to 20.2^{0}c and31^{0}c to 36.7^{0}c respectively, in which their respective peak values were identified in the month of June.

Fig. 2.1 Average monthly mean temperature at Sodera, Nura -Era and Metehara



Concerning, the temperatures at Nura -Era area, it varies between a mean monthly minimum temperature of 11.5 to 16.9^{0}c to a mean monthly maximum temperature of 28.9^{0}c to 34.2^{0}c with a mean annual temperature of 23.24^{0}c for the last 18 years. The temperature data of Sodere station represents a temperature data record of a few years with missing data and as a result it does not represent a real pictures of the temperature of the area.

Table 2.1 Average monthly mean temperature, calculated from mean monthly data from N.M.S.A (^{o}c)

	Jan	Feb	Mar	Apr	Jun	Jul	Aug	Oct	Nov	Dec	Mean Ann Temp
A2	29	30.9	31.9	32.6	34.2	30.6	30.4	31.4	29.9	29	28.34
B2	11.8	14.5	15.6	16.8	19.1	17.5	17.5	14.6	11.9	12	14.46
C2	20.4	22.7	23.75	24.7	26.65	24.05	24	23	20.9	20	21.65
A1	31	32.5	34.2	34.7	36.7	33.2	32.3	33.6	32.2	31	30.87
B1	16.2	12.5	18.7	19.2	21.7	20.2	19.7	16.5	13.9	14	16.25
C1	23.6	22.5	26.95	27.9	26.7	26	26	25.05	23.1	22	25.51
A3	30.2	29.8	31	32.5	32.5	31.5	31.4	32.9	31.2	30	28.833
B3	12.2	14	14	15.9	16.4	16.5	16	15.7	16	12	13.725
C3	21.2	21.9	23	24.2	24.5	24	23.7	24.3	23.6	21	21.325

Where A=average max. monthly mean, B=average min. and C= average monthly mean
1= metehara(1985-2002), 2=Nura-Era(1977-2002) 3=Sodere (1998-2002)

However, from the assessment of the limited data it can be said that the temperature of the area is supposed to be varied from a mean monthly minimum of 12.1^{0}c to16.9^{0}c and a mean monthly maximum temperature of 29.7^{0}c to 33.5^{0}c. Even though, the temperature record for of some localities were not available but from the assessment of the available data, it can be concluded that, the temperature of study area as a whole is supposed to show the same trend as the above described stations, except with the possibility of insignificant variations that can be attributed to local altitude variations over the area.

As can be depicted from fig.2.1, the study area has a mean annual temperature of 23.2 ^{0}c to 25.5^{0}c at Sodere and Metehara respectively.

2.1.2 Wind speed

According to the assessment of wind speed data collected by NMSA, the monthly maximum mean wind speed at Metehara area lies in the range of 2.1 m/s to 3.0 m/s (measured at 2.00 m above ground level), while a monthly minimum mean wind speed fall in the range of 1.0 m/s to 1.6m/s. The peak values of both monthly maximum and monthly minimum mean wind speed occurred in the months of June, July and August, with their values vary in the range of 2.6 m/s to 3.0 m/s and 2.08 m/s to 2.39 m/s respectively.

On the other hand, Nura- Era area, experienced a mean monthly maximum wind speed and mean monthly minimum wind speed existing in the range of 1.8 m/s to 3.8 m/s and 1.45m/s to 3.15 m/s respectively.

Table 2.2 Average monthly mean wind speed at Nura-era and Metehara (m/s) (tabulated from mean monthly data obtained from NMSA)

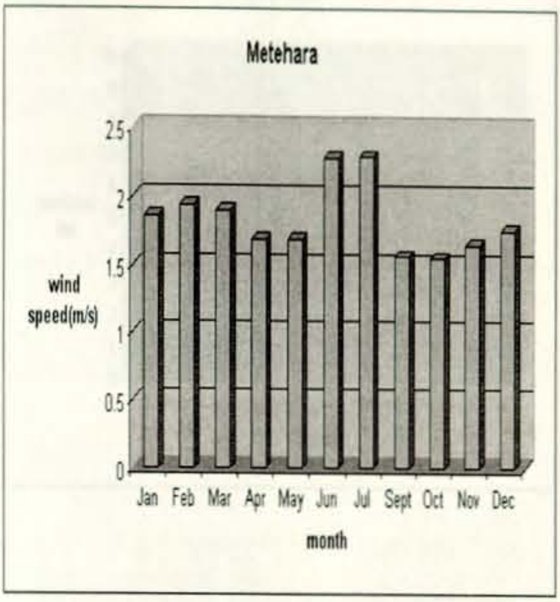
	Jan	Feb	Mar	Apr	Jun	Jul	Sept	Oct	Nov	Dec
A1	2.4	2.5	2.4	2.2	3	2.6	2	2.1	2.3	2.5
B1	1.5	1.6	1.5	1.3	1.8	1.8	1.2	1	1.3	1.6
C1	2	2.05	1.95	1.75	2.4	2.2	1.6	1.55	1.8	205
A2	1.8	2.2	2.3	2.5	3.7	3.8	2.4	1.9	1.8	1.8
B2	1.3	1.2	1.1	1	2.4	2.5	1.3	1	1.3	1.3
C2	1.6	1.7	1.7	1.75	3.05	3.15	1.85	1.45	1.55	1.55

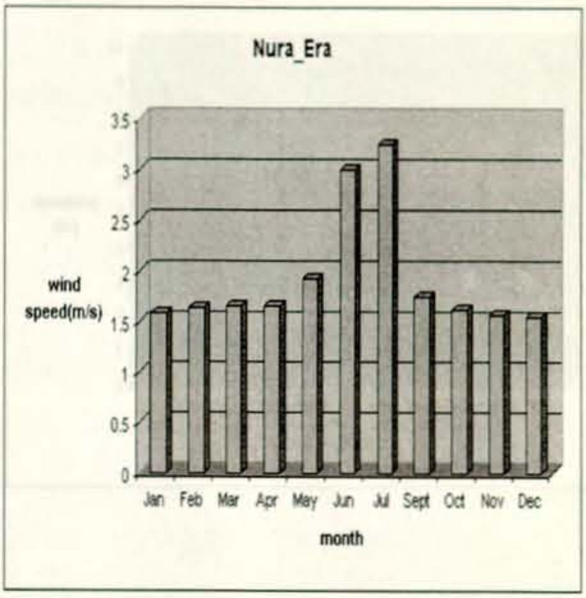
Where A= Average Max. monthly mean. B= average min. monthly mean and C= Average montly mean

1= Metehara(1985-2002) and 2=Nura-Era(1977-2002)

The peak values of the monthly maximum mean wind speed at Nura - Era area varies between 3.0 m/s and 3.8m/s while the peak values of the mean minimum monthly wind speed lie in the range of 2.1 m/s to 2.5 m/s. The stated maximum values of both maximum and minimum monthly mean were occurred in the months of Jun to Augest. For the sack of quick visual understanding about the distribution of the wind speed in the study area, graphs have been drawn for Sodere, Nura-Era and Metehara stations respectively. Accordingly Nura-Era and Metehara show relatively higher values in the months from June to August, while that of Sodere shows relatively higher values in the months of April to July and September to November.

Fig. 2.2 Average monthly mean wind speed at Nura - Era and Metehara





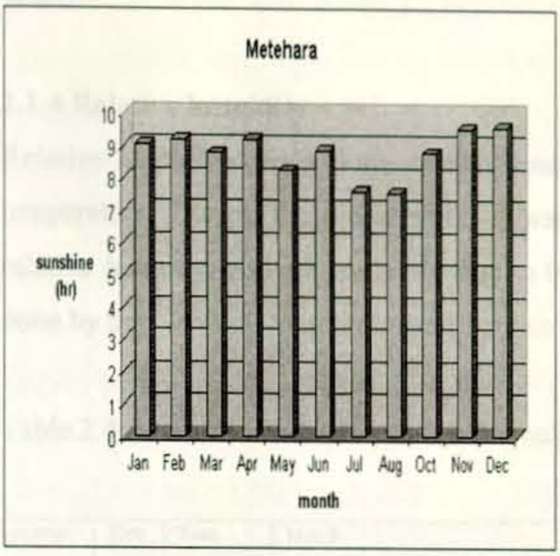
The respective maximum values were identified in June, July and August, which are more or less corresponding to the months where the monthly maximum rainfall took places at both Metehara and Nura-Era areas.

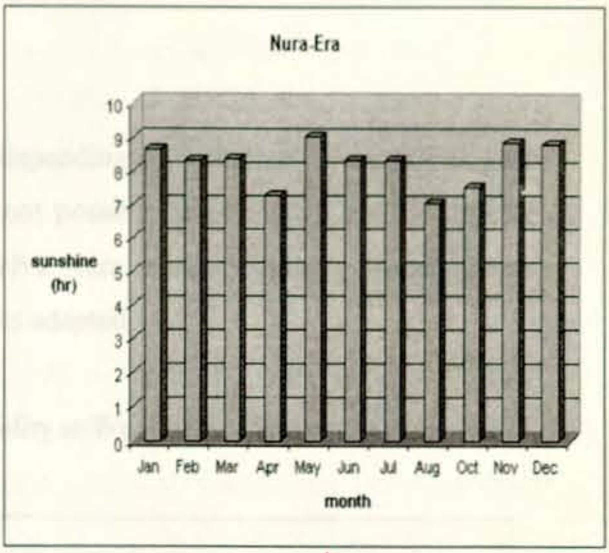
Even though the analyzed wind speed data were available only from two stations (Metehara and Nura Era), in the study area, it can be concluded that the area in general experiences the mean monthly maximum wind speed lying in the range of 1.8 to 3.8 m/s and monthly minimum wind speed varying between 1.45 and 2.5 m/s.

2.1.3 Sunshine hours

According to the result of the assessment and analysis of sun shine hour data collected at Nura- Era and Metehara by NMSA for the last 17 years, the study area experiences the mean annual sunshine hours ranging from 2920 hours at Nura Era to 3176 hours at Metehara.

Fig. 2.3 Average monthly mean sun shine hours at Nura - Era and Methara





As can be seen from the graphs drawn using mean daily sunshine versus months, the relative lower value of sunshine hours occurred in the months July to September at Metehara. While that of Nura-era occurred in April and August to October. The remaining other months shows relatively higher values with more or less consistent pattern of sunshine hour distribution.

Table 2.3 Average monthly mean sunshine duration (in hour)

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept.	Oct	Nov	Dec
9.05	9.2	8.78	9.2	8.24	7.6	7.6	7.54	7.76	8.79	9.54	9.58
8.62	8.29	8.35	7.25	9.01	8.3	8.3	7.02	7.4	7.5	8.83	8.75

In general, the monthly mean daily sunshine hours over the area for last 17 years varies in the ranges of 3.3 to 10.3 and 6.4 to 10.5 at Nura-Era and Metehara respectively. The two areas can be taken as the two extreme end points of the study area and as a result, the remaining areas lying between two stations are supposed to have values that may lie in the above stated ranges. Finally it should be noted that the average daily sunshine hours ranging from 7.0 to 8.8 at Nura Era to 7.5 to 9.6 at Metehara and accordingly the area experiences more or less consistence trends of sun shine through out the months of the years.

2.1.4 Relative humidity

Relative humidity varies from time to time, depending on variation in rainfall and air temperature. During the thesis work, it was not possible to obtain up to date data of relative humidity and consequently five to twelve years relative humidity measurements done by the National Meteorological Service has adapted.

Table 2.4 Average monthly mean relative humidity at Wonji, Metehara and Adama (%)

Location	Elev	Year	Month											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wonji	1540	1970-75	54.7	49.9	52.6	52.0	52.2	51.8	65.1	66.8	64.7	57.3	51.6	53.3
Metehara	955	1959-75	57.4	56.6	56.6	51.9	59.9	54.4	61.2	64.4	63.4	59.2	60.8	63.5
Adama		1990-01	53	51.8	54.5	54	48.3	55	67.2	68.1	64.5	55.3	48.6	51

2.2 Hydrology

The source of all water types on the earth surface and in the subsurface is primarily from precipitation and this holds true for the study area. Awash River and Lake Beseka are major water bodies in the area, which dominantly present hydrological feature of the area. In addition to this, numerous minor tributary rivers are observed in the region but almost all of them are intermittent streams. The contributions of these rivers to Awash River discharge at different gauging stations seem insignificant.

Hot and cold springs are other water bodies in the area, that present at different places. Except the hot springs at the south western periphery of Lake Beseka, which supply large amount of water to the Lake body, the contributions of the other springs to hydrology of the area are not much appreciable

2.2.1 Rainfall

Rain is part of the atmospheric precipitation that falls on the earth surface in the form of water droplets less than 0.02 inch in diameter and it is the most important form of precipitation in the hydrologic cycle. The spatial and temporal variation of the rainfall in Ethiopian is strongly controlled by the position of the inter-tropical convergence zone (ITCZ), which represents a low-pressure area of convergence between tropical easterly and 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 the country. The big summer rains occur all over the country. During this period the whole country is under the influence of equatorial westerlies from South Atlantic Ocean and southerly wind from the Indian Ocean. On the other hand, when ITCZ moves to the south, the country will be under the influence of continental air currents from north and northeast. These winds originated from North Africa and west Asia in spring (March. April, May) the ITCZ lies in the southern parts and a strong cyclonic cell (low pressure area develops over Sudan winds from the Gulf Aden and Indian Ocean cross the central and southern Ethiopia and form the relative smaller Belg rains. The area under consideration is being part of the southeastern area of the country dominated by bi-model rainfall pattern. It is expected to receive rainfall during summer and spring with maximum rainfall is evidently experienced in summer (Tenalem and Tamiru, 2001). To confirm this, 5,21, 18,10,10,10,and10years data were analyzed for sodere. Nura-Era, Metehara, Adama, Melkasa, Wonji, and Wolenchiti stations respectively and the graphs of the mean monthly rainfalls for these stations have been drawn. These graphs show that the area has two-rainfall season, which are rainy and dry seasons. The rainy seasons include the months July to October (summer), and March and April (Belg) are months with rains. Where as the rest months belong to dry season with minimum rainfall in the range of 3.67 to 4.06 mm of rainfall in the months of November and December. According to the assessment of the records obtained from both stations, the area receives the maximum values of rainfall in July and August months. In addition to this, an attempt to analyses the five-year data from Sodere station was made, however, being these data were mostly incomplete the result of the analysis was not enables to have a clear picture about rainfall distribution pattern of the area. However in the year where the data was complete, the area seems to show more or less similar rainfall pattern as the other two stations.

So that it can be concluded that the rainfall in the area varies from a mean annual rainfall of 519.01mm at Metehara to a mean annual rainfall of 949.36 mm at Wolenchiti station. In general, the rainfall amount and distribution is believed to be largely dependent on geographical position with respect to the general air and moisture, humidity, wind speed, sunshine, etc, and orographic factor that can affect the precipitation.

Table 2.5. Annual mean value of rainfall at different stations

Station	Mean annual rainfall (mm)	Altitude (m.a.s.l)	Period	Source
Metehara	519	960	1985-2002	N.M.S.A.
Nura – Era	599	122	1977-2001	N.M.S.A.
Sodere	691.73	1390	1998-2002	N.M.S.A.
Wonji	800.60	1540	1985-1994	N.M.S.A.& Halcrow, 1989.
Awash Melkasa	709.822	1540	1977-2001	N.M.S.A. & Halcrow, 1989
Nazareth	868.74	1622	1985-2001	N.M.S.A. & Halcrow, 1989
Wolechiti	949.36		1990-2001	N.M.S.A.
Average annual Rainfall	734.2			N.M.S.A

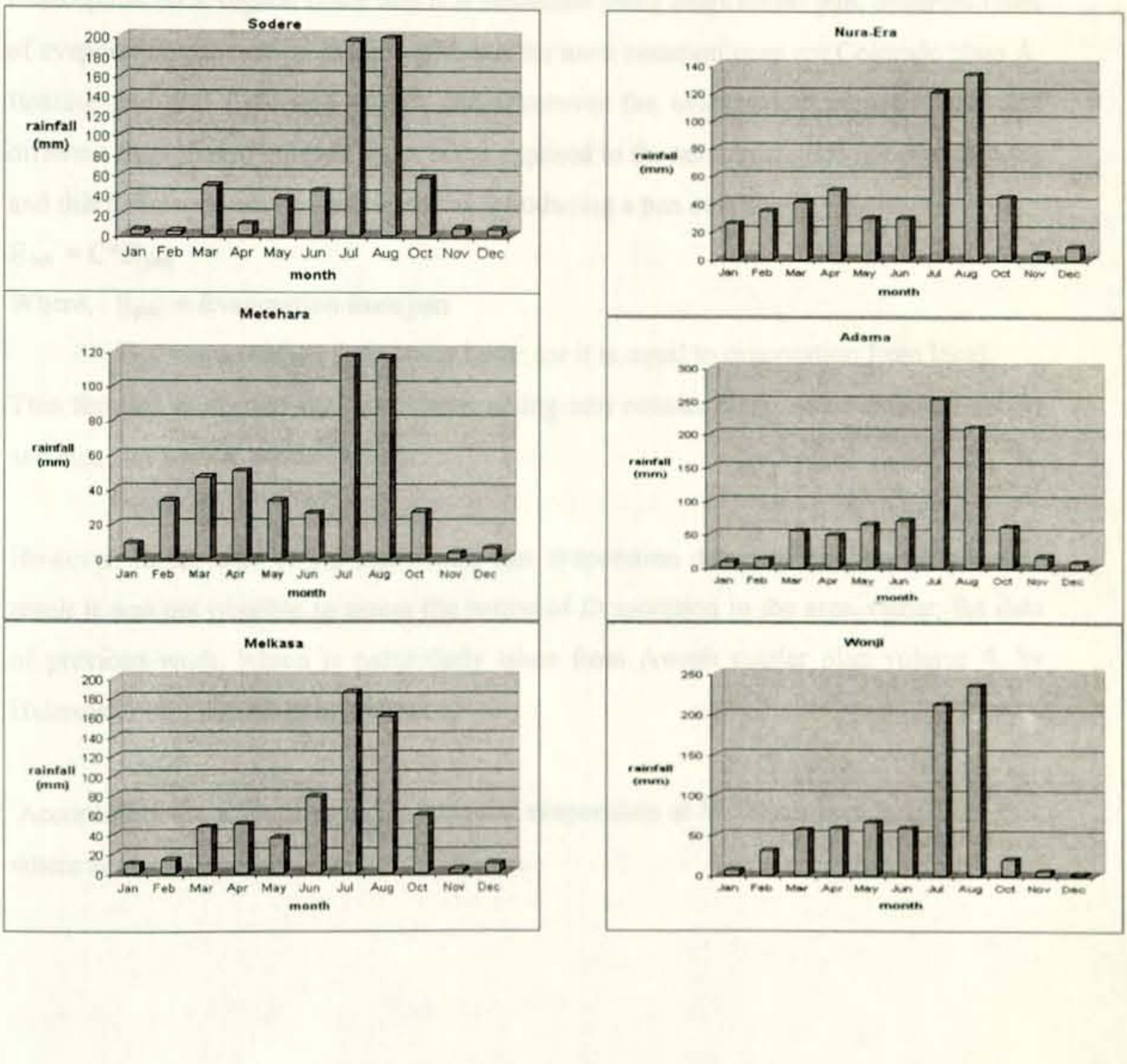
Source: Halcrow and N.M.S.A.

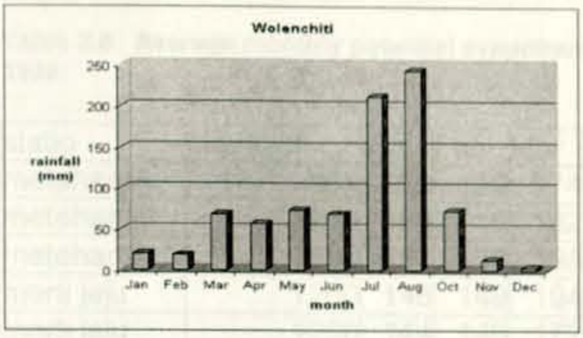
Even though it is true that the rainfall amount and distribution is affected by both geographical position of the areas and their climatologically elements like temperature, humidity, actual vapor pressure, wind speed, sunshine, etc. as well as orographic influences, the rainfall data from different gauging station in the site and its vicinity show that the rainfall has direct relation ship with the altitude of the area, as can be depicted from table 2.6

The Arithmetic mean annual of the existing gauge stations in the site and its surrounding is calculated to be 734.20mm/l (table 2.5).

Moreover the graphs of average monthly mean have been drawn to evaluate the rainfall distribution patterns in the study area. Accordingly the graphs of average monthly mean of different rainfall gauge stations, the graphs indicate the region experiences more or less bimodal rainfall pattern in which the maximum rainfall has been observed in July and August.

Fig. 2.4 Average monthly mean rainfall at Sodera, Nura-Era, Metehara Adama, Wonji,,and wolenchiti stations





2.2.2 Evaporation and Evapotranispirtion

It is the transfer of water in to the atmosphere from free water surface, a bare soil and or interception on a vegetal cover and it is measured using evaporation pan, different types of evaporation pans exists in the world, but the most common ones are Colorado class A. floating pan and Colorado sudden pan. However the evaporation from the pan will different from that of a larger water body, exposed to the some meteorological conditions and this difference can be illuminated by introducing a pan coefficient, that is

$E_{lak} = C{*}E_{pan}$

Where, E_{pan} = Evaporation from pan

E_{lak} = evaporation from water body (or it is equal to evaporation from lake).

This formula is derived by researchers, taking into consideration some standard shape, and size and environmental setting.

However, in the case of the study area, pan evaporation data was not available and as result it was not possible to assess the nature of Evaporation in the area, rather, the data of previous work, which is particularly taken from Awash master plan volume 4, by Halcrow, 1989, was adapted, (table2.6)

Accordingly the average monthly potential evaporation at Metehara area is 1 77.17 mm where as that of Nura-Era area is 167.92 mm.

Table 2.6 Average monthly potential evapotranispiration, source Awash Master plan, Halcrow 1989

statio	elevation	Jan	Feb	Mar	Apr	May	Jun	Jul	Sept	Oct	Nov	Dec
metehara	951	139	139	174	176	203	236	199	188	170	136	134
metehara	1000	153	155	182	191	199	203	187	176	174	153	147
metehara	100	162	157	198	196	212	207	197	182	186	161	155
merti jeju	1250	148	149	194	163	199	211	175	183	179	157	139
merti jeju	1200	144	146	172	180	188	192	176	166	164	144	136
wonji	1540	131	133	158	153	157	148	139	132	142	130	125
wonji	1500	159	149	196	186	181	171	182	140	105	158	156
wonji	1500	131	133	156	164	171	174	160	151	149	131	126

It was observed that the maximum mean monthly PET values of 200mm and 208mm were occurred in months of June at Nura-era and Metehara station respectively. These results are indicating that the evapotranspiirton over the area exhibits an increasing trend from the upstream to the down streamsides of the region, which seems to have direct relationship with the temperature and inverse relation with the altitude of the area.

Evapotranspiration is the conversion of water into vapor, through both process of evaporation and transpiration and transport of vapor in to the atmosphere. In the region, it is one of the hydrological parameters that transfer the rainwater into the atmosphere. As can be confirmed from table 2.6&2.7, the mean monthly evapotranspiration of area is always exceeding the corresponding mean monthly rainfall and hence it can be said that it consumes all amount of the rainfall available. To confirm, the above-mentioned data, an estimation of potential evapotranspiration and evaporation were made using Penman empirical formula.

Penman's method

Penman presented a theory of free water Evaporation E_O based on the application of the Energy balance approach and vapor gradient condition. The energy Balance can be expressed by

$E'_o = 60 E_o$

Where E'_o = heat required in cal/cm^2 day

E_o = Evaporation in mm/day

The vapor gradient condition is expressed by the application of Dalton's law.

$Eo = C\ (e_s - e_a.)\ f(u)$

Where E_o = open water Evaporation

C= an empirical constant

e_s =Saturation vapor pressure at saturation temperature, t_a in millimeter mercury.

e_a = actual vapor pressure in the air in millimeter mercury.

f (u) = wind function, which depends on specific site.

u= wind speed at 2 meters above the ground surface in m/sec.

For specific site the penman's formula can be expressed as:

$E_o = 0.35\ (e_s - e_a)\ (0.5 + 0.54u)$

Based on Penman's formula, E_o can be estimated using a nomogram, making use of;

-Mean air temp in (c^o)

- Mean relative humidity, (the value at Wonji and Metehara can be applied)
- Mean wind speed at 2m above the ground (u)
- Relative duration of brightness, which is the ratio of numbers of hours of sunshine per day and maximum possible number of hours sun shine per day.
- Location on earth (North - 9^o)
- Season of the year.

As the meteorological data of the study area are presented as mean monthly values, evaporation (E_o) is calculated using

$E_o = 0.35(e_s-e_a)\ (0.5+o.54u_2)$ rather than using a nomogram that require a daily data. The calculated Eo values using of average monthly daily meteorological data is presented in table 2.7

Table 2.7 Eo & ETO calculated using the average meteorological data

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Sep	Oct	Nov	Dec	Localities
Rhave for Metehara												
Wonji & Adama	55.03	52.77	54.57	54.4	53.47	53.73	64.5	64.2	57.37	53.67	55.93	
es(Kpa)	3.625	3.17	3.78	3.891	3.98	4.316	3.715	3.79	3.525	3.21	3.184	Metehara
e_a(Kpa)	1.995	1.673	2.06	2.117	2.13	2.319	2.396	2.433	2.022	1.723	1.781	Metehara
e_s-e_a(Kpa)	1.629	1.497	1.72	1.774	1.85	1.997	1.319	1.357	1.503	1.487	1.403	Metehara
Eo (mmHg)/Day	6.929	6.367	7.30	7.33	7.89	8.494	5.61	5.772	6.393	6.325	5.968	Metehara
E_O (mmHG)/Month	214.8	184.66	219.10	219.91	244.47	254.83	173.923	178.932	191.793	196.077	179.032	Metehara
ETO(mmHg/day)	2.518	2.68	2.90	2.82	3.454	3.14	2.604	2.46	3.223	3.325	2.293	Metehara
E_{TO}(mm/month)	78.058	78.3	87.00	84.601	107.074	97.34	78.12	73.8	99.913	99.75	71.083	Metehara
e_s (Kpa)	2.693	3.071	3.26	3.4	3.629	3.834	3.183	3.263	3.137	2.82	2.845	Nura Era
ea(Kpa)	1.482	1.621	1.78	1.85	1.94	2.06	2.053	2.095	1.8	1.513	1.591	Nura Era
e_s-e_a (Kpa)	1.211	1.45	1.48	1.55	1.689	1.774	1.13	1.168	1.337	1.307	1.254	Nura_Era
E_o (mmHg/day)	5.151	6.168	6.30	6.593	7.184	7.546	4.807	4.968	5.687	5.559	5.334	nura-Era
E_o(mmHg/Month	159.7	178.86	188.86	197.79	215.528	233.92	144.196	154.013	170.61	172.342	160.019	Nura era
E_{TO}mm/month	62.59	67.22	73.29	74.76	87.079	94.61	78.69	69	69.44	65.22	63.674	Nura era

Evapotranispirtion (E_{To}) is calculated using Penman-Monteith equation given by

E_{To}=o.408 (R_n-G)+(γ900/T+273) U_2 (e_s-e_a)/Δ+γ (1+o.34U_2)

Where ET_o= reference evapotranspration (mm/day)

R_n= net radiation at the crop surface (MJ/m^2/day)

G= soil heat flux density (MJ/m^2/day)

T= air temperature at 2m height (^{o}c)

U_2= wind speed at 2m height (m/s)

e_s= saturation vapour pressure (Kpa)

e_a = actual vapour pressure (Kpa)

e_s-e_a= saturation vapor pressure deficit (Kpa)

Δ= Slope vapour pressure curve (Kpa/^{o}c)

γ= Psychrometic constant (Kpa/^{o}c)

The FAO Penman-Monteieth equation determines the evapotranspiration from the hypothetical grass reference surface and provides a standard to which evapotranspiration in different periods of the year or in other regions can be compared and to which the evapotranspiration from other crops can be related. Using the above formula and monthly average meteorological data ET_O has been calculated and the results are indicated in table 2.7.

2.2.3 Run off

The evaluation of the flow of the catchment area was made through the assessment of the Awash River discharge data obtained from the data Bank of Ministry of water Resource Development, for Wonji, Nura–Era and Metehara (Period, 1970-2000,1975-1996 and 1982-2001 respectively (table 2.8 and 2.9), where the readings are indicating the runoff values of Awash River, occurring up steam of these respective points, in such away the record at Nura - Era represents, the total value of the up stream of the station between Nura Era and wonji guage stations and that of Metehara station corresponds to the total value of runoff in the catchment area between Metehara and Nura Era guage stations.

Table 2.8 Awash River run-off at Nura-Era guage station (discharge at Nura Era-discharge at Wonji) in m^3/s, calculated from discharge data at Wonji and Nura Era guage stations.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Oct	Nov	Dec
1976	6.464	0.113	5.311	1.413	4.151	5.42	0.054	10.156	11.813	10.34	7.303
1977		5.673	7.98	1.987	9.594	20.3	4.81	20.36	3.367	19.32	29.629
1978		19.03		0.146	8.52	12.2	11.704	24.888	1.04	7.66	8.139
1979		6.722	7.522	9.166	9.203	11.52	25.29	23.276	14.573	0.927	16.146
1980	4.081	1.582	2.025	4.363	4.735	4.27	6.681	5.541	3.443	6.93	9.717
1981	19.312	5.28	4.887	5.153	5.818	6.87	8.187	36.865	15.225	12.01	1.665
1982	20.966	1.863	4.887	10.967	6.404	4.14	7.15	19.337	9.224	5.929	4.185
1983	4.385	0.591		2.433	48.503	6.149	0.995	8.009	7.529	11.9	11.808
1984	1.873	1.484	3.103	4.132	2.704	1.418				7.722	4.875
1985	4.732	3.446	2.797	6.13	3.676	8.07	4.599	14.04	3.326	1.529	1.212
1986			4.749	1.43	2.736	1.2	2.209	6.334	2.904	47.28	0.259
1987	15.754	0.1984	5.1	10.5	13.025	2.673	7.416		4.524	5.22	3.783
1988	7.322	0.298	0.603	4.329	0.766	0.97	25.234	48.604	5.376	0.447	0.7004
1989	3.174	4.606	3.361	9.525	4.949	4.166	10.003	21.529	2.502	5.17	0.274
1990	2.767	18.456	15.38	15.997	0.019	2.19	9.68	34.793	1.034	0.948	9.457
1991	4.964	0.221	6.139	9.651	1.034	0.965	8.376	17.398	4.968	10.39	0.916
1993	0.736	21.174	5.402	3.282	2.178	8.63	8.521		16.919	8.017	5.805
1994	1.741	4.476	4.902	3.182	4.873	2.434	35.033	26.628		7.481	2.266
1995	11.452	5.348	8.551	2.637	8.581	35.9	77.912	86.14	46.726	42.761	46.746
1996	26.108	6.444	4.231	2.637	5.636	34.88	79.735	54.21	48.409	49.946	44.609
Average	1.972	2.809	2.386	3.3553	2.867	1.294	14.823	16.523	5.329	3.441	0.0739

Table 2.9 Awash River Runoff at Metehara guage station (discharge at Metehara-Discharge at Nura Era) in m3/s, calculated from discharge data at Metehara and Nura Era

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	oct	Nov	Dec
1982	16.737	21.176	25.5	20.641	13.912	25.6	29.271	12.62	22.31	11.55	11.902
1983	16.08	14.991	21.67	18.825	33.216	15.9	11.377	8.497	1.377	5.105	3.914
1984	9.044	14.571	15.8	18.038	14.793	12.8	16.192	48.67	18.339	15.52	16.124
1985	18.202	16.604	18.48	16.641	15.609	15.9				12.06	11.16
1986			10.27	12.258	13.089	15.9	16.008	5.5	21.183	15.21	15.091
1987	10.421	13.413	5.501	16.265	32.687	23.5	24.705	20.63	24.238	22.95	24.862
1988	25.871	24.572	25.62	19.292	15.403	13.6	29.661		18.304	17.06	17.355
1989	17.536	17.549	18.68	12.979	18.585	23.4	20.488	28.48	17.622	14.71	13.644
1990	13.376	1.558	18.05	17.318	12.884				14.247	21.02	12.46
1991	13.8	13.275	17.22	17.91	16.699	11.6	16.34	56.2	11.272	9.107	12.303
1992	11.761	6.146	14.01	6.428	12.039	12.5	13.259	10.89	4.122	5.734	3.91
1993	0.559	0.26	8.312	6.521	9.2	5.59	1.786		11.468	3.672	2.857
1994	8.805	7.385	12.71	11.059	3.09	18.8	21.98	53.53		25.11	28.922
1995	28.558	6.458	2.635	10.891	25.405	42.8	59.82	66.14	68.989	64.86	63.175
1996	24.543	11.413	10.37	14.627	22.795	51.1	86.208	64.727	52.407	63.47	47.315
Average	15.378	11.185	14.99	14.646	16.067	20.6	23.548	24.04	20.015	20.48	17.359

The data of these stations were assessed in order to evaluate the runoff of each sub-basin lying between two consecutive stations and accordingly it was observed that the readings at Metehara which is the down stream stations (Nura-Era) is less than the reading at Nura Era. As indicated in table 2.9 the difference between the discharge measured at Metehara and Nura Era guage station in the corresponding months of the year, 1982-1996,indicate a negative values with exception to a very few months. The overall average value of each month is represented by negative value, which indicates absence of runoff flow in the catchment area.

Between Nura Era and Metehara. This situation can be attributed to the rainfall intensity, which is less than evapotranspiration rate in most months. Moreover it indicates that the tributary rivers between Nura Era &Metehara have no insignificant contribution to Awash River discharge. Consequently the area between Nura Era and Metehara does not show runoff component. This can be related to either the rain fall in these months are less than the rate of evapotranispiration or due to the application of large volume of river water to the irrigated lands in the region between Nura-era and Metehara. But the main reason for the absence of runoff in the region can be attributed to the fact that the rainfall in the region is always less than the potential evapotranispiration. So that it can be concluded that there was no run off component leaving the region between Metehara and Nura Era during precipitation. To reach at this conclusion, the monthly discharge measurement of Awash River of each month of the respective year at the upper side of each station of the sub basin are subtracted from the corresponding months at the down stream stations and the result gave negative values for all months except July and September where the data were available with out missing in formations.

The absence of run off in the area also indicates that springs, tributary rivers as well as precipitation in the area have insignificant contribution to the total discharge of Awash River. This fact indicates that the area in general has higher Evapotranspirtion rate than the rainfall intensity.

CHAPTER THREE: - GEOLOGICAL SETTINGS

3.1 REGIONAL GEOLOGY

The geology of the study area and its surrounding is compiled from geological map of Ethiopia (scale 1:2500,000) by Kazmin, 1975) Geological map of Nazareth (scale, 1:2500,000 by EIGS, 1978, report on the structure and volcanic Geology of an axial portion of the Main Ethiopian rift, by Jan1. GIBSON 1. : Department of Geology Haileselassie University (A.A), 1978. Accordingly only one major rock types, namely Cenozoic sequence were identified.

3.1.1 Cenozoic sequence

The Cenozoic sequence includes a range of igneous rocks and sediments of different origin as out lined below.

3.1.1.1 Ashangi Group

This group is part of the Trap series as defined by Mohr (1970) and has been sub-divided in to five units in ascending order: - Alaji, Tarmaber, Arba Guracha, Anchar and Arba-Gugu.

1. **Alaji Basalt** (Age between 28 and 15 myr (Kuntze etal. 1975).

A succession of up to 800 m of predominantly aphyric flood Basalt rests un- conformably on the eroded surface of the Mesozoic sediments represented by limestones of the upper Jurassic Gabredare formation and sandstone of the cretaceous Amba Aradam formations. The topmost members of the succession are essentially of porphyritic varieties and near Asbe Teferi northeast of the Nazareth map area have been dated as 14 myr old, (Kuntze etal. 1975). They belong apparently to the Jebel sadale central - type complex that structurally and in age correlates with the Temaber basalt on the opposite side of the rift (Zanettin and Justin OP.Cit). The main difference between the Alaji basalt on the southeastern plateau and those of the Ethiopian plateau is the scarcity of silicics in the former. This unit was not identified in the study area but it is occurring at the eastern margin of the study area belonging to the catchments of the upper Awash valley.

2. Anchar Basalts and Arba Guracha silicics

Along the eastern margin of the rift Alaji Basalts are conformably over lapped by a unit of flood basalts siliciceous rocks which is in turn over lapped with slightly unconformity by silicics of the Nazareth group. In the Anchar area the unit is represented by about 400 m of basalts with general intercalation of ignimbrites, the one at the base being 12.4 myr old. To the south & northeast the basalts are laterally replaced by welded and unwelded ash -flows and in the Guracha valley and in the vicinity of Asebe Teferi (NE of the mapped area) the section is essentially silicics.

The Anchar Basalts form the lower part of the rift volcanic succession (not confused with the pre rift " traps " or plateau basalts.

3. Arba Gugu basalt

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

4. Chilalo and badda Trachytes

According to data from Justinvisentin etal. 1975, kuntz etal. 1975, two elliptical shield volcanoes on the eastern rift shoulder they belong to numerous groups of trachyte volcanoes developed in the upper Pliocene on both sides of the rift. Chilalo volcano frist erupted, followed by Trachytes while Badda evolved from basalts and trachy basalt 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 coincided 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.

3.1.1.2 Post- Ashangi Group volcanic

This sequence includes Nazareth and Wonji Group that composed of a range of igneous rocks of different ages occurrence as out lined below.

1. Nazareth Group

The group 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 out crop in the rift escarpments and on the adjacent plateau margins. The different lithologic types of this group have an age between 9.5 to 3 myr old.

In the rift the Nazareth Group attains thickness of up to 250m, possibly more, while on the rift shoulders only a few meters of ignimbrites are generally observed. There is no doubt that the bulk of eruptions were restricted to the sagging rift. The silicic centres such as Gara Gumbi (Gara Gumbe rhyolites) were active in the period between 7 and 5.5 myr (Christiansen etal. 1975) so that central type explosive eruptions played significant part in the formation of the Nazareth volcanic Silicic centers were especially abundant during the latest stage of the Nazareth volcanism, as is evident from the wide distribution of rhyolitic domes cutting through older ignimbrite sheet (older Alkaline per alkaline Rhyolites Domes).

The lower most Ignimbrite flows of the Nazret Group intercalated with the chorora sediments are 9.5 myr old (Kuntz etal. 1975). An upper limit of the Group is older than 2.5 myr possibly 3 to 3.5 myr (the age of the over lying Bofa Basalts) Numerous K- Ar determinations of the Nazareth silicics (Morbidelli etal .1975 mohr 1974) fall between 7 to 6 and 1.5 myr with a maximum in 5.5 and 3.5 myr. The Dino ignimbrites, unconformable on the Nazareth silicics. The time of formation of the Nazareth group is there fore between 9.5 and 3 to 4 myr, which are close to the age established by Zanetin and Justin-Visentin (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 Nazareth volcanism and Chilalo Badda volcanoes were formed, during late stages.

2. Bofa Basalt (3.5-2.5 mys)

In the rift the silicices of the Nazareth Group are over lapped by a unit of fissure flood basalts, which was named after its type locality at Bofa village similar basalts were previously named wolenchite Basalts (Meyer etal. 1975), Bishoftu Basalts (Zanettin and Justin-Visetin 1974). However, none of these units have precise stratigraphic boundaries, and they most probably include younger (Pleistocene) basaltic flows separated from Bofa Basalts (Pleistocene) basaltic flows separated from Bofa Basalts by an important stage of tectonics. The Bofa basalts are not restricted to the central part of the rift floor. They represent an episode of fissure eruption, which immediately followed a major faulting episode.

3. Wonji Group

Mayer, et al 1975, suggested the name the Wonji series for the volcanic related to the belt.

As pointed out by many authors (Mohr, 1967, and others, Meyer et al 1975, Gibson 1970, Dakin & 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 out side the belt the bulk of the Pleistocene to recent volcanism is undoubted controlled by this tectonic feature.

The Wonji Group includes all the rift volcanic formed after the last major episode of rift faulting which followed accumulation of the bofa Basalts The oldest volcanic of the Wonji Group, the Dino Ignimbrites overlapped strongly faulted Bofa Basalt, but are not themselves affected by this faulting.

The Wonji Group comprises the following units

A. Dino ignimbrites

B. Pantelleritic volcanic centers

C. Recent and recent fissure basalts

The group also includes some minor unit such as hyloclastites explosion centers and rhyolite domes.

A. The Dino Ignimbrites: - cover a considerable proportion of the rift floor and other a number of flows of compact fiamme ignimbrites in place intercalated with basalts and unwelded pyroclasts.

In the Awash Gorge this ignimbrite rests on the Bofa Basalts with a paleosole horizon at the base, and is dated as 1.5 mys. According to Dak in (in press) the ignimbrite may have originated from the old almost eroded volcanic center of Tinish (small) Fantale, north of Fantale volcano.

B. The Pantelleritic volcanic centers:- are aligned en- echelon along segments of Wonji Fault Belt. The main products of eruption consist of per alkaline Rhyolite and Trachytes with some pumice, pitchstone and obsidian occurring mostly at late post - caldera stages. The sequences of eruption differ from center to center .A feature of the acidic volcanic centers is the formation of large calderas in some cases the whole volcano has collapsed leaving behind a circular area of subsidence (Gedemsa caldera and Kone caldera. Fantale volcano is surrounded by a roughly circular area of subsidence measuring 50 by 16 km not clear on the surface) such extensive volcano tectonic collapse definitely indicates a relatively shallow magma chamber and indirectly supports the postal origin of the per alkaline silicics.

C. Pleistocene to sub - Recent fissure Basalt: - 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 basalt contemporaneous with early stages of development of the Pantelleritic volcanoes was a fissure while the youngest eruptions were of central type.

3.1.1.3 Lacustrine Deposits

Adjacent to and beneath many of the existing Lakes in the valley floor are lacustrine clays and silts overlying sand and gravels. In the south, extensive areas of these variable thickness deposits (up to 200 m near Dhera) occur between Lake Ziway south of the Basin, and Lake Koka, and in the vicinity of Dhera, Nazareth and the Wonji - Shoa Sugar Estate. Lacustrine deposits border and seal Lake Beseka and are extensive to the West of Lake Gedebassa and Dalay. Gypcretes and halites form part of the lacustrine deposits in the area of Lake Gamari and Lake Abe, (Hal crow, 1989). Many present- Day marsh areas are associated with lacustrine deposits amongst which are Becho and Borkena at high level elevations, and the Mulushet Marshet that occur low on the pediment slopes. The large wetland area to the west of Gewane is a good example adjacent to the Awash River (Halcrow, 1989).

Table 3.1 Stratigraphy of the regional geology

Epoch	Age	Group	App. thickness	Rock types
Cenozoic	Recent	Riverine Alluvium	Ni	Gravels, sands, silts
	Recent	Afar Plains Deposits	Ni	Gypsiferous limestone
	Recent to Pleistocene	Lacustrine deposits	Up to 200m	Clays, silts, sands and gravel
	Recent to Pleistocene	Wonji	Ni	Rhyolites, Ignimbrites and basalts
	Recent to Pleistocene	Magdala (Afar)	(75m)	Ignimbrites, rhyolites, agglomerates and basalts
	Upper Miocene to upper Pliocene	Pediments and Riverine Alluvium	Not well indicated (100m)	Gravels, sands, silts and clays
	Recent to Miocene	Ashangi	200-1200m	Alkaline basalt

Note: Ni = not identified

3.2 Tectonics

During up lift of the Ethiopian plateau along sequence of rigid tectonic movements took place. These movements produced numerous step faults that originated the actual Ethiopian Rift Valley. These faults usually run parallels to each other for many hundreds of Km in direction NNE - SSW, NE – SW or N-S.

The formation of the RiftValley is also responsible in the origin of depressions now occupied by tectonic lakes which, going from N to S are known as lake Ziway, Abijata Langano, Awash and furthers, Margherita and Chamo. Several faults, which affect the floor of the Rift valley, transformed the geological formations in to many "horst " and "graben". The faults displace even the most recent formations, evidence that the tectonic sinking of the rift valley is still active.

3.3 Geology of the study area

The geology of the study area is covered with various rock types of volcanic rocks with different mode off occurrence and ages, and lacustrine and alluvial sediments which are mainly identified at the relatively flat lying terrain between wolinchiti and Nazareth towns, and at the flat lying plain of Metehara area. The different volcanic rock types of the area ate dominantly belonging to Nazareth and wonji group. According to their relative age and composition the different litho logical units are presented below starting from the oldest to the youngest in the stratigraphic sequences.

Nazareth group: The group composed of a thick succession of welded ignimbrites with fiamme pumice ash and rhyolite flows and domes with rare intercalations of basalt flows. In the rift proper the group attains a thickness of up to 200-250m and tends to thin out on the escarpment of the rift. The main constituents of the group are: -

1. Ignimbrite

Ignimbrite is the common rock types existing at the southern and northwestern part of the area like the area dhera-sodera north and northeastern side of walinchite. It occurs as several sheets of variable thickness in which some sheets are only 0.5 to 1m thick while the other exceeds 20m, in some places the ignimbrites are separated by paloesole while at other out crops it interbedded with thin layers of graded lacustrrine deposits made up of cemented sand and tuff. Generally, the ignimbrites appear welded in the lowest part with typical glassy striations or fiamme while the upper parts of the rock is much softer and more friable, commonly not well welded and contains high pumice content. The rocks are coarse grained and commonly contains small inclusion of hydrothermal altered foreign rocks. The ignimbrite is fractured with columnar joints and its upper part is a weathered surface of a few meters thick of a very fine-cemented material.

The ignimbrite is permeable but since it is mostly composed of glassy and its upper weathered and hydrothermal inclusion makes it impervious. According to DiPoala (1972) petrographically these rocks are made up of phenocrysts and inclusion of basaltic fragments in the groundmasses of very fine vitric dust. The phenocsysts include alkali feldspar of the type anorthoclase, plagioclase as small crystal is occasionally observed in few sections where the basaltic inclusions are abundant. The ingredients of the area have many features in common however small differences exist mainly with respect to texture due to a different way of deposition and welding after eruption.

2. Pumice

Pumice is another volcanic product of Nazerat group in the area. It occurs as a several wide spread beds without welding. This unit due to its susceptibility to weathering and none interconnected porosity nature, it can constitute an impervious layer. This units is occurred in many places either on top of ignimbrite or as inter bedded layer and it is identify in many places between walinchiti and metehara as well as between Bofa and Nura- era.

3. Tuffs

This is a volcano sedimentary product, which found in many places composed of thin layers of volcanic sands of fine ash interbedded with silt or clay. This unit is identified interbedded with ignimbrite. Both pumice and tuff units of Nazareth group are identified in the areas around Sodere, Doni and Tibila occurring at the plat laying terrain along the Awash valley (basin).

4. Older Rhyolites and Domes

There are several occurrences of silicic lavas on the floor of the area, mostly forming rhyolitic domes. According to Christiansen etal.1975, petrographically these rocks are soda alkali rhyolites. This unit is found at Bofa ridge, around Sodera area, around both eastern side of Walinchite. This unit consists of light covered rhyolitic lava associated with intercalation of obsidian flows. The unit shows porphyritic texture with alkali feldspar phenocryst.

The rhyolitic domes are commonly fed by big dykes which because of the fracturing can represent an easy descending way for surface water and for thus reason, those areas in which acidic lave domes are abundant are said to be relatively more permeable.

5. Bofa Basalt

The name Bofa Basalts was coined by the E.I.G.S (Kazmin etal. 1980) to all the Pliocene rift floor basalts. The Bofa basalts are well developed in the northern and central part of the main Ethiopia rift forming a wedge between Nazareth group and Dino formation. Bofa basalts are flood Basalts mostly aphyric; locally vesicular and fresh with several flows separated by scoriacious horizons. The Quaternary pyroclastic volcanic products and continental sediments conceal this unit. This unit is identified at the area of Bofa village, south of Abadir farm and west of Beseka Lake at a considerably large distance. Bofa basalts show well developed columnar joints with the opening size vary between 2 and 3 cm and joint spacing of about 1m, the rock is vertically faulted and jointed.

6. Wonji group

The group composed of Dino ignimbrit, pantelleritic volcanic centers and sub recent and recent fissure basalts. This unit includes all rift volcanics formed after the last major episode of rift faulting which follow accumulation of the Bofa basalts.

a. Dino Ignimbrites

The Ignimbrite consists of a number of flows compact fiamme ignimbrites in place intercalated with basalts and unwelded pyroclastics. This unit covers a large area between Tibila and metehara farm area and it is frequently inter bedded with paleosoil and overlies the strongly faulted Bofa basalt. This unit is not affected by faulting. They are jointed rocks.

b. Pleistocene-sub recent and recent fissure basalts

They are mainly concentrated along the wonji fault belt, and in the study area, they cover a considerable large area laying between walinchiti and metehara that extends to Awash River valley in the south. The basalts differ in degree of preservation of original flow surfaces the youngest flows of the historical period are fresh "aa" lava basalts. The basalts occur as a series of several sub-horizontal lava flows rarely exceeds 20m over larger area (surfaces). The thickness of every flow rarely exceeds zone and between the layers, levels of scoriaceous layer (lava) of some cm thick are always present, which is the first distinction between them and the trap series basalt. The basalt is always very fresh and their surfaces area abundantly scoriaceous. The young basalts generally show a consistent in their mineralogical composition. The differences observed are mainly textural, which can be aphanic or ophitic. The rocks are always completely crystalline.
The permeability of the basalts is usually high due to numerous crakes and columnar joints.

The Pleistocene to sub recent porphyries basalts with columnar joints are covering a considerable large surface of the eastern side of Awash River and the area south of Abadir farm. Whereas the recent aphyric basalts are occurring in the western side of Awash River locally appearing in extensive sub recent porphyritic basalts.
The recent aphyric basalts are products of fissure eruption and they are highly vesicular with inter connected open spaces that acts as conduit for the movement of subsurface water.

Basaltic hyaloclastites (Qwh) are volcanic eruptions deposited under water. They are medium grained and loosely connected basaltic rocks having small aerial coverage.
Pleistocene to sub recent basalts (Qwb1) are vertically and horizontally jointed.

c. Trachytes

The trachytes occur locally but are not widespread in the area. Petrographically they are alkali trachytes, characterized by numerous large alkali feldspar crystals of the type anorthoclase fayelite often as big phonocrysts clino-pyroxen, clino-amphibol the rocks are strongly fractured and they belong to fantale volcanic of trachytic flows and domes.

d. Young Ignimbrites

They are mainly covering the northern, northeastern part of Metehara that represent one of the youngest volcanic rocks in the area. The rock of this unit is dark grey with highly scoriaceous textures. The exposure of this unit is associated to Wonji fault belts, belonging to the youngest Fantale volcanic. The rock is grayish green, fresh, columnarly jointed with blisters and crevasses, in the area west and south of fantale but as one goes east of Fantale, the rock is highly weathered and the joints are filled with clay materials.

e. Obsidians

They form thick viscous lava flow associated with pumice. Some times they are completely non-porphyritic, but generally the prophyritic ones are more abundant. These rock are always strongly fractured, therefore their permeability is very high. The exposure of these rocks are identified locally at northern side of Beseka Lake (at far distance)

f. Young bedded explosive tuffs

These are finely to coarsely laminated pyroclastic materials with pumiceous and tuff beds. This is a volcano-sedimentary product and found in many places consisting of thin layers of volcanic sands or fine ashes interbedded with silt of clay. Another volcano sedimentary products is represented by recent alluvium which is generally homogeneous and made up of fine sands and clay. Some times it is very thick and covers large areas.

g. Unconsolidated sediments

The unconsolidated sediments consist of alluvium and lacustrine sands and clays.

h. Alluvium

It covers Abadir and Metehara and along the Awash River, Metehara and Abadir sugar plantation areas are covered by alluvium with a thickness of up to 43 meters. The alluvium grades from sandy clay to sand and gravel beds down wards. The alluvial sediments are Holocene in age and their thickness reach about 40m in Metehara and Abadir area.

i. Lacustrine sediments

The Lacustrine sediments occupy the area between Nazareth and Wolinchiti, and between Wonji and Awash Melkasa. These Lacustrine sediments are consisting of Clay, silt, tuffs travertine, diatomite with intercalation of pumice are widely distributed. They are Pleistocene to Holocene in age and they are deposited from extensive lakes during the Pleistocene pluvial. In Nazareth, walinchiti and wonji, the thickness of the lacustrine sediments varies between 30 and 40m.

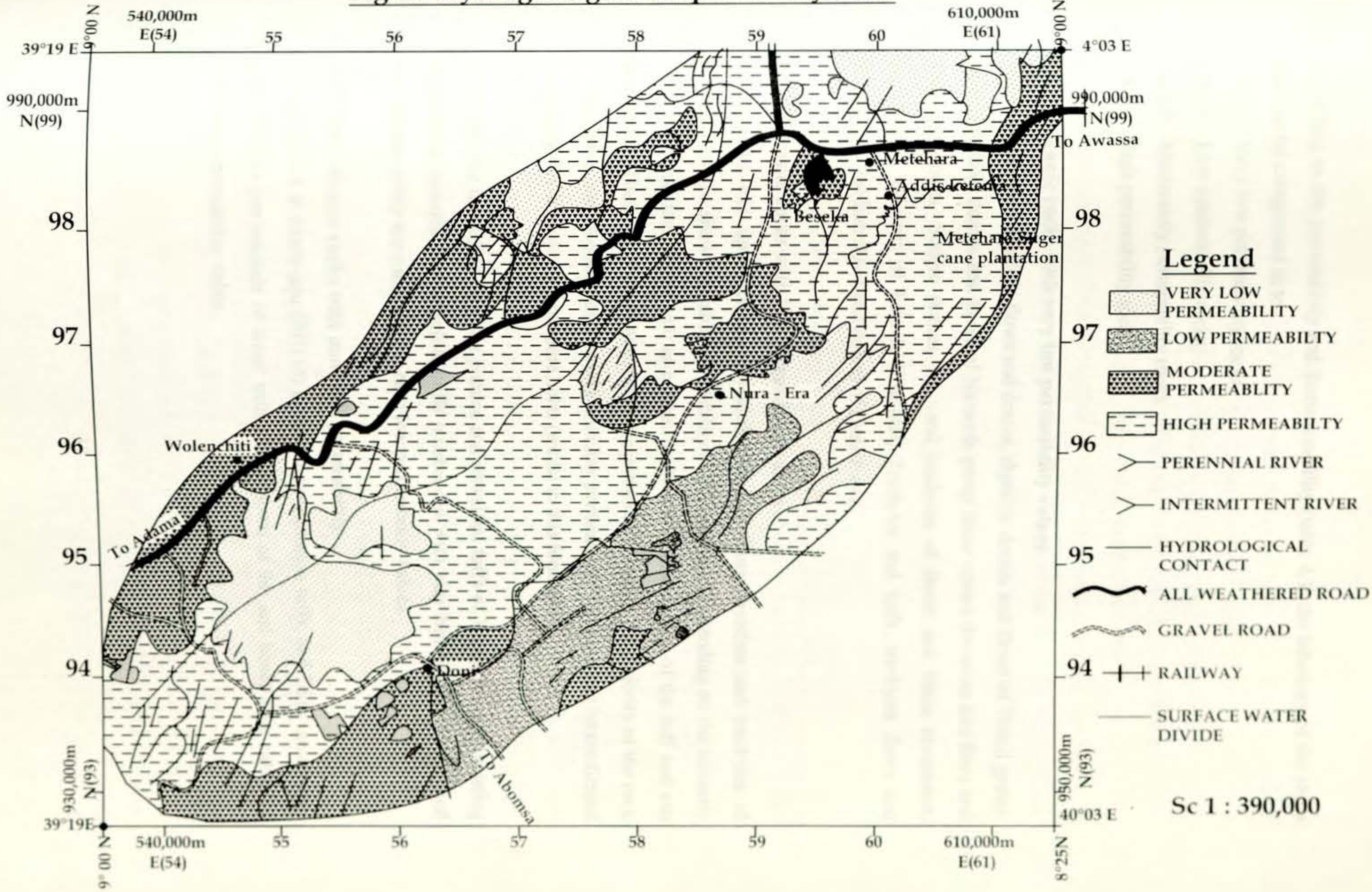
CHAPTER FOUR: - HYDROGEOLOGY

4.1 Hydrogeological characteristic of lithological units

Ground water is a water in permeable geological formations known as aquifers, which may be subdivided into porous, fractured and karastic aquifers, in which porous aquifers are made up of sands and Gravels size particles where the groundwater flow takes place in pores between the grains with a flow velocities range from fractions of 1m/d to a few m/d. in fractured rocks. The groundwater movement is restricted to fractures, fissures and cracks by mechanical stresses in any hard rock and the groundwater flow velocities range from less than 1m/day to tens or hundreds of m/day but the velocity is generally decreasing with depth. Therefore, ground water storage of the geological formation depends on pore spaces occurring in the rocks. Topographic features, precipitation, runoff distribution and irrigation, hydraulic properties of lithologic units and boundaries of aquifers are among the other factors that control the amount of groundwater in the reservoirs.

The description of the different lithologic types have been presented in chapter 3 and the aquifer classes to these units are made by taking into account the Transmissibility and permeability, values estimated using Meyers chart (table) or pumping tests result on the some of the wells and field observations related to primary features like grain size distribution and cementing materials for unconsolidated sediments and secondary fractures like faults and joints for volcanic rocks of the study area.

Fig 4.1 Hydrogeological Map of Study Area



According to the permeability and Transmissibility (table 4.1) the lithology of the study area can be categorized in to

4.1.1 Very low permeability rocks
4.1.2 Low permeability rocks
4.1.3 Moderately permeability rocks
4.1.4 High permeability rocks.

4.1.1 Volcanic rocks with very low permeability values

These rocks include acidic flows and domes, rhyolitic domes and flows of Wonji group. Older rhyolitic domes and flows of Nazareth group those covers the areas like Beru and Teru mountains, Sodere domes, etc., and trachytes of Boset and Hada mountains, pantelleritic volcanic of Fantale Rhyolites, Trachytes and tuffs, trachytes flows and domes and obsidian flows and domes of Fantale area.

4.1.2 Volcanic rocks with low permeability values

Those rocks like ignimnbrites, unwelded tuffs, ash flows rhyolites and trachytes of Nazareth groups shows variable permeability in different areas depending on the intensity of jointing and faulting as well as on their particle size distribution of the tuff and ash flows beds. Therefore, except where they are jointed and faulted, the majority of the rock of this group can be classified as a rock with low permeability values as can be confirmed from the specific yield of some bore holes (wells) in this formation.

Secondly, the unwelded rhyolitic pumice and unwelded tuffs of Wonji group consisting of rhyolitic pumice and unwelded tuffs interbedded with clay bed which can reduced their permeability are considered to have low permeability values.

4.1.3 The volcanic rocks with moderate permeability

A well drilled at Merti-jeju (BH116) in the young explosion tuffs, and Dino ignimbrites gives 4 liters per seconds of water with a draw down of 9m and hence they exhibit a moderate permeability value.

4.1.4 The volcanic rocks with high permeability

Recent aphyric Basalts of wonji group, which is the products of fissure eruption, are highly vesicular with interconnected open spaces, can store and transmit appreciable quantity of groundwater, so that they are considered to have high permeability.

Young ignimbrites of Fantale volcanic, which is fresh and jointed as seen in the west and south of Fantale, where the pumping test were done in some wells such as BH10, at Metehara town, shows a yield of 12 liter /second with a maximum draw down of about 1.38m for 72 hours of pumping. Basaltic hyaloclastes, which is medium grained and loosely cemented rock of volcanic eruptions deposited under water, are supposed to have high water storing and transmitting property. They are considered to exhibit high permeability value. Due to their very small area exposures, they are not mapped on the map.

4.1.5 Pleistocene to sub recent basalts

The pumping tests in some of the bore wells in these unit in the study area show a yield that varies between 1.4 l/sec and 5 l/sec with no draw down to a draw down of 0.70m in the wells at thc locality of Abura.

Bofa basalts with well developed jointing having an opening size of 2 to 3 cm and jointing spacing of about 1m. The depth to groundwater in this unit is more than 100 meters at Bofa area, as a result of vertical joints extending to a deep depth in which most of precipitation infiltrates without meeting an impermeable bed in between. In general, taking into account the open nature of the joints, the Bofa basalt is supposed to have high permeability.

Regarding the permeability of unconsolidated sediments of alluvial and lacustrine origin, it is independently treated as follow. Alluvial sediments cover Metehara and Abadir sugar plantation areas with a thickness of about 43 meters. The alluvium grades from sandy clay to sand and gravel beds progressively down ward. The boreholes in this area have a specific capacity lying in the range of 0.9 to 6.5 l/sec /m. the sand and gravel beds have high water storing and transmitting capacity. Hence the alluvial deposit is grouped as a high permeable formation. But at the places where thickness of alluvium is not thick, groundwater of modest quantity can be obtained from hand-dug wells. In this case the alluvium is considered to have moderate permeability. The Lacustrine sediments occupy between Nazareth and Wolenchiti, and Wonji and Awash Melkasa area. They show different permeability in different localities. The specific capacity of this units varies from 0.65 l/sec / m to 24.6 l/ sec / m, depending on the variation of particle size distribution of the beds in the stratigraphic sequence from place to places. Hence it can be said that the unit exhibits the permeability values in the range of moderate to high and even it may have a low permeability value where its beds are composed of clay size particles as in the case of the bore hole at east of Dhera town where the groundwater is not encountered up to a depth of 200 m.

Table 4.1 Boreholes with high to very low permeability

Locally	BHNO	Depth of saturation penetrate (m)	Water table	Specific capacity l/se/m	Specific capacity gal/m in/ft X4.83	Estimated T.in gal/day/ft	Estimated T m/day/ft	Estimated T.in m/day	Aquifer
Metehara	12	30.9	WT	2	9.65	High	High	High	Alluvium
>>	14	32.05	>>	3.1	14.90	2,000	52	1.62	>>
>>	136	21.40	>>	0.6	2.90	4,000	104	4.36	Vesicular basalt
>>	137	25.10	>>	1.1	5.31	7,500	195	7.77	
>>	138	20.90	>>	0.9	4.35	6,000	156	7.46	Alluvium
>>	139	60.00	>>	4.0	19.32	35,000	910	15.17	>>
>>	140	19.34	>>	1.6	7.73	10,000	260	13.44	>>
>>	142	0.20	>>	1.2	5.80	6,500	221	24.02	>>
>>	143	29.0	>>	1.37	6.62	9,500	247	8.51	>>
>>	144	21.9	>>	6.5	31.39	50,000	1,300	59.36	>>
Awash Melkasa	154	15.5	>>	1.43	6.91	12,000	312	20.13	Pleistocene sub recent basal
Metehara	9	3.6	Piestic	12	57.96	High	High	High	Dino Ignimbrit
>>	10	38	>>	8.7	42.02	100,000	2600	68.42	
>>	11	18	>>	12	57.96	High	High	High	Dino Ignimbrite
>>	12	30.8	>>	2	High	>>	>>	>>	Fine grained ba
>>	14	32.05	>>	3.1	14.97	35,000	910	28.39	Fine grai ignimbrite
>>	28	127.4	W.T	0.22	1.06	1,500	39	0.31	
>>	30	9	>>	0.22	1.05	1,500	39	0.31	Laccustrine
>>	31	13.7	>>	0.83	4.01	6,500	169	12.33	>>
>>	3	9.14	>>	1.0	4.83	1500	195	21.8	>>
>>	5	68.60	>>	0.03	0.14	250	65	0.09	Nazareth Group
									>>

Source: Adapted from hydrogeology of Nazareth area, by Getahun Kebede 1987.

4.2 Ground water movement

Ground water in the area is topographically and fault controlled that is grounwater moves to ward Awash River. Most of faults act as conduits

For ground water movement while some act as barrier, the later case happened when ever the fault fractures are sealed by secondary materials such as clay produced as a result of high degree of chemical weathering and precipitation of hydrothermal minerals like calcite, silica Opal, etc.

4.3 Ground water recharge

Part of the high rainfall on the west and eastern high lands are considered to contributes varying recharge to the groundwater depending on the soil, rock, topographic and structural conditions in the area, while a considerable proportion of the rain is supposed to go as quick runoff to the lowlands. On its way down the escarpment, some of the portion of quick runoff is considered to recharge the groundwater where the flows cross fault zones.In the lowlands direct recharge to the groundwater is expected to occur from direct precipitation, though much of rainfall is supposed to lose as evapotranspiration.

4.4 Exploitable water resources

The groundwater in the aquifers covered with recent aphyric basalts, young ignimbrite, basalts, Bofa basalts, Alluvium and most lacustrine sediments are considered to be exploitable in terms of quantity, however, the ground water south and west of Fantale mountain at Metehara area are generally characterized by high concentration of sodium and fluorides as well as high value of TDS and EC seems to make it unexploitable for both agricultural and domestic uses because of poor quality of water.

In general, most of the groundwater of the region, where the aquifers are covered by acidic volcanic rocks and other rocks associated with fumaroles and hot thermal springs are supposed to have high concentration of Na^+ ions and fluorides, which makes their exploitability for normal agricultural and domestic uses unattractive with respect to quality.

Where as the groundwater derived from those permeable basaltic formations with faults and joints are considered to be exploitable both in terms of quality and quantity provided that they are not associated with geothermal springs and fumaroles which are supposed to cause an increase in the fluorides contents to the extent that can make the water unpotable. According to Halcrow, 1989, in the uplands area the occurrence of shallow groundwater in the area is attributed to flat topographical gradient and water accumulation on the low permeability ignimbrites of Magdala group and any major groundwater development in such shallow ground water areas would not be possible unless significant alluvium is present, which does not appear to be the case.

Deep groundwater occurrence is expected, their use for potable purpose considered being limited due to their higher concentration of TDS, EC and fluoride as a result of the effect of rock and water interaction. The shallowest depths to groundwater near Addis ketema (10-25 m) below the ground surface where irrigation water expected to affect the heads (Hal crow, 1989).

As with the uplands, the ground water in the Awash valley bottom is very limited. In general, the main problem of the ground water in the region is dominantly related to fluoride concentration that mostly exists beyond the standard settled for drinking. The main cause of high content of fluoride in the groundwater of the area is supposed to be associated to the presence of wide spread of rock like rhyolite, Obsidian etc., and the frequent presence of Fumaroles and geothermal springs in the volcanic rock of the region. Beside the presence of Fluorides, the TDS and EC of the majority of the deep groundwater in the region seems beyond the allowable limits recommended for drinking eater with reference to TDS and EC valves. There fore, the exploitation of the deep ground water for the potable water is generally unattractive owing to its poor quality. In most of the ground water of the area, the dominant cation component of the ground water is observed to be sodium ions.

CHAPTER FIVE: GEOCHEMISTRY

5.1 General

The physical property of natural water includes pH, Eh, EC, hardness temperature, etc. Whereas chemical properties of water consist of dissolved ions mainly comprising of major ions, minor ions and trace elements, organic substances, dissolved gases, etc. The major sources of dissolved ions are soils and rocks with minor amounts come from atmosphere. While the major source of many dissolved gases is either from atmosphere, soil zone, deep sedimentary basin (petroleum fields) or magmatic fields. Water (H_2O) has a dipole characteristic, which makes it to be universal solvent. Being the water is universal solvent it can react with many chemical compounds and physical environments so that it is difficult to get pure water in H_2O form.

5.1.1 Hardness

Hardness might be considered as the soap consuming property of water. Where the minerals that are removed by soap remains as an in soluble scum. Most of the effects observed with soap results from the presence of calcium and magnesium, thus hardness is generally defined in terms of these constituents alone. Other ions, which might precipitate soap, include H+ and polyvalent metals, but they are in significant.

Hardness is usually expressed in terms of $caco_3$ and it may divide into two types: carbonate and non-carbonate hardness. Carbonate with Hco_3^- and small amount of CO_3^{2-} present and it called temporary hardness as it can be removed by boiling. Which precipitates Ca and Mg carbonates and sulfate minerals. Non-carbonate is the difference between total hardness and carbonate hardness and it represents those amounts of Ca and Mg that combine normally with sulphate, Cl^- and NO^{3-} ions. Durfere and Becker (1964) define range of hardness concentration in mg/l and proposed the following classification.

Table 5.1. Classification of water on the basis of Hardness

Hardness, $CaCO_3$	Description
0-60	Soft
61-120	Moderately hard
121-180	Hard
>180	Very hard

Source: - principles of hydrogeology by Tenalem and Tamiru, Jun.2001.

Analytical hardness (H) is given by the formula:

H= 2.5 ca + 4.1mg where ca and mg are given in mg/l.

5.1.2 Hydrogen activity (pH)

The effective concentration of H^+ ions can be most confidently expressed in logarithm units and abbreviation 'pH' representing the negative base 10 log of the hydrogen activity in moles per liter, or pH =- log H^+

Water is said to be either acidic or alkaline (basic) depending on the effective concentration of H^+ ions. Hydrogen ions in water cause it act as an acid. The capability of water to neutralize acid or reduces the number of H^+ ion in the solution is called alkalinity. The acidity and alkalinity characteristics of water are basic to the understanding of the water chemistry. The pH of the water can be determined in situ with a pH meter. At 25^0C pH < 7 indicate an acid solution whereas a pH >7 indicates alkaline solution while PH of 7 is said to be neutral.

The alkalinity of natural waters depends on the total concentration of CO_3^{2-}, HCO_3^- alkaline and alkaline earth hydrates in the water where as acidity depends on the occurrence is several acidic compounds which may be dissolved and more less dissociated in water as HCO_3, H_2SO_4, HNO_3, HCl etc., alkalinity measurements are commonly performed by means of titration of the water indicators.

5.1.3 Electrical conductance (EC)

It is the ability of substance to conduct electric current. Specific electric conductance is the conductivity of a body of unit length and a unit cross-section at a specified temperature. It is the reciprocal of the resistance in ohms measured between opposite faces of a centimeter cube of aqueous solutions at a specified temperature according to this definition the unit of reporting conductivity shall be µs/cm at some temperature in °C. As ion concentration increase conductance of the solution increased and as a result it provides the indication of ion concentration. Specific electrical conductance increases as the temperature increases.

There is a strong correlation between total dissolved and EC and the concentration of dissolved salts can be estimated on the basis of EC measurements using the following formula. S=AK where K is conductance in µΩ, S is total dissolved solids in mg/l and A is conversion factor for the analysis of natural water, A ranges from 0.54 to 0.96. For most ground water A is varying between 0.55 and 0.75, which gives reasonable estimates of the dissolved solids. Where A for estimating TDS of saline water us usually higher than 0.75 and for acid water it may be much lower.

5.1.4 Total Dissolved solids (TDS)

Total dissolved solids include all solid materials in solution, whether they are ionized or not. As it is related to the sum of the concentration of all concentrations, it is directly related to EC. TDS of natural water range from less than 10mg/l to more than 300,000mg/l for some brine. Thus the total concentration of dissolved solids can be used for simple classification of water.

Table 5.2 Classification of water on the basis of TDS.

Water type	TDS (in ppm)
Fresh	0-1000
Brackish water	1000-10,000
Salty water	10,000-100,000
Brines	>100,000

Source: - principles of hydrogeology by Tenalem and Tamiru, Jun.2001.

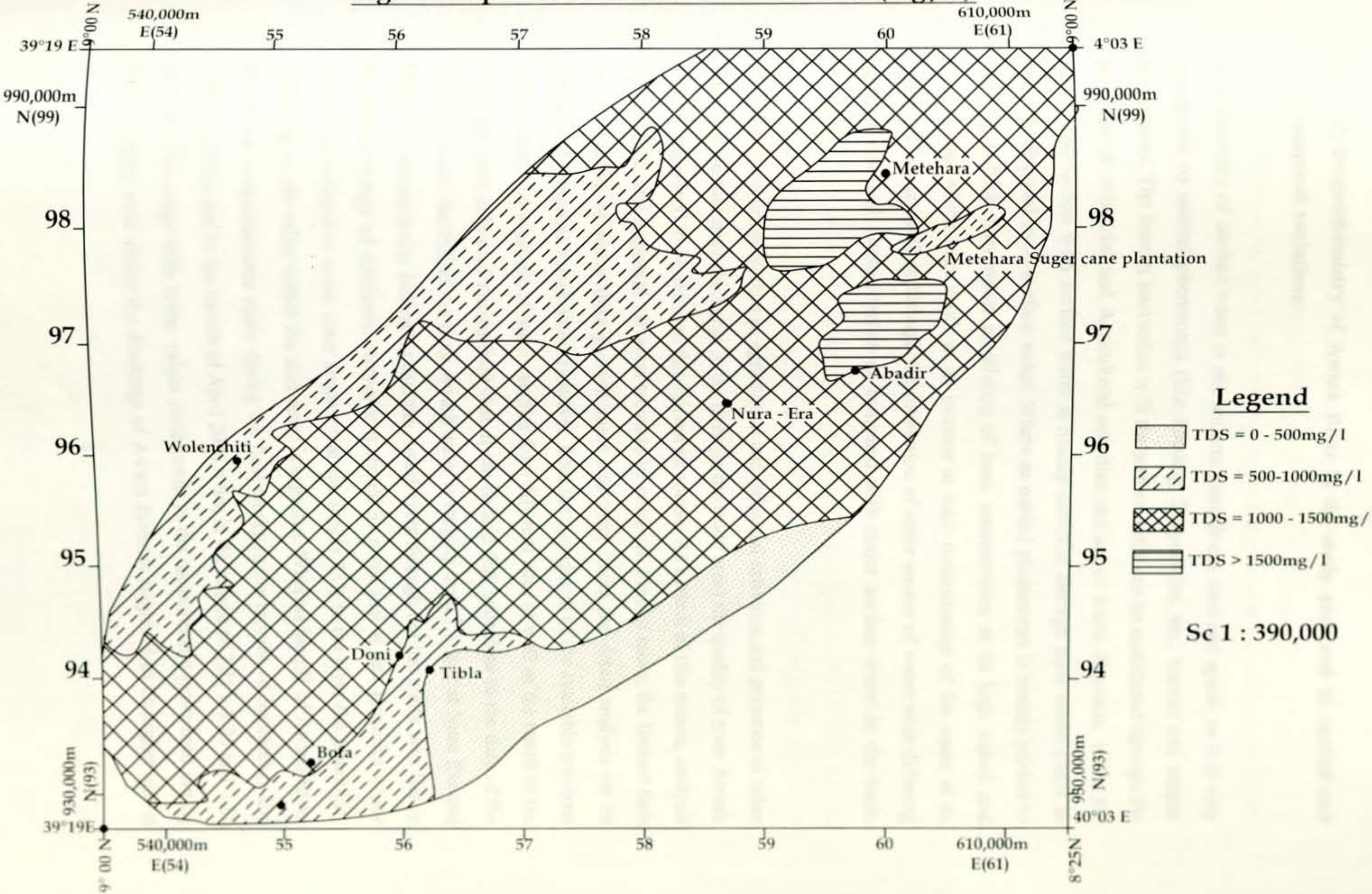
5.1.5 Major ion constituent

More than 90% of the dissolved solids in ground water can be attributed to eight ions: Na^+, Ca^{2+}, K^+ Mg^{2+}, SO_4^{2-}, Cl^-, HCO^{3-} and CO_3^{2-} ions. These ions are usually present at concentration greater than 1mg/l. other naturally occurring ions are Fe total, NO_3^-, F, strontium (Sr.) and boron (B) are occurring in the amount ranging between 0.1mg/l to 10mg/l. iron (Fe) and Nitrate (NO_3^-) are typically included in the water chemistry, while F^-, Sr., and B are less commonly reported.

Normally the total ionic concentration of cations is equal to the total concentration of ions. This character is termed as electrical neutrality, which used as checking mechanism on the accuracy of chemical analysis.

In addition to the above stated ions, Alkali metals, (excluding N and K) alkaline earth metals (excluding Ca and Mg) and transitional metals ate existing in minor and trace amount in natural water:

Fig 5.1 Map of Arial Distribution of TDS (mg/l)



5.2 Hydrogeochemistry of Awash River in the study area and its spatial and temporal variations.

The chemistry of surface water is not uniform through out time and space, as it is very susceptible to natural phenomena (like flooding, Evaporation, etc., human and animal interactions. The human interaction with the surface water can be manifested through the practices of industrial and Agricultural activities and act of waste disposals, while the animal interaction with surface water is mainly occurred through their waste (such as manure) disposal in to surface water. Where as natural phenomena is mainly related to flooding (which may result in dilution of ionic concentration at its high value) and Evaporation which may result to an increase in ionic concentration of the water at its higher value, as well as through the interaction of other source of water with differing physico-chemical characteristics as compared with major surface water in the basin (Awash).

Therefore, as a consequence of agricultural and industrial activities and presence of other water source that may discharge in the river (in the study area) the quality of river Awash water is supposed to be affected through out its course. As a result of this reason, analysis of its spatial and temporal variation seems to be complex. Further more, the limited data on the quality of water through both space and time, limits the detail analysis on its spatial and temporal variabilities. However, from the assessment of the available previous work's chemical analysis of water samples from different sites as well as the result of the water samples collected during field visit, it can be said that, according to the data of the previous work the PH of the river Awash water is ranging from 7.4 to 8 at Nura Era and Metehara respectively, indicating that the Awash river through out the study area lies in the narrow range of alkalinity. However, it should be noted that at few localities where water may subject to some other sources that can supply CO_2 to the river the possibility of falling in pH value within the acid range is expected. Whereas the pH of Awash River as per the measurements made during the field works in the months of September and October 2003, and in the month of April 2004,it lies in the ranges of 7.21 to7.35 and 7.83 to 8.85. The range with lower values corresponds to the measurement performed during the first field visit where the discharge of Awash River is supposed to be higher and at the same time the supply of $C0_2^-$ through rain is also considered to be high. While the range with higher values belongs to the measurements made during the second visit. The pH of the River water as per the measurements at each period of the field works are also lie in the narrow alkalinity ranges. But with difference in pH values at each period of the field visit.

In general the assessment of the pH data of the measurement of the previous works and the current work, indicate that the pH of Awash River seems to fluctuate with time, in which the higher values are being identified in the dry seasons. While the lower pH value corresponds to the measurement in the wet season.

Regarding TDS and EC (which are apparently exhibiting direct relationship between them) generally show an increasing trend along the course of the river with the exception to Sodere area where the Awash River shows relatively higher values of TDS and EC. The relative high TDS and EC of Awash River at Sodere is due to hot spring with a high value of TDS lying in the ranges of1425 to2812 mg/l which is discharging into the river and causing an increase in the TDS and EC of the river.

Table 5.3 Awash River Chemical Data

station	Awash at Sodere	Awash at Sodere	Awash at Sodere	Awash at Nura	Awash at Nura	Awash at Nura	Awash at Abadir	Awash at Metehara	Awash drainage AT Metehara	Awash Drai at Meteha	Awash at Metehara
Date	1982	1982	2003	1983	2003	2003	1983	1984	1982	1987	2003
Ec	1125	248.7	230	204	270	210	305	310	339	335	270
TDS(mg/l)	890	224	142	164	119.3	102.7	256	230	248	312	140.6
pH	7.6	7.9	7.42	7.7	7.29	7.26	7.5	8	7.81	6.53	7.3
Ca2+	20	34	2/1/1900	24	36	35	29.6	32	22.4	28.8	22.6
Mg2+	6.7	4	4.5	2.9	6.3	6.1	3.7	14	3.89	4.37	2.3
Na+	282	27	35.35	32.6	25	36	31	41	47	35.5	43
K+	16	6	2	nd	2.3	8	5.3	nd	7.4	8.3	13.4
HCO3-	610	171.1	118.5	146	127	132	148.8	173	170.8	165.9	110
Cl-	71	23	41	14.2	25	46	20	15	15	14	46
SO42-	110	0	23	nd	30	28	8	nd	7	8	26
F-	6	1	1.54	nd	1.2	1.7	0.67	1.5	1.7	1.68	1.7
Fe tot	0.2	nd		2.7			0.21	nd	0.03	0.08	
hardness	nd	nd	100	nd	116		nd	nd	72	90	
Sio2	71.2	19		nd		113	nd	nd	nd	nd	66
NO3-	nd	nd	0.07	4.3	0.1	0.5	nd	nd	2.2	0.88	0.6

Source:MOWR,(1981-1984)and (1997-1998) and current work,2002-2003, all concentrations are in mg/l.

According to the assessment and interpretation of the previous chemical data and physico-chemical data of the present work (table 5.8), it can be concluded that the TDS of the river water with in the study area varies between 102.1 and 277mg/l in which the lower and the higher values of TDS are measured during the first and the second field visit respectively, which is also corresponds to wet and dry season respectively. Where as EC values vary between 204 to 310μs/Cm. The larger values of both TDS and EC are assumed to be obtained from the water samples collected during dry season.

Concerning the major cation constituents, the river water is composed of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} in which calcium and sodium ions are the dominant cations with their relative concentration are occurring in the range in the 20 to 88.6 mg/l and 27 to 282 mg/l respectively. With local exception like Sodere area where Na^{+} value due to the same reason attributed as for the cause of high TDS and EC values, both Ca^{2+} and Na^{+} ions exhibit a tendency of slight increase along the course of the river, however, it should be noted that Na^{+} has a maximum value at Sodere due to the same reason mentioned above as the cause for high TDS and EC values. Where as Mg^{2+} and K^{+} ions are identified in their relatively lower proportion occurring in the ranges of 12.9 to 14 mg/l and 5.3 to 6.3 mg/l respectively. Both Mg^{2+} and K^+ show a tendency of an increase along the course of the river.

HCO_3- constitutes the dominate proportion of anions occurring between 131.8 and 610 mg/l and it seems to show a sign of a declining tendency along with the course of flow except at some localities where the supply of CO_2 may suppose to take place due to some source that can be related to both natural and human factors. In general, Na^+ and bicarbonate ions seem to increase during dry season. The next dominant anion constituent is chloride ion that varies from 14.2 to 71 mg/l in concentration, exhibiting more or less a similar trend as Na^+ ion. On the other hand, fluoride ion is also existing in the amount form 0.6 to 1.5 mg/l with more or les depicting an increasing trend along the course of the river.

Fe total ions was also detected in the river Awash water in the amount ranging from 0.2 to 18.2 mg/l with the maximum values being identified at Nura and Era areas, where big farm agricultural activities are practiced and hence it may indicates a sign of pollution owing to the impact of agricultural activities in the area.

5.2.1 Water quality of Awash River drainage

From the assessment of chemical analysis data of the water sampling collected from River Awash water drainage at some localities within the study area by Ministry of resource, 1989 and current work (table 5.3 and 5.4) the water from irrigation canal shows more or less a similar an overall physico-chemical characteristics as Awash River, except a slight increment in Na^+, K^+, HCO_3- and F^- ions, in the water of the irrigation canal. This is supposed to be probably due to evaporation effect.

Table 5.4 Physicochemical data of Awash River, drainage and tributaries rivers

Location	Sodere	Merti factor after tibila	drainage b/nTibil-Merti	Doni bridge	bole bridge (Era)	Legege fer da River	Buge River	Metehara
Date	27/9/2003	27/9/2003	27/9/2003	2/10/2003	2/10/2003	2/10/2003	2/10/2003	8/10/2003
TDS	142	119.3	120.3	107.5	102.7	102.1	114.2	140.6
EC	232	200	200	180.8	170.1	171	191.2	233
PH	7.25	7.21	7.37	7.35	7.29	7.15	7.3	7.29
Temp	23.9	25.3	25.2	22.2	22.8	27.7	25.4	25
Sal	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Source: During work field measurement

5.3. Ground water chemistry

5.3.1 The chemistry of groundwater from bore hole /Metehara area

As can be confirmed from the assessment of the lab and in situ test results of the ground water samples collected from various locations of the area, (see table5.5a to5.5d) by Ministry of Water Resource. The waters of the area are characterized by relatively higher total dissolved solid (TDS), lying in the range of 717 mg/l to 3376 mg/l. where as the electrical conductivity (EC) lies in the range of 1065 to 5500μs/cm. The electrical conductivity of a given water is the measure of the dissolved and/or suspended charged ions (particles), Which mainly related to the constituent of soluble salt in the water, consequently it shows similar trend as TDS, in such away that, the higher EC value corresponds to high concentration of TDS, exhibiting the presence of direct relationship between them. The major cation constituents of the groundwater of the area is represented by sodium ions, which lies in the range between 205 and 1460 mg/l. The higher sodium ion concentration corresponds to water with high TDS concentration. Water with high TDS seems to belong to the water samples collected from those bore holes located relatively far from Awash River and the boreholes where the possibility of the interaction between Lake water and groundwater is anticipated.

Potassium ion represents as the second constituent of the major cations of the groundwater of the area with its maximum concentration being identified in water collected from borehole at mosque in Metehara town. It occurs in the ranges from 5.6 to 162 mg/l with, the majorities of the waters in spatial distribution over the area exhibit the concentration lying above 15mg/l.

Both Ca^{2+} cations are identified in their lower amount, occurring in the ranges from 0.8 to 76.8mg/l and 0.00 to 44.75mg/l respectively. The two cations reveal similar trends, in such away that, wherever, Ca^{2+} ions occur at higher concentration the corresponding Mg^{2+} ions are also occurred at their relatively higher proportions. Mn^{2+} and Fe total are also occurring in many groundwater of the area in minor proportions lying in the ranges from nil to 1.8 and nil to 0.84mg/l respectively.

Regarding the major anions, the groundwater of the area composed of HCO_3-, $SO_4$2- and Cl^- ions, occurring in descending order in their relative concentration. In general, HCO_3- represents the major constituent of an ion existing in the range from 422.1 to 1891 mg/l through out the spatial distribution of the waters. The second larger proportion of anion is Chloride ion that lies in the range from 12.7 to 525mg/l.

Fluoride (F-), carbonate (CO_3^{2-}), Nitrate (NO_3-), and phosphate (PO_4^{3-}) ions are also other an ion constituents of the ground waters of the area, in which F- and $CO_3$2- ions are identified to be in the ranges of 2.2 to 29.75 mg/l and nil to 220.8 mg/l respectively, while NO_3- and $PO_4$3- ions are lying in the ranges from Zero to 39.6 and 0.03 to 4.9mg/l respectively. These ions are more or less occurring in all groundwater within the specified corresponding ranges with the exception of occasional missing of NO_3- and $CO3^{2-}$ ions in few waters in the Arial distributions.

The pH of the waters varies between 7.1 and 9.1 and accordingly all waters lie in the alkaline ranges but at a relatively wide range than the river water. The temperature of the waters vary between 22.3 and 40.8°C and as the result they belong to a groundwater with temperature close to local average surface temperatures and consequently they are expected to belong to shallow active unconfined aquifers. Where as the hardness of the waters vary between 4 and 300 mg/l of $CaCo_3$ and hence the groundwater of area Metehara can be classify as water types with soft (0-60) to very hard (>180 mg/l of Ca CO_3 per litter of water).

On the basis of the above general physico- chemical properties of waters, described above, and the groundwater of the area can be classified as the member of sodium carbonate water family, belonging to the aquifers of the same lithologies.On the basis of their general physico-chemical properties, the following conclusion can be made about the groundwater of Metehara area.

Table 5.5a Hydrogeochemistry of groundwater from some boreholes in the study area

location	BH Police Station	BH at Merti near Kera	Bhat Merti No.16	BH at Merti	BH at Mewtehara ortho.Chur	BH at Merti staf f quarter	BH at Kikan Village	BH at Meldiba	BH at Metahara town	BH HBH-35
date	27/11/97	27/11/97	27/11/97	27/11/97	27/11/97	2/12/1997	2/12/1997	28/1/98	5/2/1998	5/2/1998
EC	2070	1898	1384	1065	2370	1536	2820	1640	2560	2610
TDS	1245	1159	908	717	1529	953	1788	1081	1450	1878
pH	7.13	7.28	7.54	7.33	8.57	7.2	7.43	8.39	8.11	9.1
Na+	330	320	205	205	550	310	520	410	65	690
K+	21.6	18.8	19.4	9	26.4	13.2	28	17	8.5	7.3
Ca2+	76.8	74.4	68	44.8	1.6	3.6	73.6	3.2	4	5.6
Mg2+	34.5	27.7	30.1	44.75	0.97	10.7	57.4	0.49	5.35	1.46
FeTotal	0	0	0	0	0.02	0	0	0.35	0.03	0.55
Mn2+	0	0.1	0.6	1.4	0.2	0	0	0	0.4	1.8
F-	4.5	2.4	2.2	2.6	5.7	2.56	2.4	8.5	21	19
Cl-	255	215	104	24	151	12.7	351	112	188	57
NO3-	11.44	15.84	18.9	39.6	0.88	4.4	14.1	0	0	5.28
Co32-	0	0	0	0	72	0	0	31.2	36	220.8
HCO3-	627	629.5	573.4	641.7	954	624.6	695.4	668.56	951.6	1107.76
So42-	190	160	140	180	130	140	430	90	255	150
po43-	0.82	0.76	0.81	0.57	1.22	0.58	62	0.41	0.03	4.9
Alkalinity	514	516	516	470	902	512	570	600	840	1276
DO	Nd	nd	nd	nd	nd	nd	nd	nd		nd
TDS	29.8	30.6	26.6	26.6	25.1	27.2	29	41	26.5	20.3
Hardness	334	300	294	296	8	134	420	10	32	20

Table 5.5b Hydrogeochemistry of groundwater from some boreholes in the study area.

Location	BH	BH at	Bh at	BH at	BH at	BH gudina	BH at	BH at	BH at Met	Bh at Met
	Ilala	metehara	second	third	fourth	foundation	Mosque,	Catholic	ehara	ehara
	clinic	ortho. Churrtodox,Ch	camp	camp	camp		Metehara	Church	town	town
Date	18/11/97	19/11/97	20/11/97	20/11/97	20/11/97	21/11/97	25/11/97	25/11/97	26/11/97	26/11/97
EC	1980	1956	2980	2100	2680	1990	4270	5500	1613	1476
pH	8.7	7.1	7.4	7.6	7.45	7.88	8.83	8.99	7.1	7.6
TDS	1218	1266	1898	1100	1666	1166	2711	3376	1090	782
Na^+	430	415	570	400	540	460	990	1460	370	270
K^+	33	17.2	37.5	27	32	120	162	14.8	7.7	6.7
Ca^{2+}	0.8	30.4	46.4	20	38.4	2.4	1.6	1.6	50.4	36
Mg^{2+}	0.49	13.6	35	16.5	38.4	2.9	0.49	0	7.78	8.76
Fetotal	0	0	0	0.02	27.2	0	0.02	0.02	0.02	0.03
Mn^{2+}	0	0	0	0.1	0	0.1	0.1	0.3	0.8	0.2
F^-	6.9	10.9	5.4	6.3	4.2	5.5	22	29.75	7.4	6.9
CL^-	128.5	140	368	204.8	280	126	342	408	58	26
No_3^-	0.88	4.8	21.12	12	9.2	0.88	154	121	0.88	1.32
Co_3^{2}-	74.4	0	0	9.6	0	12	129.6	225.6	0	7.2
HCO_3^-	722.2	817.4	422.1	500.2	678.3	819.8	1298.1	1891	954	700.2
SO_4^{2}-	130	160	570	300	360	130	400	450	65	210
PO_4^{3-}	0.45	1.4	0.18	0.4	0.39	1.14	4.75	4.5	1.24	nd
ALKALINITY	716	670	346	426	556	662	1280	1926	782	586
DO	5.3	0.33	4	nd	2.7	nd	nd	nd	0.33	0.67
T	40.8	29	37.2	36.1	36.1	46.2	26.5	30	27	27.5
Total Hardness	4	132	260	118	208	18	6	4	158	126

1. Most of the bore holes in Metehara town and all the other sampled at Abadir, Merti and Metehara Sugar Cane farms reveal intermediate physico- chemical characteristics, that classify them as the water of the same family belonging to the aquifer of the same lithologies.
2. All these bore holes south, east of Lake Beseka exhibit relatively lover concentration values of F^-, PH and total alkalinity and an increase in Ca^{2+} ions than the local average of the groundwater from the bore holes at the west northwest and north of Lake Beseka which consistently reveals an increase in the concentration of Na^+, Cl-, $SO_4$2- and NO_3^- ions in the ground waters of these areas, may suggest that, they have been, probably subjected to different degrees of pollutions as a result of human activities for some time in the past.
3 The comprising of the over all chemistry of the groundwater of some bore holes in the area with the Awash water, may suggests that there is the possibilities of either a mixing pattern of local groundwater with that of farm drain water and the Awash river water or else, their geochemistry may be partially modified by geochemcal processes as a result of the effects of pH and Eh.

Groundwater in the Metehara area is generally considered as unconfined aquifer. The temperature of the ground water around the Lake varies from 36 to 42 °C except in the Merti sugarcane farm area. Groundwater quality in the Metehara area is generally unfit for drinking purposes. Especially that groundwater from boreholes located near by the lake in the eastern direction contains very high concentration of fluoride and other salts. This is because of the fact that, an excessive fluoride content in drinking water is toxic, and it can cause bone and teeth fluorosis.

5.3.2 Chemistry of thermal and cold springs in the study area

5.3.2.1 Sodere thermal springs

Sodere thermal springs are situated in the compound of Sodere hotel that is located at a distance of about 20Km south of Nazereth. They are emanating at the base of rhyolitc lava dome with an over all discharge estimated to be more than 100 l/s and temperature of 50 to 52 °C.

According to the assessment of the previous work and current work the water quality of the springs water is characterized by higher TDS and EC values that is lying in the ranges of 1425 to 281 mg/l and 923 to 2800 μs/cm with their corresponding maximum values seem to be occurred during the months where higher mean monthly potential Evapotranspiration takes place.

The major cation constituents is dominantly represented by Na^+ ion in the range of 500 to 639 mg/l with K^+ being the second to the extent between 30 and 50 mg/l. The high content of Na^+ ions can be attributed to the effect of water- rock interaction, in which the rhyolitic dome is mineralogical supposed to be dominated by Na^+ rich minerals. Ca^{2+} and Mg^{2+} are also identified in lower proportion. Probably, due to of their relative lower solubility values than Na.

Regarding the major anion constitutes, HCO_3- is the dominant constituent occurring between 1029.7 and 1391 mg/l and followed by Cl^- and $SO_4$2- in almost similar proportion that is lying in the range of 130 to 180 mg/l. The fluoride content of this water is between 2.5 and 4.35 mg/l, which is beyond WHO standard for drinking water. The pH of the spring water lies in the alkalinity range varying in the range of 7.07 to 7.8. Consequently, the water of the spring can be classified as sodium bicarbonate water.

5.3.2.2 Cold springs in the area

The largest cold spring is situated at the northern end of Lake Beseka near the railway line and very high concentration of TDS and high value of EC characterizes its chemistry.

Table 5.6 Water quality of cold and hot springs

		hot spring	hot spring	hot spring	hot spring	hot spring	hot spring	coldspring
	at Sodere	at Sodere	at Sodere	S.of L.Bese	S.of Beseka	ssw Bese	S.of Beseka	N.Beseka
Date	12/10/1982	13/7/83	31/1/98	4/11/1997	14/11/97	16/1/98	24/1/98	15/11/97
EC	2258	2800	1423	1608	1630	3710	1620	2130
TDS	1950	2812	1425	852	824	2385	1026	1680
PH	7.8	8.2	7.07	8	8.01	9.2	8.3	7.17
Ca2+	18.4	9.6	20.8	2.4	1.6	2.4	2.4	216
Mg2+	8.3	12.7	11.6	1.5	1	0.49	1.46	19
Na+	639	632.2	500	370	370	870	375	265
K+	50	30	31	21.3	21.3	42.5	22	11
HCO3-	1391	1268.8	1029.7	546.6	522.6	1244.4	646.6	0
Cl-	170.2	117.3	130	106.3	106.7	315	105	170.8
SO42-	130	181.1	130	160	170	300	100	85
F-	2.7	4.25	4.35	7.3	8.4	13	6.5	620
Fe tot	nd	0.2	0	0.01	0	0.12	0	4.2
Sio2	640	97.6	nd	nd	nd	nd	nd	0.21
PO43-	nd	nd	0.39	0.37	0.42	2.18	49	0.36
Mn2+	nd	nd	0	0.2	0.1	0.3	0	0
NO3-	nd	nd	0	2.66	1.8	6.16	0	27.8
Hardness	nd	nd	100	12	8	8	12	618
Alkalinity	nd	nd	844	516	520	1500	570	140
CO32-	nd	nd	nd	40.8	55.2	288	24	nd
B	nd	nd	nd	0.88	0.71	nd	nd	0.76

Note: the concenration is in mg/l

Where its TDS is 1680mg/l while its EC is measured to be 2130µs/cm and its total hardness is 618 mg/l $CaCO_3$ and hence it can be classified as a very hard water type. Na^+, Ca^{2+} Mg^{2+}, and K^+ represent the cation constituents of the cold spring water, with Na^+ ion is being the dominant cation having a concentration of 256 while Ca^2+ is the next abundant cation with a concentration of 216mg/l. magnesium and potassium are also occurred in the ranges of 19mg/l and 11mg/l respectively. The major anion constituents are represented by sulphate, bicarbonate and chloride ions, with increasing order1620, 170.8 and 85mk/l respectively. Fluorides also occur in lower concentration than near by Lake Water. The alkalinity of this cold spring is in neutral range of pH=7. Nitrate and Ca^{2+} are identified in a relatively larger proportion (27.9mg/l and 216mg/l respectively, and this indicates that there is no interaction between lake and the cold spring.

The water quality of cold spring is different from the other water sources in the Metehara area. It has very high concentration of Nitrate, sulphate and calcium and its water is very hard water. The discharge rate of the cold spring seems insignificant as compared to the hot springs in the lake catchments.

5.3.2.3 Hot spring at Beseka

There is a number of Hot Springs in the lake Beseka catchment, however the most important are Tonne and Chelelektu springs which are located at the southwestern end of the Lake (see table 5.6).

As can be confirmed from the assessment of their physico- chemical data (see table) their total dissolved solid content varies between 824 and 852mg/l and their corresponding EC values are also lying in the range of 1608 to 163 µs/cm. They have a temperature of about43.3°c. The discharge of these spins is estimated to be very high and consequently they discharge significant volume of water to the Lake. In addition to these springs, there are also some submerged hot springs in the Lake and through out the southwest periphery of the Lake.

In general, the water of those hot springs have high concentration of Na^+ ion (lying in the range of 370 mg/l) representing the dominate proportion of cation constituent while Ca^{2+} and Mg^{2+} are identified in their lower concentration, which specifically lying in the ranges of 1.6 to 2.4 mg/l and 1.0 to 1.5 mg/l respectively. On the other hand, HCO^-_3 is the dominant constituent of the major anions, with the values varying between 552 and 546mg/l.

Regarding pH and alkalinity of this hot spring, they occurred in the ranges of 8 to 8.1 and 516 to 520 $CaCO_3$ respectively. The water of those hot springs generally has high concentration of EC, pH, Na^+ and HCO_3- and like the water from Beseka Lake the divalent cations such as Ca^{2+} and Mg^{2+} are very low. In general, the water from those springs is not suitable for human consumption and irrigation purposes.

5.3.2.4 Water quality of Beseka Lake

The water of Beseka Lake is characterized by TDS and EC of a higher concentration than any other water types in study area, that lying in the range of 3416 and 4722 mg/l and the corresponding EC is lying in the ranges of 4420 to 7040µs/cm. The higher concentration in

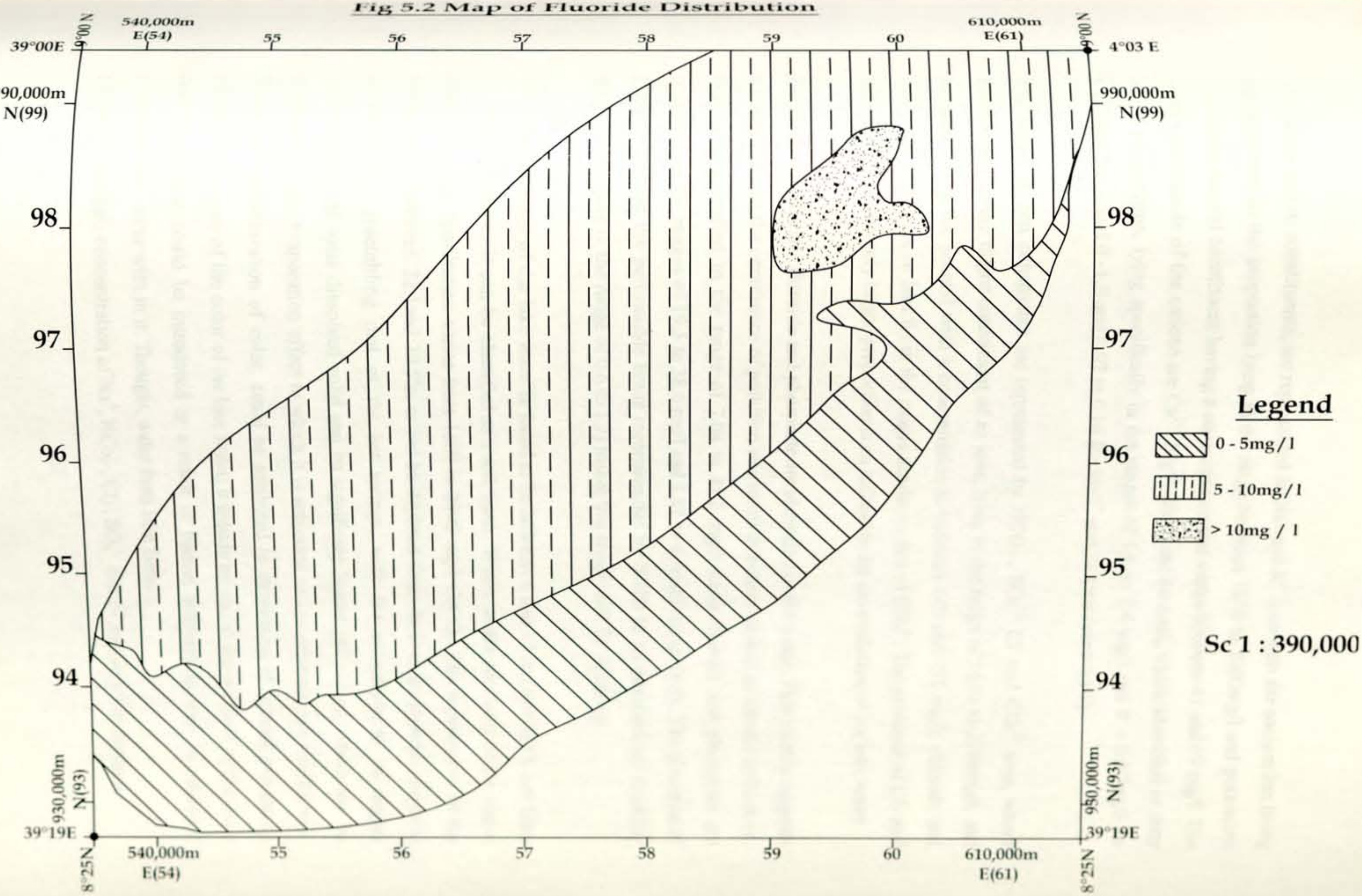
TDS and EC can be attributed to the effect of evaporation, along with the possible influence that can be imposed on water quality as a result of either geochemical processes or human activities. Consequently it can be said that, the Beseka Lake is constituted by highly mineralized water.

Table 5.7 water quality of Beseka Lake,

Location	LBS-001 Lake Beseka	point-30 L.Beseka	point-48 L.Besaka	LBS-002 L Beseka	LBS-003 L beseka	LBS-005 L Beseka	LBS-006 L.Beseka	Lake Bese ka	Lake Beseka
DATE	14/11/97	16/1/98	22/1/98	24/1/98	27/1/98	28/1/98	29/1/98	4/3/1982	30/11/83
CE	6980	6560	5230	7040	4420	4870	6720	6650	5564
TDS	4722	3542	3852	4617	3146	3494	4600	4062	4800
PH	9.44	9.44	9.44	9.45	9.34	9.29	9.44	9.7	9.6
Na^+	2080	1200	1500	2100	1450	1360	1800	1700	1590
K^+	69	41	56	69	49	50	67	115.5	70
Ca^{2+}	2.4	2.4	1.6	2.4	2.4	3.2	1.6	3.2	4.6
Mg^{2+}	0	0.49	0.49	0.49	0.49	0.97	0.97	1	0.97
FE tot	0.1	0.07	0.12	0.15	0.09	0.16	0.16	0.2	nd
Mg^{2+}	0	0.3	0.8	0.9	0.6	0.8	1	nd	nd
F^-	38.6	205	23.5	30	19.5	22	29	61	0.35
Cl^-	594	395	505	625	425	445	605	5247	492.8
NO_3^-	41.6	7.04	7.48	35.2	35.2	37.4	37.4	nd	nd
CO_3^{2-}	720	624	576	480	33.6	384	600	nd	bd
HCO_3^-	1830	1854.4	1756.8	2196	1610.4	1488.4	2196	1562	1464
SO_4^{2-}	520	500	440	700	380	370	600	375	390
PO_4^{3-}	4.4	3.8	2.62	4	2.8	1.81	3.6	nd	nd
B	4.12	Nd	Nd	nd	nd	nd	nd	nd	nd
Alklinity	2700	2560	2400	2600	1880	1860	2800	nd	nd
DO	4	Nd	Nd	nd	nd	nd	nd	nd	nd
Total hardness	6	8	6	8	8	8	12	nd	nd
T_c°	25.6	25.4	30.5	22.1	30	24.7	24.2	nd	nd

Source:- MoWR,. 1989

Fig 5.2 Map of Fluoride Distribution



The major cation constituents, are represented by Na^{+} and K^{+} ions with the sodium ion being the dominant in the proportion lying in the range between 1200 to 2100mg/l and potassium ions is the second constituent having a concentration that varies between 41 and 69 mg/l. The other constituents of the cations are Ca^{2+}, Mg^{2+}, Mn^{2+} and Fe total, which identified in their lower proportions, lying specifically in the ranges of 1.6 to 2.4 mg/l and 0 – 0.97mg/l for Ca^{2+} and Mg^{2+} and 0 -1.0 and 0.07 to 0.16 for $Mn2^{+}$ and Fe total respectively.

The major an ion constituent are represented by HCO_3-, SO_4^{2-} Cl^{-} and CO_3^{2-} ions, where Bicarbonate is the major constituent of an ions, lying in the range of 1610 to 2196mg/l, and sulphate being the second with a concentration in between 440 and 750 mg/l. chloride and carbonate that more or less lie in the ranges similar to that of SO_4^{2-}. The presence of Cl- and SO_4^{2-} in their relatively larger proportion is an indication for the evolution of the lake water.

Beside these, Nitrate, fluoride and phosphate are identified in the water. This mostly suggests an indication to the occurrence of pollution as a result of human as well as natural influences. Nitrate is identified in the range of 7.04 to 41.6 mg/l while fluoride and phosphate are occurring in the ranges of 19.5 to 38.6 mg/l and 1.81 to 4.5mg/l respectively. The presence of fluoride beyond the permissible limits recommended by WHO as an international drinking water stands (lies in the range of 0.6 to 1.7) makes this water unfit for drinking.

The total hardness of the lake water is found to be between 6 and 12 mg of $CaCO_3$ per litter of water and hence it can be classified as a soft water. Where as the alkalinity of the major water in aerial distribution varies from 1860 to 2800 mg/l $CaCO_3$. The temperature of the water varies between 22.1and 30.5°c, as can be depicted from its over all physico-chemical characteristics resembling that of the hot springs, with the exceptions to its higher concentration of total dissolved solid and its significant higher pH values, which can be attributed to the evaporation effect to which it is subjected and is apparent color difference. Those the manifestation of color, could be attributed to expression of several process in nature, but in case of the color of the lake water, it mainly be due to the presence of the other constituent that could be introduced as a result of human activates as well as chemical processes that occur with in it. Thought, water from lake Beseka,
generally has high concentration of Na^{+}, HCo_3-, CL^{-}, SO_4^{2-} and F- and very low amount

of Ca^{2+} and Mg^{2+} ions, it exhibits slight variation in concentration of ions at it's north and south ends in such away that the concentration of ion in the southern part of the lake in the relatively lower than the northern portion of the lake, which can be attributed to the inflow of fresh hot springs characterized by water quality composed of relatively lower

Table 5.8 the water quality of different water in the study area as obtain from water samples collected during field visit

Locality	TDS	ECl	pH	Na^+ (mg/l)	K^+ (mg/l)	Mg^{2+} (mg/l)	HCO_3^- (mg/l)	Cl^- (mg/l)	Ca^{2+} (mg/l)	F^- (mg/l)	Mn^{2+} (mg/l)	No_3^- (mg/l)	Hard-ness	CO_3^{2-}	So_4^{2-}
sodere hot spring near abad	1314	2190	7.3	598	31	7.84	1275	137	18	2.5	0.002	0	77		
Awash at Sodere	142	230	7.25	35.4	2	4.5	165	41	32.6	1.54	0.005	0	100		
Bore hole at bofa	629	1050	6.97	87.1	3.9	5.2	1050	140	17	1.1	0.003	0.06			400
Cold spring b/n bofaand Doni	2980	4960	9.41	1790	11	4.5	1960	2050	5.8		0.001	0.24			400
awash at Merti F	102.7	270	7.19	25	2.3	6.3	127	25	36	1.45	0.003	0.05	116		
drainage b/n tibilaand Merti F.		280	7.35	43	4.5	2.69	136	30	15.4	1.5	0.002	0.09	77		
Legeferda river(near Merti F.)	102.1	200	7.12	32	4	2.3	115	22	13	1.3	0.013	0.03	75		
Buge river near Merti Fac.	114.2	240	7.27	35	6.4	4.9	125	34	14.4	1.5	0.004	0.03	72		
drainage at Era		250	7.23	40	8	8.7	160	50	35	1.7	0.003	0.07	137		
Awash at Bole town (Era)	119.3	210	7.25	36	8	6.1	135	46	27.4	1.7	0.004	0.03	113		
awash at Metehara	140.6	270	7.3	43	13	2.3	115	42	22.6	1.7	0.007	0.5	66		
Lake Beseka at north side	4060	6540	8.89	1950	39	0.45	2050	550	1.4	20	0.009	28.5	5.4	550	
lake Beseka at west side	4150	6450	8.78	1760	40	0.45	1900	560	1.4	21	0.005	30	5.4	500	
Lake Beseka at south side	2980	4660	8.82	1340	46	0.5	1750	350	1.6	18	0.004	26	8	330	
hot spring south of L. Bese.1047		1680	8.03	375	39	1.7	630	120	2.8	7	0.004	5	15	40	

source:CDSco, central laboratory(current work).

ionic concentration than the undistributed lake water.

5.4 Summary of Hydro-geochemical properties of the different water bodies

Even-though lack of chemical analysis data of systematically collected samples from different water bodies in the region seems to limit the exactness of the conclusion, the assessment of the existing chemical data permits to draw a conclusion about the geochemical and its variability with space and times, as ca be depicted from table 5.5a, 5.5b, 5.5c, 5.5d and annex6 and 7 and the general geochemical characteristics of the groundwater of the study area is as outlined below.

Surface water (Awash River water) along the river course within the study area, shows a slight trend of an increase in both TDS and EC, except at Sodere where the concentrate ion of TDS and EC is relatively higher due to the effect of geothermal hot spring. In general, calcium, sodium and bicarbonate are the dominant ions, with the sodium being the dominant cation and the calcium and chloride are occurring in their lower proportion and the sulfate ions occur in a very low amount. In general, Na^+ and Cl^- ions present an increasing trend along the course of the river, while calcium seems to show a declining trend. Concerning bicarbonate distribution, the existing data does not show a clear trend of its distribution along the course but it represents the major constituent of the anions of the surface water. Lastly it should be noted that fluoride content shows an increasing trends along the course of Awash River.

In Metehara area the ground water from the wells close to Awash River and remote from the influence of hot springs and other indication of geothermal activities have similar composition as surface water, except the presence Na^+, HCO_3- and SO_4^{2-} ions in their relatively higher proportion. While the groundwater from the well in the vicinity of hot springs or volcanic centers, exhibits a similar composition as that of hot springs which characterized by higher proportion of sodium ions (as a dominant cation constituent) and bicarbonate ions as the major constituent of an ions with SO_4^{2-} and Cl^- ions are the subsequently existing components of the an ions being identified in their significant amounts. Regarding the groundwater in the study area in general, it can be said that, sodium is the dominant constituent with either K^+ or Ca^{2+} being the second in proportion depending on the relative location of the wells with respect to Awash River or to hot Springs and/or volcanic centers.

The hot springs and Lake Beseka have lower content of calcium and magnesium ions than the surface water but higher content of Na^+, K^+, Cl^-, SO_4-and HCO_3- than both surface and ground water of the region.

4. The main problem of the ground water of the area as a whole is supposed to be the concentration of fluoride in the extent beyond the admissible limit for drinking and higher TDS and EC concentration which make the water unfit for drinking and irrigation purposes except the water from some boreholes that can be diluted by Awash River.

   On the basis of the concentration of TDS, EC and F^- the groundwater of the region can be subdivided into shallow and deep circulating water, in which the deep circulating water are supposed to have higher content of TDS, EC and F^- due to the effect of water and rock interaction through long flow channels together with the influence of fumaroles and hot springs. The main causes for the presence of F- in higher concentration in the groundwater of the area can be related to the occurrence of acidic rocks like rhyolites, obsidian and presence of fumaroles and geothermal springs in the volcanic rock of the region. Hence, the exploitation of the deep groundwater for potable water generally seems unattractive due to its poor quality. The variation of fluoride in the groundwater of the region may also be attributed to the possible lithological variation in aerial distribution in which fluorine-bearing sequence may vary in both vertical and horizontal extent.

5. Lake Beseka is characterized by higher concentration of Na^+ and K^+ as cation constituent and HCO_3-, represents the dominant component of anions with SO_4^{2-} and Cl^- are being the second and third constituent of the anions. In general, water from Lake Beseka shows a highest value of TDS and EC than any water type in the region. But it shows lower values of Ca^{2+} and Mg^{2+}ions than most of the water in the region.

5.5 Spatial and temporal Variability of the Chemistry of surface and ground waters.

5.5.1 spatial variability in the chemistry of surface water

Even though the insufficiency of the data of chemical analysis, which were not collected systematically through space and time and other factors indirectly or directly, related to agricultural activities in the area makes the assessment and interpretation of the spatial and temporal variability of the surface water more difficult. But the assessment of the available data (table 5.3) shows that Na^+, Cl^- and HCO_3^- ions exhibit a trend of slight increment along the course of the River with the exception to the samples from Sodere which reveals relative higher valves of these ions due to the interaction of river and hot springs where the later has higher values of the major ions (table 5.3). The pH of the River water lies in the range of 7.21 to 8.85 consequently the river falls in alkaline range.

Regarding the temporal variability of the chemistry of the river, the assessment of the available chemical data of previous and present works indicate that TDS, EC, and some major ions like Na^+ seems to show a relatively higher value during dry season attributed to less dilution and strong evaporation.

5.5.2 spatial variability in the chemistry of ground water

As can be confirmed from table 5.5b, 5.5c, 5.5d, and table. The groundwater of some bore holes at northeast and east of Lake Beseka shows more or less similar geochemical behavior as Lake Water.

Table 5.9 Hydrochemistry of the groundwater in the study area.

	HVA Meteharea BH1(136)	HVA Metehara BH2(137)	HVA Metehara BH4(139)	HVA Metehara BH5(140)	HVA Metehara BH7(142)	HVA Metehara awash vill.BH	HVA Mete hara kikan village(145)
Grid	976/601	976/603	977/601	976/600	976/602	977/607	972/601
Ca^{2}_{+}(mg/l)	204	116	112	28	9.6	58	139
Mg^{2+} (mg/l)	123	35	55	23	3	32	149
Na^+(mg/l)	570	514	415	272	194	420	710
K^+(mg/l)	42	32	26	19	11	19	41
CO_3^{2-}(mg/l)							
HCO_3^-	397	417	586	526	428	539	336
Cl(mg/l)	1134	650	425	169	56	32.7	883
SO_4^{2-}	344	285	364	127	34	315	939
F^-(mg/l)	0.8	2.6	2.8	2.3	4.7	3	1.7
SIO2	91	107	95	95	87	95	93
TDS	1907.8	2161.6	2083.8	1261.3	828.3	1516.7	3295.7
SAR	7.74	10.74	7.81	9.24	17.05	10.96	9.92
PH	7.8	8	8	8	8	7.8	7.8
Hardness	1019	430.6	529.5	163.5	36.5	276	960

Source:- compiled from hydrogeology of Nazeret area, by Getahune Kebede, 1987.

The dominant major ion constituent of this water is represented by Na^+ ion and followed by k^+ ion. Whereas Ca^{2+} and Mg^{2+} are present at their lower concentration, while major anions are constituted by HCO_3^-.SO_4^{2-} and Cl^- ions with HCO_3^- represent the dominant constituent. Both SO_4^{2-} and Cl^- ions are also identified in appreciable amount. The reason for the stated geochemical behavior can be related to the interaction between Lake Water and the groundwater from these bore holes. The interaction of these waters is manifested through the intrusion of Lake Water into the groundwater. Another possible reason is that the infiltration of pollutant substances such as Na^+ and Cl^- ions from septic tanks in Metehara town.

Moreover the presence of PO_4^{3-} in the extent of 1.4 to 4.75 mg/l may shows sign of pollution that can be related to septic tanks and /or sewerage lines. This is due to the reason that phosphorus is a component of sewerage and waste from septic tanks, as the element is essential in metabolism and as a result it always present in animal and human wastes.

The groundwater from bore holes at Merti, Abadir and Metehara sugar cane farms exhibit the geochemical characteristics in between the river and the undisturbed ground water in particular occurring at west, northwest and north of the Lake Beseka except some boreholes at Abadir and Merti which exhibit high values of TDS, probably due to impact of agricultural activities. The major cations in this water are also represented by Na^+ ions. But Ca^{2+} and Mg^{2+} also occur in relatively higher amount than both undisturbed groundwater and lake water while the major anions of the water in the Merti, Abadir and Metehara sugar cane farms are represented by HCO_3^-, Cl^- and SO_4^{2-} in accordance to their relative abundance in descending order. These ions appeared in a lesser extent than both in the water from normal groundwater and Lake Water. The cause for the mentioned geochemical properties of the water can be most probably be related to the interaction between the river water and the groundwater in these bore holes through the application of the river water for the irrigation of the different crops.

In addition to this, man made factors through the agricultural activities like the application of fertilizers into the irrigated land can result in an increase in some of the chemical constituent of the groundwater, such as Ca^{2+}, Mg^{2+} PO_4^{3-}, NO_3^- CL^-, etc. Moreover, another possible cause is the use of high concentration of nitrate in the vicinity of the water supply bore holes.

The groundwater from bore holes at western, northwestern and northern side of Lake Beseka show similar geochemical behaviors as lake water, interms of major cations and anions with slight difference in their relative proportion. Na+ and K+ ions represent the dominant cation constituent in the groundwater body with Na^{+} being the dominant and the other divalent (ca^{2+} and Mg^{2+}) in a very low extent. While the major anions are HCO_3^-, Cl^-, and SO_4^{2-} ions occur in decreasing order in their relative abundance in both water bodies. But it should be clear that the individual dominant cations and anions occurred at higher proportion in the Lake water, which makes it a highly mineralized water types in the region. The clear difference between the groundwater from bore holes west, northwest and north of Beseka and the Lake water, beside EC and TDS, nitrate and F^- ions are also occurring at considerably higher proportion in the Lake water. The geochemical properties of the groundwater from these boreholes are assumed to be the result of geochemical processes owing to the interaction between water and rock.

5.5.3 temporal variability of the groundwater

Eventhough lack of chemical analysis data of systematically collected water samples at different time at the same sampling points make the assessment and interpretation of the groundwater of the region more difficult. But from some available data the following general trend can be drawn regarding the geochemical behaviors of the groundwater of the study area with respect to time. Water from bore holes located west, north and northwest of Lake Beseka reveals an overall-increasing trend in EC and TDS. This increase seems to occur as result of water - rock interaction. The major ions like Ca^{2+}· Mg^{2+} and HCO_3^- indicate a sign of decreasing tendency while Na^{+}, K^{+} and SO_4^{2-} ions show an increasing trend with time.

Table 5.10 Hydrogeochemstry of the ground water in the study area (1997-1998)

Name	Ca^{2+}	Mg2+	Na^+	K^+	CO_3^{2-}	HCO_3^-	SO_4^{2-}	NO_3^-	F	PO_4^{3-}	Fetot	Mn^{2+}	pH	EC	Hardness
BHMR-16(Merti)	44.8	44.75	205	9	0	641.7	180	39.6	2.6	0.57	0	1.4	7.33	908	2*96
BHMR-14	74.4	27.70	320	18.8	0	629.5	160	15.84	2.4	0.76	0	0.1	7.28	1898	300
BHMR-15	68	30.10	205	19.4	0	573	140	18.9	2.2	0.81	0	0	7.54	1384	334
BHMR-20	42.4	23.80	235	15.4	0	727.1	60	1.76	2.38	0.68	0	0	7.33	1536	204
BHMR-19	36	10.70	310	13.2	0	624.6	190	4.9	2.56	0.58	0	0	7.2	1536	134
BHMR-21(Kikan Villa.)	73.6	57.40	520	28	0	695.4	430	14.1	2.4	0.62	0	0	7.43	2820	420
BHA-06(Abadir)	38.4	27.20	540	32	0	678.3	360	9.3	4.2	0.39	0	0	7.45	2680	208
BHI-02 (Ilal clinic)	0.8	0.49	430	33	74.4	722.2	130	0.88	6.9	0.45	0	0	8.7	1980	4
BHM-11 (Meteahara	50.4	7.78	370	7.7	0	954	65	0.88	7.4	1.24	0.02	0.8	7.1	1613	158
BHF-08 (Gudina Fuon.)	2.4	2.40	410	118	24	758.8	120	1.32	6.2	75	0	0	7.98	1980	16
BHM-12 (Metehara town	36	**8.76**	270	6.7	7.2	700.3	210	1.32	6.9		0.03	0.2	7.6	1476	126
BHK-10 Catholic Chur)	1.6	-	1460	14.8	226	1891	450	121	29.8	4.5	0.02	0.3	8.99	5500	4

Source:- MOWR.(1997-1998)

The nitrate content of this water is identified at a lower proportion than other water types in the region, which indicates that the groundwater in the area is not exposed to pollution and hence the water can be taken as undisturbed average groundwater of the region. However it was not possible to identify its trend with time due to lack of data with respect to time.

2. The water from most bore holes at Merti, Abadir and Metehara sugar cane farms reveals a decreasing trends in the concentration of TDS with time in which the major ions are represented by Na^+, K^+, Cl^-, SO_4^{2-} and HCO_3^- with Na^+ and HCO_3^- are the dominant cations and anions respectively. While Cl^-, $HCO_3^-$and SO_4^{2-} seems to occur at a lower proportion and Na^+ at a higher proportion with time. Regarding Ca^{2+}, Mg^{2+} and K^+ ions, they are more or less identified in their relatively lower proportion. The reason for the occurrence of some ions in the water at their lower content through time can be related to the dilution of the groundwater as a result of an interaction with other water resource mostly the river water though irrigation return flow. The pH of this water group become lower through time from a range of 7.8to 8 to a range of 7.2 to7.45, this suggests that the infiltrating water has acidic nature than the groundwater.

3. Groundwater from some boreholes at Metehara town especially those located northeast and east of Lake Beseka shows an increasing trend in the quantity of the individual cations and anions. Two reasons can be proposed for the cause of this condition. The first possible reason is the man made factors in which some of the pollutant substances are supposed to be derived from a source like septic tanks and /or sewerage lines in the town. The second cause for the rising in the geochemical characteristics of the groundwater from these bore holes, can be associated to the interaction of the ground water and the Lake water in which the interaction is manifested by the intrusion of the Lake water into the groundwater. The presence of nitrate in a maximum concentration in some bore holes like bore holes at Catholic Church (221mg/l), B.H. at Mosque in Metehara town (154mg/l) and BH-26 (209mg/l) and phosphate in the range from 4.5 to4.75mg/l in these boreholes indicates a clear sign of pollution due to man made influences as a result of the first reason mentioned above.

4. The groundwater from some boreholes, located close to Awash River shows the geochemical behavior in between the river and the groundwater. This is due to the dilution of the groundwater by infiltrating river water.

5. Concerning the variability in the chemistry of Lake Water through time, it was not possible to assess and interpret due to insufficiency of chemical data with respect to time. But from the inspection of some data (table)it was observed that there is no significant changes in the overall chemistry of the lake water between the year 1982 to 1997. But according to the report on the rise of Lake Beseka, by MOWR (1989), the TDS concentration of the Lake water shows very abruptly decrease between 1971to1974 from 51.5g/l to 16.5g/l, and between 1974 to 1978 from 16.5g/l to 3.65g/l and then after it become relatively constant even-though the Lake is expanding constantly till the present time.

In general the groundwater from some boreholes northeast of Lake, indicates the decreasing tendency in TDS, Ca^{2+}, Mg^{2+}, Cl-, $SO_4^{2-}$and HCO_3^- through time, as can be confirmed table 5.5a, 5.5b, 5.5c,& 5.5d , probably due to the effect of dilution through return flow. Whereas an increase in these ions like Na^+ and K^- may be due to sodium absorption ratio (SAR) as a result of a rising in Na^+ and relative decrease in Ca^{2+} and Mg^{2+} On the other hand, the increase in TDS, $Ca2^+$, Mg^{2+}in the groundwater of some boreholes in the area may be either due to human interference with water through both the influence of settlement and application of fertilizers to crops or an intrusion of Lake water into some of the bore holes. While an increase in the overall chemistry of the groundwater west of the Lake Beseka is attributed to the interaction between water and rocks.

Regarding the groundwater from the other part of the study area, it was not possible to assess and interpret about its general geochemical behavior or trends with time because of lack of data. But from the assessment of geochemical properties of the groundwater from some boreholes at wonji and Nazareth towns (annex 7 and table 5.9) which are located in the vicinity of the study area and the geochemical characteristics of the groundwater at wolenchiti and Bofa towns, and the nature of the general geology of the area as a whole, it is possible to assume that the chemistry of the ground water of the other part of the study area may reveals similar geochemical behavior as Metehara area with relative lower proportion of the individual ion.

Table 5.11 water quality of the groundwater of the Nazaret and Wolenchiti areas.

Location	BH atfood corporation	BF at ELEL PA	BH Nazaret	BH3Mancip ality	BH1Etege Hotel Nazar.	Bh national Metalcorpor.	BH Wolench iti
TDS(mg/l)	595.7	467.5	865.4	630.4	698.2	600	
Tot.hardn.	151.9	87	74.7	183..6	141.1	804	72
Alkalinity	340	270	479.9	373.6	398	319.6	
Na^{+}(mg/l)	95.2	86.7	214.2	87.5	125	124	115
K^{+}(mg/l)	6.6	7.6	21.2	10	15	18	17
Ca^{2+}(mg/l)	44.9	27.3	23.2	48.5	43.7	24	19.24
$Mg2^{+}$(mg/l)	9.7	4.6	4.1	15.22	7.8	5	5.84
Cl-	14.2	10.6	15	6.82	3.68	26	14.56
SO_4^{2-}(mg/l)	0	0	0	0	16.05	0	77.2
HCO_3^-	414.8	329.4	585.6	455.84	485.6	390	354

5.6 Water types

To classify the different water bodies into different water types, the chemical analysis results of water samples from Awash river at various localities, cold and hot springs, bore holes and lake were plotted on piper diagrams (figure 6.1) and the different water types are determined according to their position in the central diamond shaped field. In an attempts to classify the waters in the study area into different water family groups first the concentration of the major cations and an ion like Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3-, CO_3^{2-} and SO_4-^{2} are expressed in percentage of meq/l, and by grouping Na^+ and K^+ together, the major cations and HCO_3^- are also grouped together with $CO3^{2-}$ and the major anions are also plotted on the other Piper diagram and then the cation points is projected on to the other central diamond shaped field parallel to the side of the triangle labeled Mg^{2+} and the anion is similarly projected parallel to the side of the triangle labeled SO_4^{2-}, and the intersection of the two lines on the central diamond shaped field represents the water family group of the water sample.

Applying of the stated technique and procedure, the classification of the waters in the region has been performed; accordingly, five groups of water types have been identified,

1 Sodium-Calcium Bicarbonate water type (group 1 water type)
2 Sodium Bicarbonate water type (group2).
3 Sodium Suphate water type (group3) Sulphate – chloride water type
4 Sodium Bicarbonate Suphate Chloride water (group 4).
5 . Calcium Sodium Sulphate water type (group 5)

The Sodium Calcium Bicarbonate water type corresponds to the water group from Awash River, farm drain water and groundwater from boreholes close to Awash River. This water type presents relative lower concentration of TDS and EC. Sodium –Bicarbonate water type (group 2 water) belongs to the water from the majority of the boreholes in the area, Lake Beseka water and water from hot springs in the study area. This water type also exhibibites significant amount of Chloride and Sulphate and it presents hot springs, moderate to highly mineralized water type (Lake Beseka water).

It should be noted that the lake water differs from the groundwater and hot springs waters, in color, five to six times increase in dissolved salts and higher pH value.
The composition of hot springs is the result of the composition of the rocks like basalts of Fentale Mountains and rhyolitic Domes of Sodere and deep circulating water. According to Mohr, 1970 the hot spring waters are primarily dominated by local geochemistry. Sodium Sulphate water type corresponds to the groundwater from boreholes far away from the River. This water type contains significant amount of chloride.

Sodium Bicarbonate –Sulphate – Chloride water type (group 4). This water family belongs to the groundwater from Abadir farm, Metehara Sugar Cane farm, and the areas north eat and east of Beseka.

Calcium Sodium Sulphate water type is the water group from cold springs at northern side of lake Beseka. This water type has very high amount of NO^{-3}, So_4^{2-} and Ca^{2+} ions. It is also very hard water type in the area and it differs from all water type in the area.

CHAPTER SIX: WATER QUALITY

6.1 Agricultural Water quality

The water in the Awash basin in general is dominantly used for agricultural irrigation. Beside the available quantity of water, the most important technical factors to govern irrigation development in potential irrigable land, includes, water quality, soil quality and climate within the context of development of further irrigation, the knowledge of the quality of the available water has paramount importance in laying down the proper schemes to minimize the impact on the quality of water on crops that may arise as a result of agricultural irrigation on subsequent projects or on down stream abstraction (Halcrow, 1989).

Both surface and ground water always contain dissolved salts and hence the salinity of the water in conjunction with the type of soil to which the water applied govern their suitability for crop irrigation, methods have been devised for classifying water according to their availability of sodium. The most commonly used method to evaluate salinity is determination of EC measured in term of micro s/cm and sodium hazard determination which is obtained from the available relative concentration of Na^{+}, Mg^{2+} and Ca^{2+}, ions, commonly the sodium absorption ratio (SAR) is used to measure sodium hazard.

6.1.1 Water quality for agricultural uses with Reference to electrical conductivity

6.1.1.1 Awash River

As can be confirmed from the assessment of the previous and the present works data, electrical conductivity of the Awash River within the study area lies in the range of 200 to 273 micro s/cm with slight increasing trends along the course of the river during dry season.

According to the guide line developed by the United States Department of Agriculture, for the classification of water with respect to specific electrical conductance (EC) as an index of salinity hard and sodium absorption ratio as an index of sodium hazard (table 6.1) the Awash river water is generally considered as the water presenting a low to moderately salinity hazard. In which a moderate salinity hazard is presented by water collected from the river at

Metahara area while at the remaining areas it presents low salinity hazard with the exception to Sodere area due to the presence of thermal hot spring. Therefore, irrigation at Metehara would imply incorporation of leaching into the irrigation regime.

Table 6.1 classification of water on the basis of EC and SAR values.

Water class	ECµs/cm	Alkali hazard (SAR)
Excellent	Less than 250	Up to 10
Good	250-750	10-18
Medium	750-2250	18-26
Bad	2210-400	> 26
Very bad	> 4000	--

Source: the EC between 250-750µs/cm can be used on most crops provide that the leaching techniques are applied.

On the basis of EC and SAR values the agricultural quality of Awash River water falls in excellent to good water classes

6.1.1.2 Ground water

a. Borehole

The ground water from bore hole at Metehara area producing EC lying in the range of 1198-5500µs/cm and as a consequence the ground water of the area can be classified as the water-producing medium to bad salinity hazard (in terms of EC) and hence it cannot be used for agricultural irrigation purpose.

In general the EC values shows direct relationship with distance away from the river and hence the agricultural water quality of the groundwater from bore holes far away from Awash River is becoming more deteriorating in agricultural quality. Groundwater away form the river is predominately sodium sulfate water type with significant chloride and magnesium. The average electrical conductivity (EC) of groundwater in this area indicates poor to very poor quality. Whereas the groundwater existing at the area relatively close of Awash River shows a chemistry half way between river water and groundwater. The water type is sodium calcium bicarbonate with appreciable magnesium and sulphlate ions. The average electrical conductivity of this water indicates medium to bad quality water.

b. Beseka and hot springs

The chemical composition of Beseka lake water indicates that it is a highly mineralized and brackish, with high fluoride and chloride levels. According to the result of the measurement of specific electrical conductance (EC) during field visit, the lake water produce EC values that vary form 5000 to 6820 µs/cm and the lower value of the range is exhibited by the water sample collected from the southern part of the lake adjacent to hot springs. On the other hand the assessment of previous work data indicates that the EC values of the Lake water are lying in the range of 4420 to 7040µs/cm. In both cases with reference to EC values as index of salinity hazard falls in the same salinity range denoted as very bad salinity hazard. Hence the Lake water cannot be used for agricultural irrigation under normal condition.

Table 6.2-- physicochemical data collected during field work

	Sodere hot spring	Sodere spring	Sodere spring	Cold Spring b/n bofa& doni	BH Bt Bofa	Lake Beseka west side	lake Beseka South	hot spring at suoth of Beseka
Date	27/9/2003	27/9/2003	27/9/2003	2/10/2003	7/10/2003	8/10/2003	8/10/2003	8/10/2003
TDS	1349	1350	1375	3120-3150	623	4150	2980	1047
EC	2280	2290	2300	5080-5130	1045	6450	4660	1680
PH	8.06	8.05	8.1	9.45	6.99	8.78	8.85	8.06
Temp	50.1	52.6	52.7	23.5	33.4	28	35	43
Sal	1.1	1.5	1.1	2.2	0.7	3	2.2	0.9

Regarding the hot springs in the study area, they produce an EC value generally varies in the ranges of 2280 to 2300µs/cm for Sodere hot Springs and EC value of 1752µs/cm for hot spring at southwest of Lake. Accordingly the water of hot spring at Sodere produces bad salinity hazard while the hot spring at southwest of the Lake presents medium salinity hazard. On the other hand, the cold spring between on Bofa and Doni and the cold spring at the north of lake Beseka present EC values of 5130µs/cm and 2130 respectively and the respective water produce very bad and medium salinity hazard and as the result both of them are not suitable for any crop irrigation under normal conditions.

Lastly the groundwater at Bofa reveals the EC value of 1045μs/cm and as a result it is classified as the water with medium salinity hazard with respect to EC as index of salinity hazard.

In general, the groundwater from bore holes, hot springs and cold springs with the exception of Awash River water with reference to EC as index of salinity hazard are considered to be unfit for agricultural irrigation for any crop irrigation except with continuous leaching on highly permeable soil and with extremely salt tolerant crops. However as could be confirmed during field work the areas around the Lake are totally covered by clayey sit or silty clay of alluvial and / or lacustrine origins and the Fantale volcanics which are supposed to show low permeability and unfavorable conditions for normal crop growth.

6.1.2 Water quality for Agricultural uses with reference to Sodium Adsorption Ratio (SAR)

Water quality problems in irrigation area include salinity and toxicity. Excessive salinity occurs when there is an accumulation of salts in top soils, sodium has a far reaching effect on soils most sodium in natural water originates with the release of soluble products during the weathering of plagioclase feldspars and its minor amounts may come from the mineral halite (NaCl) and aerosol.

Sodium hazard on crop development in semi-arid climate where evaporation rate is high can be expressed in terms of the ratio of sodium to calcium and magnesium ions, According to the United states Department of Agriculture, the Sodium hazard effect can be calculated by the sodium adsorption ratio (SAR) using the following formal.

$$SAR = Na^{+} / \sqrt{Ca^{2+} + Mg^{2+}/2}$$

Where all the three ions are expressed in mill equivalent per litter (meq/l)

According to the result of the analysis of current work and previous (works) chemical composition of the water samples collected from different localities with reference to the sodium absorption ratio (SAR) as index to Sodium hazard (table 7.3) and their classification for agricultural purposes are independently outlined below.

Table 6.3 SAR values of different water bodies

Awash. River	SAR	hot&cold Springs	SAR	Lake Beseka	SAR	bore holes	SAR
Atsodere	13.94	Sodere	31.24	LBS-001	369.27	Ilala clinic	108.09
Atsodere	1.16	Sodere	31.43	point30	184.45	Abadir 2nd	15.4
At sodere	1.67	sodere	25.2	LBS-_002	322.76	Ortho.Ch	12.77
at Era	0.82	L..Beseka	46.53	LBS-003	222.86	abadir 4th	16.29
At Abadir	1.43	L..Beseka	56.89	LBS-004	276.68	Gudina Fu.	50
At Metehara	1.52	L.Beseka	66.08	LBS-005	223.58	Mosque	317.55
-----	-----	L.Beseka	133.71	LBS-006	276.68	merti	5.21
-----	------	L.Beseka	47.17	LakeBeseka.	213.73	Kikan Vill.	11.03
-----	------	cold spring					
----	------	near railway	4.64	lake Beseka.	238.21	Mediba	56.42
-----	------	-----	------	Lake Beseka	175.53	BH-45	77.95
-----	-------	-----	-----	------	-----	Wolenchiti	5.88
----	-----	----	------	------	----	Melka jilo	48.02

6.1.2.1 Awash River

The calculated SAR for all the Awash River water collected at various localities lies in the range of 0.82 to 13.94 with the lower and higher Values corresponding to the values obtained from the water samples collected from Era and Sodere areas respectively. According to the guide lines developed by the United State Department of Agriculture recommendation for water classifications on the basis of SAR values, the calculated SAR values for Awash river water at different localities of the study area indicates that it has an excellent water quality for the purpose of irrigation. However, taking into account the fact that the top soil of the irrigable land in the area is either covered with clayey silt or silt clay soils of alluvial and /or lacustrine origins, characterized with low permeability values along with the presence of high rate of evaporation suggests that the possibility of the occurrence of sodium hazard is anticipated unless a proper irrigation schemes will be applied to control the sodium extent in the soil as a result of its exchange for Ca ion and high rate of evaporation of irrigation water as a result of improper application of water in to the cultivated land.

6.1.2.2 Ground water

a. Ground water from Boreholes

The calculated SAR values of the ground water from the Boreholes in the Metehara area varies between 5.21 and 317.55 with the maximum value corresponding to the water samples collected from boreholes at mosque (Metehara town) and B.H at Catholic church in Metehara. Whereas the water samples with lower values of SAR are collected from boreholes relatively located close to Awash River.

In general, the analysis of the chemistry of the Groundwater specifically with reference to SAR as index of sodium hazard indicates that there are water quality problems for all groundwaters in Metehara area except those wells located close to the river, which likely have a chance of getting dilution of high ground water salinity by infiltrating river water.
As can be seen from the plot of SAR versus EC on figure 7.1for the classification of irrigation water, the groundwater of Metehara area, falls in the category of C_3-S_1 (high conductivity and low sodium hazard) and C_3-S_4 (high conductivity and very high sodium hazard).

Therefore, both on the basis of the measured electrical conductivity and Sodium absorption Ratio (SAR) the groundwater of the area seems to be unsuitable for agricultural irrigation under normal conditions.
Despite the ground waters from Metehara area where there are relatively sufficient previous chemical data, the groundwater at the other localities in the study area were not available and even it was not possible to collect the water samples for chemical analysis (during the present work. This is due to the nature of the well construction that does not allow collecting the samples just at the location of the wells with the exception of the well at Bofa village.

The groundwater at Bofa well presents an EC value of 1045 Micro S/cm and accordingly it can be classified as water with medium salinity hazard to crop irrigation. Concerning the groundwater at the other localities it was not possible to categorize them for irrigation purposes due to the lack of chemical as well as physical data.

But taking into account the geologic nature and the general chemistry of surface water (Awash river) at this area it can be suspected that the ground water outside Metehara area will present a medium water quality for irrigation and can be used on most crops provide that the leaching techniques are applied in accordance with the soil type and the period over which the water is applied. However the nature of the top soil of the irrigable land in the study area which is covered by clayey silt and or silty clay that seems to favor the exchange of N^+ for Cation in the soil may suggest the possibility of the occurrence of sodium hazard through prolonged irrigation practice is not out of expectation.

b. Springs (cold and hot)

The calculated SAR value for Sodere hot spring varies between 11 and 18 which classifies it as a water with good quality for irrigation but on the basis of EC value it presents medium to high salinity hazard and accordingly it can be classified as a water in the category C_3-S_2 (high salinity and medium sodium hazard) and it is supposed to be difficult to use for irrigation. In addition to this its low discharge makes the spring water unsuitable for irrigation. Regarding the water of hot spring at the south of Beseka lake which has a considerable large discharge value the calculated SAR value of its water varies between 66 and 237 and as result the water classified as the water that presents a very high sodium hazard on any crops but according to the classification on the basis of EC value it is classified as the water which presents a very high sodium hazard on any crops. But according to the classification on the basis of EC values it is classified as the water with medium salinity hazard, and based on both EC and SAR values the hot spring water at Metehara falls in the category of C_3 -S_4 and hence the water is unsuitable for irrigation.

In spite of the low discharges which may disregard the usefulness of cold spring located north of Beseka Lake, The sodium adsorption ration (SAR) was calculated and a value of 0.93 was obtained and accordingly the water falls in an excellent water class for irrigation. However on the basis of EC value it presents high salinity hazard and hence using both EC and SAR as index of classification the water of cold spring at Metehara is in the category of C_4- S_1 which is considered to be unfit for irrigation under normal condition.

c. Lake water (Beseka)

The calculated SAR values of the water from the Lake Beseka lies in the range of 246 to 753 which indicates that the water of the Lake belongs to a water class of a very bad water for irrigation and it can not be used for irrigation. This is due to high concentration of Na^+ ion in the water which favors the exchange capacity of Na^+ for Ca^{2+} in the soil which together with the accumulation of the Na^+ in the soil arise as a result of the effect of evaporation leads to the lowering of permeability of the soil to such an extent that can totally prevent the root of the crops from obtaining water.

6.2 Water quality for Domestic uses

6.2.1 General

The quality of water for domestic uses is evaluated in relation to certain developed Guidelines and standards. In general the developed and developing countries have different standards of water quality for drinking, but the universally accepted standard for domestics use is the water quality standard developed (recommended) by world health organization (WHO).

The quality of water for domestic uses refers to the quality of water as compared to certain developed standard or guide lines whether it is within the allowable limit or not. Thus the quality of water for drinking can be evaluated in comparison with the reference to both chemical and microbiological standards in the case of developing countries like Ethiopia which does not have its own well developed standard yet the universally accepted WHO standards for domestic uses is used as a reference for the evaluation of the water quality.
For the water quality for drinking with reference to chemical standard, the first compound to be considered is nitrate. Nitrate is a constructive element in natural ground waters and hence once large-scale nitrate contamination has occurred, it will take a considerable period of time before it is naturally attenuate through de- nitrification or dilution. This implies that it has long-term effect.

6.2.2 Surface water / Awash river/

Form chemical point of view the water from the Awash River where the majority of people (in the study area) with the exception of some camps of Nura- Era and Metehara state farms depends on Awash River for drinking. Its quality with respect to WHO chemical standard seems to be suitable. Some of the cations and anions that are mainly related to water quality for drinking are independently presented below with their relative extent of existence in water.

Nitrate

Nitrate leads to oxidation of normal hemoglobin to methaemoglobin that is unable to transport oxygen to the tissues. This may result in a dark blue coloration and in some cases as phyxiation and death hence the presence of nitrate in the natural waters for drinking should be seriously considered whether it is with in the allowable limit as compared with certain settled standards/ Guide liens .In the case of the Awash River water in the region under consideration the nitrate content (as No_3^- form) of the water at Nura-Era lies in the range 0.7-4.3 mg/l while that of Metehara area varies between varies between 0.88-2.2 mg/l and in both area its content lies much below the maximum admissible values, which According to WHO standard is 50mg/l.

Fluoride

Fluoride in drinking water can have toxic effect in both excess and deficiency condition .The excess of fluoride may lead to dental or skeletal fluorosis and the deficiency may cause dental carries, which is weakening of the teeth. Thus in some circumstances fluoride may be added to the drinking water supply. The acceptable concentration of fluoride in water is partly related to climate, as in warmer climates the quantities of water consumed are higher and as a result leading to greater risk of fluoride problems as overall intake decreases.

The fluoride content of the water of Awash River in the region varies from 0.6-1 mg/l at Sodere and at Nura-Era and from 0.67 to 1.5 mg/l at Metehara while the fluoride content of the drainage water in irrigation channel at Metehara area varies from 1.68 to 1.70 mg/l that lies beyond the upper limit of WHO standard and accordingly the drainage water is unfit for domestic uses but the Awash River water is with in the allowable limit of WHO standard with reference to fluoride. Though the Awash River with respect to in organic constituent generally lies within allowable limits but due to its high turbidity and high bacterial pollution it is not fit for domestic uses without treatment.

6.2.3. Ground water for drinking

a. **Water from bore holes**

The fluoride content of the borehole at various localities of Metehara area various between 2.2 and 73 mg/l and this makes the water from bore holes at Metehara area are unsuitable for drinking being the fluoride content of all the water from boreholes is lying in the ranges beyond the admissible limit of WHO standard. Whereas the Nitrate content of the Boreholes water varies between 0.88 and 209 Mg/l and the maximum values corresponds to waters of Boreholes located in the farm and settlement camps which supposed to be exposed to some source of pollution due to the impact of the use of in organic fertilizers and in direct agricultural impacts related to the settlements in the agricultural camps while the lower Nitrate content associated to the water from bore holes located relatively for away from the farm and settlement areas.

In addition to this Mn ions were detected in the water of the majority of boreholes with the extent varies between 0.1 and 1.8 mg/l while festal were also identified in the range of 0.02 to 0.84 mg/l. The content of Mn ions of the water from some boreholes at the region indicates that the water is not fit for drinking as the detected values are beyond the admissible limit even with respect to Ethiopian standard.
Regarding its quality with respect to major caion and anions such as Ca^{2+}, Cl^- and $S0_4^{2-}$ the water of the majority of the Boreholes exhibit the values with in the allowable limit with exception to waters form some boreholes, which revealed chloride and sulphate values beyond the recommended range.

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b. Quality of Water from Beseka Lake for drinking

The nitrate concentration (as NO_3^-) of the water of Beseka lake collected at various localities of lake varies between 7.04 and 41.6 mg/l that falls in the recommended limit of WHO standard for drinking waters. The fluoride content of the Lake water varies in the range from 10.6 to 61 mg/l, which falls out side the admissible ranges. Therefore it is unfit for drinking, beside this the average values of Mn ions and some major anions like Cl^- and So_4^{-2} ions are also identified in the range beyond the recommended limits (see table5.9) while Ca^{++} ions Fe totals are occurred in trace amount (1.6-6.4mg/l for Ca and 0.07 to 0.2 mg/l for Fe total, lying in the admissible range. The pH of the lake water lies in the range of 9.29 to 9.7mg/l. Thus the over all chemistry of the of the Lake water makes it unfit for domestic uses.

c. Quality of hot and cold spring water for drinking

The water from Sodere hot springs exhibit the fluoride content of 2.7 to 4.35 mg/l while its Cl and SO_4^{2-} contents vary in the ranges of 117.3 to 170.2 mg/l and 130.to 181 mg/l

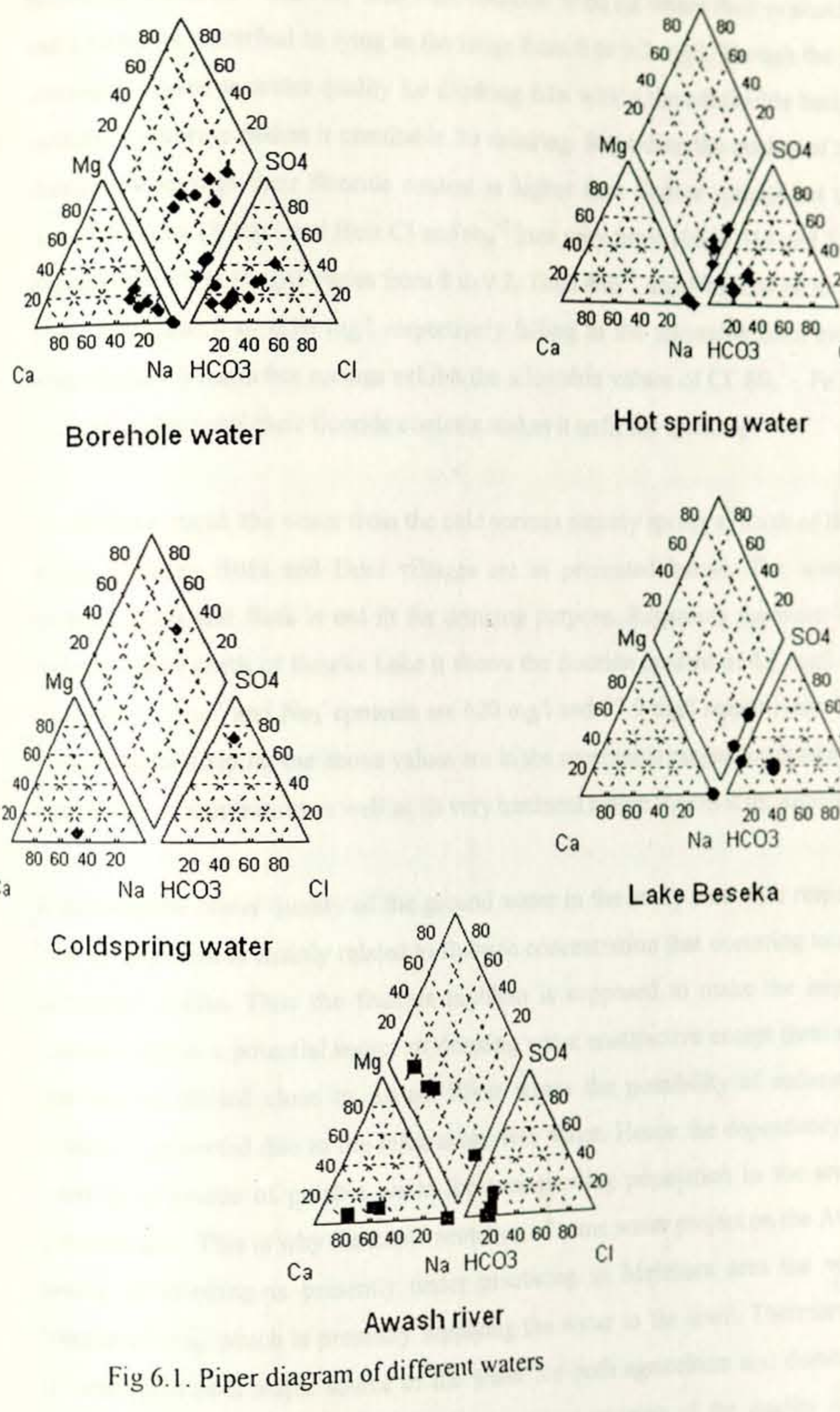


Fig 6.1. Piper diagram of different waters

respective. The Mn^{2+} and No_3^- ions were obtained to be nil where their evaluation were made and Fe total is identified to lying in the range from 0 to 0.2 mg/l. Though the majority of its chemistry related to water quality for drinking falls within the admissible limits, but its high content of fluoride makes it unsuitable for drinking. Regarding the quality of the water from Beseka hot springs their fluoride content is higher than Sodere springs hot that lies in the range of 5.5 to 13 mg/l and their Cl and so_4^{-2} ions vary from 105 to 315 and 150 to 300 mg/l respectively while the pH varies from 8 to 9.2. Their Mn^{2+} and No_3 ions lie in the ranges of 0 to 0.3 mg/l and 0 to 6.16 mg/l respectively falling in the allowable limit even though, the water of lake Beseka hot springs exhibit the allowable values of Cl^- $S0_4^{2}$-, Fe total and mn^{2+} ions concentrations/ their fluoride contents makes it unfit for drinking.

On the other hand, the water from the cold springs namely spring at north of Beseka lake and spring between Bofa and Doni villages are as presented below. The water from spring between Doni and Bofa is not fit for drinking purpose. Regarding the water quality of cold spring located north of Beseka Lake it shows the fluoride content of 4.2 mg/l and 85 mg/l of Cl^- while its So_4^{-2} and No_3^- contents are 620 mg/l and 27.9 mg/l respectively. With exception to its fluoride content, the above values are in the acceptable ranges for drinking water but its high F^- ion concentration as well as its very hardness nature makes it unsuitable for drinking.

Regarding the water quality of the ground water in the study area with respect to domestic uses the problem is mainly related to fluoride concentration that occurring totally beyond the acceptable limits. Thus the fluoride problem is supposed to make the importance of the groundwater as a potential source of drinking water unattractive except from some boreholes that can be drilled close to Awash River where the possibility of reducing the fluoride content is expected due to the infiltrating river water. Hence the dependency on the ground water as a source of potable water for ever-growing population in the area seems to be questionable. This is why the implementation of some water project on the Awash River as a source of drinking is presently under practicing in Metehara area the water supply of Nazareth town, which is presently supplying the water to the town. Therefore, Awash River is considered as a major source of the water for both agriculture and domestic uses in the region under consideration and hence a proper mentoring of the quality of Awash River water is required to properly utilize it through prolonged period of irrigation practices.

CHAPTER SEVEN: IMPACTS OF AGRICULTURAL ACTIVITIES ON THE GROUNDWTER QUALITY

7.1 General

Besides the geological process like dissolution and precipitation, hydrolysis, adsorption in the unsaturated zone and exchange process in the groundwater zone which are supposed to have an obvious influence in altering the ground chemistry from its initial one as consequence of water and rock interaction through long flow channel, very long contact time and contact surfaces, the water quality can also affect through direct and/or indirect biological processes as well as man made factors. The indirect influences of biological process on the ground water chemistry includes change in-soluble salts of the soil due to microbial break down of in soluble substances, temporal with- drawl of nutrients by higher plants and an increase of the co_2 content of the ground air through the process of roots respiration and microbial activities.

In addition to this, the groundwater as well as surface water quality can be affected through human and animal waste Products that contribute to the supply of soluble salts. In general, the effect of biological process on the groundwater quality are manifested mainly through the increase or decrease in the concentrations of some chemical compounds like nitrate, sulfate, etc, as a result of nitrifying or denitrifying processes caused by microbes as well as through their catalyst effect in the reduction of sulfate. On the other hand, the changes in the quality of ground and surfaces waters can be caused through both direct and indirect influences of human activities. The direct effects of man on the quality of waters caused by the addition of natural and synthetic substances into the waters due to the activities of man that can be manifested mainly through the process of the application of fertilizers and herbicides to the agricultural crops. The chemistry of waters can also be indirectly affected by human settlement, which is also indirectly related to agricultural activity. Further more, the indirect effects leading to the changes in the water quality as a result of man made factors can be occurred by human interference with hydrological, physical, chemical, and biological process without any direct addition of substances into the waters. The best example of indirect effect caused by human made factor is the rise in CO_2 content of the ground air due to the cultivation of soil by man.

In general, man causes the significant changes in the waters but the major change causes by man and animals are expected only when human settlement and large-scale animal husbandry are involved.

According to Mathess, (1972) anthropogenically polluted groundwater is water in which the total dissolved and suspended solids caused directly or in directly by man is higher than the maximum permissible concentration relative to the limiting values are laid down in national and international guidelines for potable, agricultural or industrial waters. Therefore, the first possible agricultural activities on the groundwater and Awash River water where agricultural activities are extensively under practices are supposed to be water pollutant that could be occurred as a result of the application of fertilizers and pesticides to agricultural crops. The raised in the contents of bicarbonates, chloride, ammonia, nitrate (NO_3^-) ions and high value of manganese & phosphates ions can serve as the indicator of groundwater pollution, however it has to be proved at any given time and place that these indicators are not attributed to geological origin.

7.2 Agricultural Activities in the Region

The majority of the irrigable land in the region is occupied by state farms in which the considerable large proportion of irrigable land are under perennial crops dominated by sugar cane and citrus crops. Sugar cane is highly successful crop produced by the Sugar Corporation at Wonji and Metehara centers, while Horticultural Development Corporation runs several farms along Awash River. Besides these, the production of maize, cotton, tomato, onion, orange, mango, etc.

Almost all farms use fertilizers of different types such as urea, phosphate, etc. The main fertilizers applied to most crops is urea (46% N) which on many farm is the only fertilizer applied. Where as, phosphate in the form of triple super phosphate (approximately 18% P) and diammonimum phosphate (approximately 21% N and 23% P) is also applied on most crops in the region, except sugar cane. In addition to the application of fertilizers, insecticides and fungicides are applied to most crops. The lists of pesticides used in Awash valley are presented in the table below.

Table 7.1 List of pesticides used in Awash valley	
Aldnix 48%	Medopar
Azodrin (DDT) 10/10	Mencozev 80%
Anthio	Mitac 20%Ec- ULV
Anetellic	Nuvacron 40,SEW
Acarin	perfection
Basudin 600 EC	parathion 50%
Cymbush	Quel tox
Curacron	Ripcord
Cidial 85 AS	Roger 40 ULV
Codal 400 EC	Roudup
Dursban 40 ULV	Ronstar/Divron
Dimecron 100 SCW	Santara
Ditane M-45	Sunicion 50 EC
Dursban 24 ULV	Safsan
Ekathin 24 ULV	Thiodan 25 ULV
Exactin WF	Thiodan 35% EC
Ethion 50 ES	Thionex 25 ULV
Endrin 1.6 ULV	Tiezene 80
Fertilion combi	Torbidan
Gusathion	Tamaron
Koicide 101	UltracideUlvair
Hosathion	Combi 500
Metasystox R 50	Volt Custahacion

Sources: original source is Awash Agricultural Corporation data abstracted from table 3 and 7 in Halcrow 1985, Annex J.

Hence it is evident that in the region where agricultural activities are extensively under practice, the ground water is supposed to be susceptible to pollution mainly as the consequence of the applications of fertilizers and pesticides as well as through the act of human wastes products disposal, which includes the infiltration of waste from septic tanks and solid waste disposal associated to human settlement related to agricultural activities. Therefore, possible infiltration of waste from septic tanks in the area of human settlements, and fertilizers and pastorals applied to agricultural crops are considered as major sources of possible groundwater pollutants. Presently the agricultural activities run on the geological formations that totally covered by alluvial, laccustrine and unwedded fine-grained tuff of volcanic rocks. In Metehara farms, the agricultural activities are totally performed on alluvial and laccustrine deposits whereas Nura-Era farms run on alluvial and unwedded fine-grained tuff composed of silt to sand size particles. Regarding the future expansion of the agricultural activities in the study area, it is totally controlled by the geology of the area. The different volcanic rocks that surrounding the alluvial and the laccustrine deposits are not suitable for agricultural activities, so that the future expansion of the agricultural activities in the area are largely dependent on the presence of alluvial and laccustrine deposits. In addition to this, in Metehara area, the rise in the level of Beseka Lake has also influence on the expansion of the farms area unless proper measure could provide.

7.3 Inorganic fertilizer

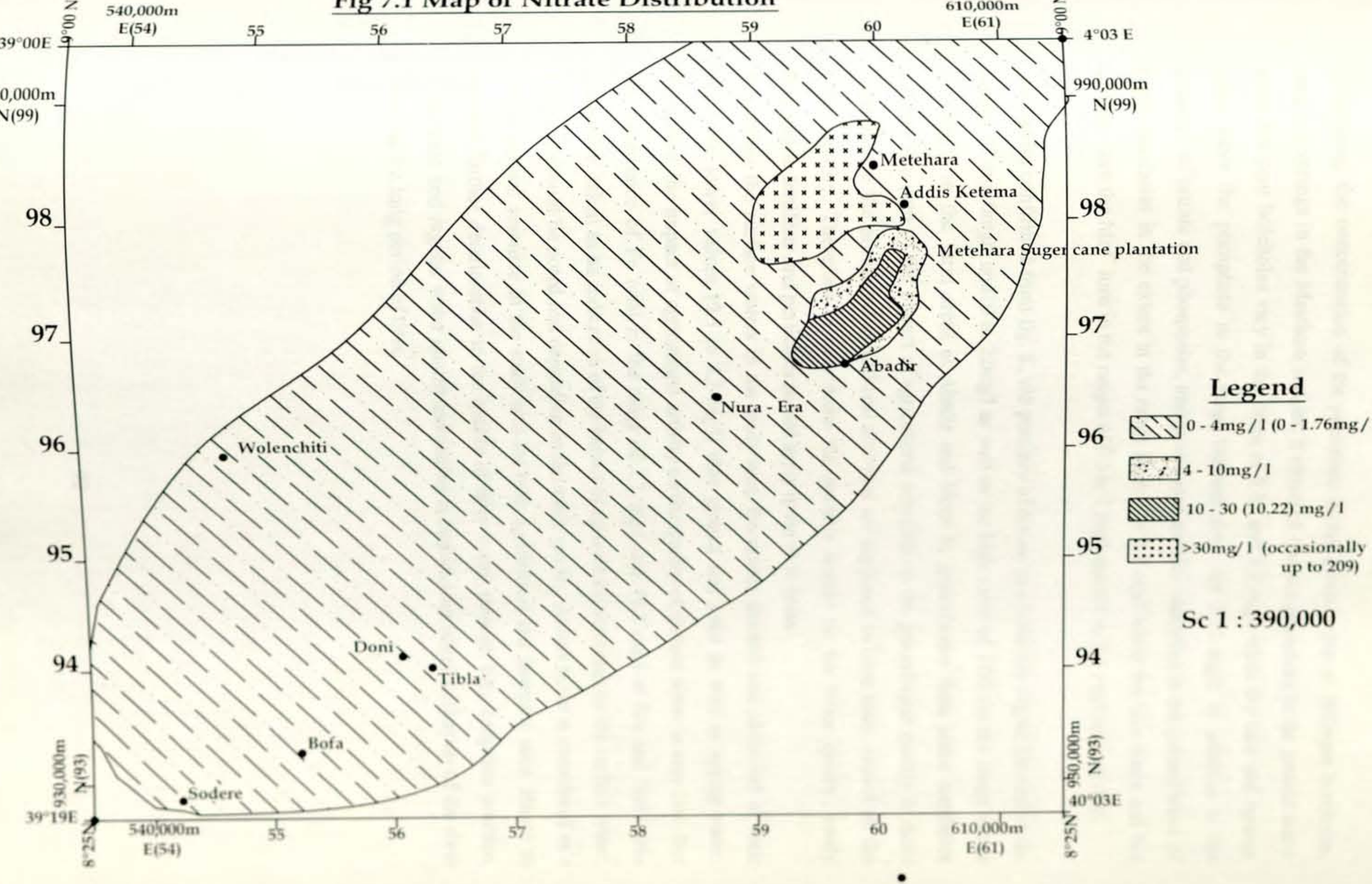
As already mentioned above, all farms used fertilizers of different varieties such as nitrogen and phosphate bearing fertilizers, among which urea (46% N) is the major product applied on many crops in a various farms consequently, the possibility of getting nitrate and phosphate concentrations in the ranges beyond the admissible limits of national or international guide lines for potable agricultural or industrial water in the ground and surface water of the region is anticipated. Moreover, the use of fertilizers are considered to be the major cause to rise in the amount of soluble salts in the ground water such as chloride, sulphate, nitrate, phosphate, calcium, potassium, magnesium, ammonia and sodium in various amounts. In addition to this, all fertilizers are supposed to cause indirect effect by stimulating bacteria in the soil. In the case of the region or Awash valley, where nitrogen and phosphate bearing fertilizers are dominantly applied to many crops, the presence of nitrate and phosphate in the groundwater in the extent beyond the average limit is anticipated. Consequently in the Metehara farm areas where relatively higher values of inorganic fertilizers are supposed to be applied, shows the nitrate content in the range of 1.76 to 21.12 mg/l. This value is in the range of admissible limits for drinking. Hence the groundwater in the farm areas does not show a clear sign of deterioration in quality as a result of the application of fertilizers. But the comparison between the relative abundance of NO_3- concentration in most boreholes at Merti, Metehara

Sugarcane and Abadir farm areas and the boreholes located far from the farm areas indicates that the groundwater from some boreholes particularly those located West, North and northeast of Lake Beseka show low values of nitrates than those boreholes in the farm areas. This situation can be taken as the sign of the impact of the application of fertilizers to the various crops. To visualize this concept, it should be noted that the nitrate content of the majority of the Boreholes in the farm areas are lying in the range of 9.2 to 21.12 mg/l. Whereas the No_3^- content in the boreholes far from the farm areas is lying in the range of 0.88 to 1.76mg/l, which clearly indicates some sign of the impact of the Agricultural activities on the quality of the groundwater of the Metehara area. However in contrary to the stated general trends of NO_3^- distribution in the ground water of some well in the farm areas show lower values of nitrate probable due to local variation in the purifying capacity of the soils in the unsaturated zone, or due to nitrifying effect of microorganisms or else due to high rate of NO_3- in take by crops.

In addition to this some boreholes in Metehara town reveals NO_3^- concentration, which have been identified in the extent beyond the recommended limit of WHO standard. Thus boreholes includes borehole at Mosque in Metehara (154 mg/l), B.H near Catholic Church (121 mg/l) B.H H.BH 26 and 27 with NO_3^- in the amount of 209 mg/l and 149.6 mg/l respectively. The high value of the NO_3- in these boreholes are most probably related to the pollution that can be associated with the Septic tank or sewage lines and this indicates a clear sign of pollution or contamination due to man made factors possibly through the effect of Human settlement. It could be reached at this conclusion, taking in to consideration the fact that the existence of nitrates, Na^+, and Cl^- in their relative high values in the ground water of thus boreholes, which can be related to the presence of human excreta.

The ground water in the majority of the Boreholes have the NO_3^- contents in the range of 0.88 to 37.4 mg/ l while the nitrate concentration of hot and cold spring 0.0 to 6.16 mg/l and 27.9 mg/l respectively and Lake water falls in the range of 7.04 to4 1.6 mg/.

Fig 7.1 Map of Nitrate Distribution



Concerning the concentration of the phosphate in the groundwater of different boreholes, lake and springs in the Metehara regions, it observed that the phosphate in the ground water from different boreholes vary in the range of 0.03 and 9.2 mg/l while the lake and springs water have the phosphate in the range between zero and 2.13 mg/l. In addition to the presence of nitrate and phosphates, manganese ions are also identified in the ground water of many boreholes in the extent in the range from 0 to 1.8 mg/l while the lake water and hot springs have the Mn^{2+} ions in the ranges of 0.3 to 1 mg/l and 0.1 to 0.3 mg/l respectively.

As can be confirmed from fig. 8., the presence of nitrate in a relatively higher amount in the ranges of 4to10mg/l and10 to 22mg/l as well as the high value of TDS (in the range above 1500mg/l) in the farm areas at Abadir and Merti in groundwater from some boreholes indicate the sign of the impact of agricultural activities on the groundwater quality in these areas Hence the prolonged agricultural activities are supposed to have more impact on the water quality. Therefore to over come the possible impact on the water quality, easily degradable fertilizer and pesticides should apply in the farm areas.
Regarding the surface waters in the study area, the nitrate amount was identified in their relatively lower values (0.3 to 4.3 mg/l) than ground and Lake as well as spring water. Therefore, the impact of agricultural activity on the quality of surface water is very low. But the occurrence of Fe total in the range of 2.7 mg/l and 18.2 mg/l at Era and Nura area respective, taken as an indication of the impact of agricultural activities on the surface water. Lastly it should be noted that depending on the water quality, Awash River is considered as a major natural resource in the study area for both agricultural and domestic uses. Hence to prevent further deterioration in the quality of river water, through long irrigation practice, systematic and regular water quality monitoring is required for better utilization of the river water in the long period of time.

7.4 Pesticides

Though the presence of organic chemical of pesticides origin in the ground water is expected where the application of pesticides on the crops in big farms are under practice unless their geochemical behavior in the water and soil with respect to the physical, chemical and biological processes which control their persistence, and transport which supposed to avoid their infiltration into the ground water. However, due to luck of data on the analysis of organic chemical of pesticides origin, it was not possible to determine their exact values in the water of the study areas. Moreover, it worth to note that the analysis on the chemistry of the pesticide origin are not carried out in any laboratories in the country, so that it was not possible to quantify the impact of the application of pesticides on the ground and surface waters in the region (Awash valley). However according to the list of the pesticides used in the region none of these are persistent and all are to be degradable (Lacto 1985 annex1) and the fact that the top soil of the irrigable lands are mostly covered by clayey silt and /or silty clay which characterized by low permeability material, it is possible to say that the impact of the applied pesticides on the ground water as a source of pollutants are not in the condition that can endanger the quality of ground water.

However, even if there was no available data on the level of pesticides used in the study area nor their concentrations in Awash River or canals. But all the pesticides are supposed to cause some degree of toxicity. Thus a risk of toxicity to people and cattle using the canal and drainage water is anticipated. In view of this it is essential to carryout a study of such incidences in order to identify their nature and causes. In particular the study shall be related to those workers and other who are subjected to repeated exposure to the pesticides, which may reveal a cumulative effect, resulting in the gradual onset of poisoning symptoms.

CHAPTER EIGHT: IMPACT OF BESEKA LAKE LEVEL RISE ON WATER QUALITY

8.1 Impact Beseka lake level rise on water quality

According to the assessment of the available data, agricultural water quality of Awash River water with respect to EC (200-273µs/cm) falls in a good water class, for agricultural water uses. Where as its agricultural quality with respect to Sodium Adsorption Ratio (SAR) as a measurement of an index of Sodium hazard lies in the range from 0.58 to 0.75,this indicates that the river water falls in an excellent water class for agricultural purpose.

Regarding the agricultural water quality of the groundwater from bore holes except those located close to Awash River, produces an EC values between1050and 5500µs/cm while its SAR value lies in the range of 4.82 to 317.55. Consequently the over all agricultural as well as drinking water quality especially with respect to fluoride content, the groundwater is identified in a conditions which is not suitable for both agricultural and domestic uses. On the other hand, the water from Lake Beseka, cold springs and hot springs are exhibiting the water quality that is not suitable for agricultural and domestic uses. Hence, this situation makes the Awash River as a major water resource in the study area which requires due attention to preserve its quality and its proper utilization for prolonged agricultural and domestic uses without deterioration the quality. Therefore, attention has to be given to water quality and environmental problems that can be caused due to the impact of further water resource development in the area. This is because of the fact that ecological changes that had resulted through the development will create conditions favorable for introduction and propagation of different diseases such as malaria, Schistosomiasis, Dysentery etc. Therefore, the impact of According to the work of Halcrow, 1989, the major environmental health problems currently identified, include malaria, Schistosomiasis and Onchocerciasis, Leishaniasis and Arboviruses. Hence the impact of future development of the water resource shall be considered in relation to the existing environmental health conditions as well as the introduction of further hazards related to expansion of irrigation, development of high water table area, water harvesting and spate (river flood) irrigation.

future development of the water resources in the study area require due attention with regard to environmental and health problems as well as water quality deterioration that can be related to prolong agricultural activities which are supposed to result in the problems of salinity and pollution. In addition to this the rise of level of Lake Beseka can be also taken as other impact of the water resource on the environmental and water quality of Awash River as well as groundwater from some bore holes near the Lake through time.

According to the work of Halcrow, 1989, the major environmental health problems currently identified, include malaria, Schistosomiasis and Onchocerciasis, Leishaniasis and Arboviruses. Hence the impact of future development of the water resource shall be considered in relation to the existing environmental health conditions as well as the introduction of further hazards related to expansion of irrigation, development of high water table area, water harvesting and spate (river flood) irrigation.

Currently Awash River water is identified in a good water quality especially for agriculture while groundwater, Lake water, cold and hot springs are already identified in a condition, which is not suitable for agriculture and domestic uses. However, further water resource (Awash River) development is assumed to cause salinity and agricultural pollution problems through the application of fertilizers and pesticides as well as the influence of human settlement associated with agricultural activities and Urban development. Beside this the rise in the level of Lake Beseka with time will pose impact on the quality of the water of the area, even at the present, it has been felt on the quality of water supply from some bore holes at Metehara town the occurrence of F^- and NO_3^- ions in the ranges beyond the recommended limits can be taken as the indicators of the impact of Lake water on the quality of groundwater from some boreholes. Hence, in the future unless possible-controlling mechanisms are applied on the rising level of Lake Beseka, flooding of adjacent lands and services such as road and rail will be continued. This situation is assumed to cause drainage of the highly saline Lake water into the Awash River water that can induce salinity in the river water and adversely affects the quality of Awash River water for both agricultural and domestic uses in Metehara area and other localities below Metehara town. The rise in the salinity is related to the development of high water table area through prolong agricultural activities and application of excess water into the irrigated lands without proper management.

The application of excess River water into the irrigated lands through prolong agricultural activities together with the effect of high rate of evapotranspiration in the area is assumed to result in an accumulation of soluble salts in the top soil formation which can prevent the water from reaching the root zone of the crops and result in low productivity of agricultural crops in the area. Moreover the further development of agricultural activities in the study area is assumed to lead to the problems of agricultural pollution in the groundwater of the area. The polluting substances that can change in the natural water quality of the River and the groundwater is derived from fertilizers and pesticides applied to irrigated lands as well as due to poor sanitary facilities in the irrigated area especially in the camps and settlement villages (which is not presently satisfactory) and act of waste disposal.

8.2 Impact of the rise in the level of Lake Beseka on environment and water quality

At present the impact of the rise in the level of Lake water have been felt in (deterioration of) the groundwater quality from some bore holes in Metehara town as well as in an increase in the salinity of the groundwater as a result of intrusion of highly mineralized lake water into the groundwater at the northeastern side of the lake and development of high water table. The rise in the level of lake water has also caused problems on the existing infrastructures like road, railway line, Metehara sugar cane plantation, grazing lands, etc. The main road and railway from Addis Ababa to Diredawa have been previously constructed close to the lake, the rise in the level of Lake water resulted in the submergence of railway and road below the lake water which required raising of these services to maintain the transportation from Addis Ababa to Diredawa. Consequently the railway Enterprise and Ethiopian Road Authority have been forced to raise these infrastructures several times. According to the work of the Ministry of water Resource, on the rise of lake Beseka almost every year, the railway line has been raised three times in which each rising has costed 3 million birr while the Ethiopian road authority has been made road maintenance almost every year since the rise in the level of lake water has been recognized.

As the lake is situated close to Metehara sugar cane plantation its rise has caused serious problems on the farmlands. According to the report of MOWR (1998) a land area of about 161.55ha of Metehara sugarcane plantation has been affected, in which 55.55ha of the land has been totally lost while the productivity of the remaining 106ha become very poor as a result of insufficient mechanical operation caused by high water table and high sodium salt deposit. In addition to this, the grazing and woodlands have been affected and as a result it caused serious problems on Nomadic people in the area.

The report of MOWR (1998) on the rise in the level of lake Beseka indicated that in the early 1960s the lake area was $5km^2$ and in 1998, it covered about $40km^2$. This indicates the complete loss of $35km^2$ land, out of which an area 0f $0.55km^2$ belongs to Metehara sugarcane plantation while the remaining $34.45km^2$ corresponds to grazing and woodlands. Hence it can be concluded that the rise in the level of Lake water has caused a serious problems on social and environment, and the quality of the natural water. Therefore, unless a proper remedial measures will be taken on the rise in the level of lake Beseka, in the future the flooding of the adjacent lands and services and further the over flow of the Lake water is anticipated. If this is the case, drainage of highly saline Lake water into Awash River will result in adverse deterioration of the quality of both Awash River and groundwater. The deterioration includes the quality for both domestic use and agricultural application.

A number of big farms are in operation in the area lying below Metehara town and hence the deterioration in the water quality leads to serious problems on the economy of the region in particular and the country in general.

Beside the above mentioned impacts, it should be noted that Awash River is the major fresh water resource for drinking purpose, for the major part of Afar People and hence due attention is required in regards to the pollution that can be caused due to the applied remedial measures. The impact of the release of water from Beseka Lake into Awash River must be addressed to the down steam users.

8.3 Remedial measures to control the rise in the level of lake Beseka

According to the previous work on the rise of Lake level and remedial measure by MOWR (1989) Lake water discharging into Awash River is one of the proposed remedial measure to control the Lake level rise of Lake Beseka, however, as can be observed from table 9.2 it results in change in the relative proportion of the individual ions of the river water like Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, $CO_3^{2-}$and HCO_3^{2-}. Except Ca^{2+} andMg^{2+} ions the change is manifested through an increase in their relative abundance in the River water along the River course. However, except F^- all these ions occur within the permissible limited setted by WHO for both drinking and agricultural uses.

Table 8.1 Water quality of Awash River before and after mixing lake water into Awash with the ratio of 1:49 are calculated from the original data from laboratory of MoWR.

nature of sample & locality	Aver.che . prop.of L.water	awash at Metehara before mixing	awash at Meteahar after mixi. mixing	awash at melkesa before mixing	Awash at melkasa after mixing	awash at Mile before mixing	awash at Mile after mixing	awash at tendaho after mixing	awash at dubti before mixing	awash at dubti after mixing	awash at asaita before mixing	awash asaita after mixing
EC (micro s/cm)	5974	273	386.84	342	454.64	582	689.84	683.96	624	731	582	684.8
Na^+(mg/l)	1702	34.5	67.85	114	145.76	80	112.44	123.71	105	137.94	92.5	124.6
K^+(mg/l)	60.2	5.9	7.1	5.7	6.79	9.8	10.81	10.81	10	11	9.2	10.2
Ca^{2+}mg/l)	2.16	21.6	21.19	37.7	6.67	33.6	32.95	31.38	33.6	32.95	32	31.3
tota Fe(mg/l)	0.57	2.9		10.2	10.00	6.32	6.196	5.71	7.78	7.63	6.32	6.19
F^-(mg/l)	25.8	1.37	1.86	1.15	1.64	1.4	1.9	1.93	1.4	1.9	1.39	1.88
Cl^-(mg/l)	539	9.18	19.78	9.93	20.51	44	53.9	50.96	49	58.8	41	50.9
NO_3^-(mg/l)	35.2											
CO_3^{2-} mg/l)	480	nil	9.60	9.6	19.01	12	21.36	21.36	12	21.36	12	21.3
HCO_3^- (mg/l)	1937.36	131.8	167.91	180.6	215.74	244	277.87	275.5	231.8	265.91	246.4	280.
SO_4^{2-} (mg/l)	606	11	22.90	13	24.86	17	28.78	27.8	12	23.88	12	23.8
SAR	266	1.85	7.13	4.25	9.49	3.32	7.57	9.14	4.7	9.93	4.48	9.71

Regarding F^-, it occurs in the range beyond the recommended limit (WHO 1.5 mg/l) after discharging Lake water into the River in a ratio of 1: 49 by volume at all point below

Metehara. The change that could arise after discharging is presented in table 9.1. Moreover, the concentration of F^- is expected to be more than the value indicated in the table 9.1.

The majority of the people in the region below Metehara are dependent on Awash River for drinking. Hence this fact emphasis the requirement of due attention on the health risk that can be caused because of the water quality with respect to F^- concentration that exist beyond the recommended limit. Beside this an increasing trend in the temperature along the course of the river will further aggravates the health problems associated with F^-concentration that exists above the permissible value (1.5mg/l) through the effect of an increase in the consumption of water as a result of high temperature in the region.

CaF_2 precipitation is required to reduce F^- discharging water. On the other hand, according to the work of MoWR(1989) the Lake water is increasing from time to time. Since 1977 it has been increased at an average of 5.7Mm^3/y and then continuously increasing trend has been observed since 1987. Its average increment is 7.45Mm^3/y. Moreover an average of 13Mm^3/y increment has also been observed since 1996. The critical volume of the Lake water at which an overflow to Awash River is 325.69 million m^3, which will attain at 952.95m.a.s.l. And the Present Lake volume (1989) is 231.306 million m^3, which corresponds to 950.701m-.a s.l.

Based on the above data and regression analysis the MoWR, proposed the time of the overflow of the Lake water into Awash River will occur **at 12 or** 16 year time in accordance to the data and regression of the Lake volume increment since 1987 and an average increment since1977 respectively. This situation makes the recommendation of other remedial alternative unfeasible to control the rise of Lake Level. Hence the proposed lake water discharging into Awash River as a remedial measure to control the lake level rise is considered to be the better alternative, even though it also has a drawback of deteriorating the river water with respect to F^- concentration. This is because of the fact that leaving the lake without intervention and trying other mechanism to control the effect that can be caused on the road, rail, and the town leads to the overflow of the lake water, which can lead to adverse deterioration to the quality of the river water than the effect caused by the discharging. Therefore to utilize the water resources (such as Awash River) for prolong period of time without adverse deterioration in the water quality the following controlling measures should be taken.

1. Reduce the use of fertilizers and pesticides. This can be achieved by testing the soil of the study area with a view to determine its nutrient makeup and lacking nutrient and apply only the fertilizers bearing the lacking nutrient, or apply manure rather than fertilizers.
2. If possible, grow crops that require little or no fertilizers and the pesticides.
3. Apply easily degradable fertilizers and pesticides.
4. Rotate irrigated crops.
5. Properly locate, construct and maintain septic system and improve waste disposals system in the camps and settlement villages.
6. Establish and operate cost effective water quality monitoring system for agricultural uses.
7. Prevent adverse effect of agricultural activities on the water quality for other Social and economic activities through optimal use of, on- farm inputs and minimization of the use of external inputs in agricultural activities.
8. Establish biological, physical and chemical water quality criteria for agricultural water users.
9. Improve sanitary facility in the camps and settlement villages.
10. Apply proper scheme of irrigation.
11. Irrigate during morning and evening when the evaporation rate is assumed to be lower.
12. Apply a controlling mechanism on the rise in the level of Lake Beseka.

CHAPTER NINE: THE IMPACT OF ANTHROPOGENIC ACTIVITIES ON WATER QUALITY

In order to assess and evaluate the impact of the practice of recreation at different recreational centers on the quality of Awash River water at Sodere, the measurement of pH, CE and TDS have been made at up and down steam side of Sodere compound and at various places between the two extreme points, especially at the localities close to different recreational centers. Accordingly the pH of Awash River was identified to be 8.1 and 7.83 at up and down streamsides of the compound respectively. While the pH the at the localities close to the recreational centers were appeared in the range from8.05 to8.22, in which the lower pH value corresponds to the measurement made near Abadir bath where the discharge of hot spring into in to Awash River has been experienced during recreation period and the value of pH belongs to the measured performed adjacent to the swimming pool near the restaurant next to the main entrance gate.

The assessment of the measured pH of Awash River more or less falls in narrow alkalinity range with the exception to the measurement made at down steam side of Sodere compound where the over all effect of hot springs on the quality awash river is anticipated to be manifested. This is due to the reason that the different hot springs at the area next to the main gate are collectively discharging into the river though collector drainage pipe. The measured ph of Awash river at the localities below the point where the discharge of springs are occurring was identified to be 7.83 and the reason for this lower value seems to be related to the over all effect of hot springs on the quality of Awash River.

The EC of Awash river along the course of the river within the compound was identified to occur in the range from353 to 783 mic in which the lower value seems to be related to the measurement made at the locality where the amount of hot springs water is supposed to be minimum while the maximum is presented by the measurement performed at the point where the over all impact of hot springs on the quality of Awash river is expected to be manifested. Regarding TDS of the river, it shows similar trends as CE, as the two-parameters exhibit a direct relation ship between them. The measured pH CE and TDS data of Awash river at the different point along the course of the river within Sodere compound, indicate that, the river water reveals a clear sign of deterioration of water quality due to the impact of the interaction between hot spring and the river.

Table 9.1 Physical data of different water bodies in the study area, as measured during April field visit

locality & water body	PH(mg/l)	Eh(m v)	Ecmicros	TDS(mg/l)	data of meas.	Temp. (co)
awash R. up stream	8.1	-0.91	453	295	16,april,2004	24.4
Awash R.Abadir bathr	8.05	-0.87	518	337	16,april,2004	26.2
awashswiming p.big 8.2		-0.94	358	234	16,april,2004	25
Awash swimng p.small	8.22	-0.95	353	229	16april,2004	24.7
awash dsteamof sodere	7.83	-0.77	783	470	16april,2004	30.2
Awash at Doni bridge	8.85	1.21	425	277	26,april,2004	26.7
awash at Merti jeju F.	8.1	-0.76	358	234	27,april,2004	25.1
Awashat Bole bridge	8	-0.86	365	240	27, april,2004	26.1
B.h. at Bofa	7.55	-0.38	1276	269	26,april,2004	31.9
Drainge at Merti factor	8.166	-0.094	541	294	26, april,2004	24.3
spring near Doni	10.35	-2	5110	3325	26,april,2004	26.8
drainage abadisa comp	8.22	-0.95	392	255	27,april,2004	24.9
drainageabadisa com.	8.23	-0.91	392	256	27,april,2004	25.5
Drainage tesfa hiwot co.7.84		-0.76	404	263	27,april,2004	24.9
drainage Bole bridge.	8.24	-0.94	354	233	27,april,2004	26.3
Sodre hot spr.abadir	7.21	-0.23	2500	1825	26,april,2004	48
sodere spr. Next to gate	7.27	-0.25	2450	1450	26,april,2004	48.9
hot spr. From colle.pip	7.26	-0.24	2190	1190	26,april,2004	48.8

From the assessment of the measured pH CE and TDS data, it was not possible to distinguish the impact of recreation on the water quality of Awash river as the change in the quality of the river water is assumed to be caused mainly due to the impact of hot springs. However, the practice of recreation at different centers is supposed to have some impacts on the quality of Awash river as its adds some salts and liquids wastes into the river but the sign of the change in the quality of the river water is considered to be identified during the period where the recreation activities are practiced by large number of people.

As the measurements of pH CE and TDS of the current work were made during the period where few people are practicing the act of recreation, hence the data does not show a sign of the impact of recreation on the quality of Awash river water at Sodere.

CHAPTER TEN: CONCLUSIONS AND RECOMMENDATIONS

The main target of the study is to evaluate the hydro chemical characteristics of the different water bodies, their temporal and spatial variability, agricultural and domestic quality, and the impact of agricultural activity on the water quality of the area. It was identified that, the TDS of the groundwater of the area falls in the ranges 0 to 500mg, 500 to 1000mg, 1000 to 1500mg >1500mg/l. It shows spatial variability in which the TDS of the ground water of the majority of the area lies in the range from 1000 to 1500mg/l while the TDS in the range above >1500 belongs to the ground water from some boreholes at Abadir and Merti farm areas and Metehara town as well as lake Beseka water, and cold and hot springs.

The chemical analysis of water samples show that there is five water family in the area with some interconnection except cold springs. The main problem of the groundwater in the region is related to fluoride concentration in which at the majority of the area its concentration occurs above the recommended drinking standard. Due to this reason, Awash River can be taken as the major fresh water resource in the area for both drinking and Agricultural purposes and hence, due concern should be given to Awash river water, by applying proper water management system & regular water quality monitoring system.

The ground water from considerably large parts of the study area does not indicate a sign of pollution as a result of the impact of agricultural activities in the region, except in some boreholes at Metehara town, and Abadir and Merti farm areas where relatively high value of nitrate concentration and TDS values were observed, which suggest some sign of the impact of agricultural activity on the quality of the ground water. In particular some of the boreholes in Metehara town exhibit a nitrate concentration that falls in the range 121 to 209mg/l, which clearly indicate the pollution due to leakage from septic tanks or as a result of the interaction between lake Beseka and ground water. Therefore, in order to avoid the adverse deterioration of the ground water quality through future agricultural activity in the area, proper sewage lines should be constructed and/or apply proper remedial measure to control the rise of the level of Beseka lake.

Regarding the groundwater at the majority of the study area, it is free from the sign of pollution as a result of the impact of big farms, but to avoid the possible pollution in the future due to the impact of pronged agricultural activity in the area, proper water management and regular water quality monitoring should be applied. The major cation of the ground water of the area as well as lake Beseka water are represented by Na^+ while the major anions is constituted by HCO_3^- ion.

The lake Beseka water is a highly mineralized water types in which its NO^-_3 (30 to 37.4mg/l and fluoride (19.5 to 28.5mg/l) ions are identified at relatively larger amount.

Except the hot springs at the southwest periphery, which contributes a large amount of water to lake Beseka, the cold springs in the area have no interconnection with the ground water, but Sodere hot springs dichargiing into Awash River while the hot springs at the south western side o0f the Lake Beseka has contribute a large volume of water to the Lake.

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Sunshine (hour)	8.62	8.29	8.35	7.25	9.01	8.3	8.3	7.4	7.5	8.83	8.75	NuraEra#(1977-2002)
PET (mm)	153.3	150.3	184.7	187.7	204.7	215.3	194.3	182	176.7	150	145.3	Metehra# (1985-2002)
PET (mm)	146	147.5	183	171.5	193.5	201.5	175.5	175	171.5	150.5	137.5	NuraEra#(1977-2002)
Discharge (in m^3/s)	31.986	31.809	29.25	33.708.	35.71	37.485	45.892	72.1	46.638	38.3	36.56	Wonji(1970-2002)
	32.522	33.688	33.22	54.19	37.66	36.623	57.465	94.8	42.622	39.51	39.83	NuraEra(1975-1996)
	20.286	21.881	20.59	18.22	24.47	21.081	59.805	89	35.118	21.17	21.72	Metehra(1982-2001)
Rainfall (mm)	4.87	3.43	49.75	11.43	37.02	44.5	196.25	73.1	57.83	7.38	6.58	Sodere(1998-2002)
>>	25.69	34.44	41.42	49.35	29.3	29.71	119.91	41.4	44.63	4.06	9.06	NuraEra(1977-2002)
>>	8.81	33.54	46.94	50.33	33.63	26.42	117.32	46.3	27.26	3.64	6.34	Metehara(1985-2002)
>>	8.64	13.36	54.67	48.52	64.82	70.01	253.02	107	61.12	15.9	8.17	Adama(1990-2001)
>>	9.82	13.5	47.41	49.94	35.76	78.86	185.5	72.3	59.31	3.27	9.36	Melkasa(1990-2001)
>>	5.81	30.43	56.7	59.01	65.54	58.18	212.43	90.2	19.46	5.58	2.16	Wonji(1985-1994)
>>	20.19	18.28	68.58	56.77	73.38	68.83	212.04	104	72.78	12.58	3.11	Wolechiti(1991-2001)

Annex 2 – Average monthly mean rainfall at different stations, Calculated from monthly mean rain fall data, from N.M.S.A

Locality	Jan	Feb	Mar	Apr	May	Jun	Jul	Sep	Oct	Nov	Dec	Elevation
Adama(1992-2001)	11.9	14.8	49.20	48.3	59.2	69.6	251	112	59.4	19.3	7.7	1622
Wonji(1985-1994)	5.81	30.43	56.70	59.01	65.54	58.18	212.4	90.2	19.46	5.58	2.16	1540
Awash mel.(1991-201	9.82	13.5	47.41	49.94	35.76	78.86	185.5	72.3	59.31	3.27	9.36	1540
Sodere(1989-202	4.87	3.43	49.75	11.43	37.02	44.5	196.3	73.1	57.83	7.38	6.58	1390
NuraEra(1977-2002	25.69	34.44	41.42	49.35	29.3	29.71	114.9	41.4	44.83	4.06	9.06	1220
Wolenchiti(1991-201	20.19	18.28	68.58	56.77	73.38	63.83	212	104	72.78	12.58	3.11	
Metehara(1985-202)	8.81	33.54	46.94	50.33	33.63	26.42	117.3	46.3	27.26	3.64	6.38	960
Average	12.44	21.2	51.43	46.45	47.69	53.01	184.2	77.1	48.7	7.97	6.34	

ANNEXES

Annex 1 – Summary of mean monthly values of different metrological and hydrological elements

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Sept	Oct	Nov	Dec	Locality
Temperature (0c)	23.6	22.5	26.45	26.95	27.9	29.2	26.7	26.7	24.8	23.05	22.5	Metehra (1985-2002)
Temperature (0c)	20.4	22.7	23.7	24.7	25.6	26.65	24.1	24.4	23.3	20.9	20.2	NuraEra(1977-2002)
Temperature (0c)	21.2	21.9	23	24.2	25.2	24.5	24	24.2	24.3	23.6	21.3	Sodere(1989-2002)
Wind speed (m/s)	1.86	1.94	1.9	1.69	1.69	2.28	2.29	1.56	1.55	1.65	1.75	Metehra# (1985-2002)
Wind speed (m/s)	1.58	1.64	1.65	1.65	1.92	2.98	3.24	1.74	1.61	1.56	1.54	NuraEra#(1977-2002)
Sunshine (hour)	9.05	9.2	8.78	9.2	8.24	8.87	7.6	7.76	8.79	9.54	9.58	Metehra #(1985-2002)
Sunshine (hour)	8.62	8.29	8.35	7.25	9.01	8.3	8.3	7.4	7.5	8.83	8.75	NuraEra#(1977-2002)
PET (mm)	153.3	150.3	184.7	187.7	204.7	215.3	194.3	182	176.7	150	145.3	Metehra# (1985-2002)
PET (mm)	146	147.5	183	171.5	193.5	201.5	175.5	175	171.5	150.5	137.5	NuraEra#(1977-2002)
Discharge (in m^3/s)	31.986	31.809	29.25	33.708.	35.71	37.485	45.892	72.1	46.638	38.3	36.56	Wonji(1970-2002)
	32.522	33.688	33.22	54.19	37.66	36.623	57.465	94.8	42.622	39.51	39.83	NuraEra(1975-1996)
	20.286	21.881	20.59	18.22	24.47	21.081	59.805	89	35.118	21.17	21.72	Metehra(1982-2001)
Rainfall (mm)	4.87	3.43	49.75	11.43	37.02	44.5	196.25	73.1	57.83	7.38	6.58	Sodere(1998-2002)
>>	25.69	34.44	41.42	49.35	29.3	29.71	119.91	41.4	44.63	4.06	9.06	NuraEra(1977-2002)
>>	8.81	33.54	46.94	50.33	33.63	26.42	117.32	46.3	27.26	3.64	6.34	Metehara(1985-2002)
>>	8.64	13.36	54.67	48.52	64.82	70.01	253.02	107	61.12	15.9	8.17	Adama(1990-2001)
>>	9.82	13.5	47.41	49.94	35.76	78.86	185.5	72.3	59.31	3.27	9.36	Melkasa(1990-2001)
>>	5.81	30.43	56.7	59.01	65.54	58.18	212.43	90.2	19.46	5.58	2.16	Wonji(1985-1994)
>>	20.19	18.28	68.58	56.77	73.38	68.83	212.04	104	72.78	12.58	3.11	Wolechiti(1991-2001)

Annex 2 – Average monthly mean rainfall at different stations, Calculated from monthly mean rain fall data, from N.M.S.A

Locality	Jan	Feb	Mar	Apr	May	Jun	Jul	Sep	Oct	Nov	Dec	Elevation
Adama(1992-2001)	11.9	14.8	49.20	48.3	59.2	69.6	251	112	59.4	19.3	7.7	1622
Wonji(1985-1994)	5.81	30.43	56.70	59.01	65.54	58.18	212.4	90.2	19.46	5.58	2.16	1540
Awash mel.(1991-201	9.82	13.5	47.41	49.94	35.76	78.86	185.5	72.3	59.31	3.27	9.36	1540
Sodere(1989-202	4.87	3.43	49.75	11.43	37.02	44.5	196.3	73.1	57.83	7.38	6.58	1390
NuraEra(1977-2002	25.69	34.44	41.42	49.35	29.3	29.71	114.9	41.4	44.83	4.06	9.06	1220
Wolenchiti(1991-201	20.19	18.28	68.58	56.77	73.38	63.83	212	104	72.78	12.58	3.11	
Metehara(1985-202)	8.81	33.54	46.94	50.33	33.63	26.42	117.3	46.3	27.26	3.64	6.38	960
Average	12.44	21.2	51.43	46.45	47.69	53.01	184.2	77.1	48.7	7.97	6.34	

Annex 3 - Rainfall record of Metehara station, source N.M.S.A

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Oct	Nov	Dec	Yearly total Rainfall (mm)
6.3	0	29.6	76.6	104.5	12	167	154	4.4	0.05	0	553.85
0	41.6	43.2	25.9	13	51.8	64.3	67.1	4	0	7	317.9
0	24.6	71.2	78	74.8	0	53.6	110	2.8	0	0	415.4
12.6	29.6	11.3	23.7	7.8	11.3	154	136	18	0	11.9	415.8
0	28	104.8	101.3	7.5	82.1	48.7	92.7	5.6	0	12.7	483.4
0.5	220.8	58.1	62.9	1.8	0.9	146	76.9	2.1	0	0	570.4
0	54.3	56.1	46.7	53.3	15.4	137	132	11.7	0	0	506.5
25.8	50.3	0	75.8	16.8	62.6	90	158	49.6	5.7	2.3	536.5
43.8	59.5	0	139.6	57.3	23.7	100	104	21.9	_	56.9	606.7
_	0	6.5	21.4	55.4	38.6	248	132	0.1	12.7	1.9	516.6
0	43.5	81.9	44	10.5	28.5	47.3	144	0.5	0	0	400.3
27.6	0	97.3	35.1	80.5	26.5	205	101	1.6	7.5	0	581.7
29.7	0	12.6	44.3	11.5	34.5	140	53.8	112	14.6	0	453.1
0.8	18.1	76.6	34.2	14.9	4.7	78.2	136	78	0	0	441.1
0	0	73.6	6.2	15.9	16.7	136	151	76.2	2.2	0	478.1
0	0	1.8	20.7	36.9	29.6	136	153	47.3	11.9	9.4	446.2
_	_	_	_	_	_	_	_	_	_	_	
2.6	0	73.3	19.3	9.3	10.2	43.2	80.8	_	_	_	
8.81	33.54	46.94	50.33	33.63	26.42	117	116	27.3	3.64	6.38	

Annex 4 - Rainfall record of Nura-Era station, source N.M.S.A

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Oct	Nov	Dec	Yearly total
											Rainfall (mm)
nd	nd	16.4	21.9	nd	33.9	66.2	61.4	122	nd	nd	321.6
26.9	15.5	18.2	73.3	19.4	nd	nd	132	133	0	39.5	457.6
nd	0	39.8	1.3	48	42.9	55.1	nd	nd	nd	nd	187.1
nd	nd	42.6	10.5	nd	nd	nd	nd	nd	nd	nd	53.1
nd	nd	nd	nd	nd	nd	128	30.8	7.1	0	0	166.2
0	54.5	36	32.3	2	60.9	85.4	103	6.1	0	nd	380.3
0	11.3	57.1	47.5	134.6	3.2	45.8	211	3.8	0	0	514
13.3	23.2	4.5	45.3	0	23.1	128	194	11	0	4.7	447
0	46	89.8	160.3	1.4	57.1	115	174	8.9	0	16.2	668.2
1.4	302.8	73	107.8	2.3	2.7	200	118	_	0.5	0	808.4
0	47.2	130	17.3	17	17.8	210	138	11.6	0	0	588.1
45.2	6.7	nd	59.2	14.2	21.5	147	205	35.3	10	18	562.2
118.4	20.6	0	100.5	41.2	9.6	118	125	34.8	0	6	574
0	0	77.5	28.1	58.1	73.3	211	131	12.5	20.5	12.1	623.6
0	31.2	40.7	103.8	14.1	52.3	74.2	158	0	0	0	474.1
158.7	0	11.7	94.2	82.1	42.8	110	144	12.2	30.8	0	685.7
21.2	0	14.6	6	0	0	41	37.5	164	nd	nd	284.7
nd	nd	31.3	0	14.8	39	126	153	141	4.4	0	508.8
0	0	0	30.7	31.5	14.8	108	181	79.6	2.8	13.6	461.2
0.3	26.5	31.8	22.3	28.3	31.6	143	103	0.8	0	0	387
25.7	0	71.9	24.7	18.4	8.3	74.8	133	24	0	34.8	415.6
25.69	34.44	41.42	49.35	29.3	29.71	115	133	44.8	4.06	9.06	516.01

Annex 5 - Rainfall record of Sodere station, source N.M.S.A

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Oct	Nov	Dec	Yearly total
											Rainfall (mm)
nd	nd	nd	nd	0	17.5	203	213	101	0	0	
nd	nd	78.4	2.9	10.4	68.7	182	223	110	0	0	
0	0	2.9	16.9	0	19.2	nd	179	20.5	29.5	19	
0	0	99.9	10.8	111.6	92.3	293	226	nd	nd	9.2	
14.6	7.3	17.8	15.1	63.1	24.8	107	158	0	0	4.7	4459.9
4.87	3.43	49.75	11.43	37.02	44.5	196	200	57.8	7.38	6.58	
	_ no data										

Annex 6 -Geochemical data of some borehole in Metehara area

Source:- MoWR, 1998

Location	BH Ilala clinic	BH at metehara ortho. Ch.	Bh at Second Camp	BH at third camp	BH at fourth camp	BH gudina foundation	BH at Mosque, Metehara	BH at Catholic Church	BH at Metehara town	Bh at Metehara town
Date	18/11/97	19/11/97	20/11/97	20/11/97	20/11/97	21/11/97	25/11/97	25/11/97	26/11/97	26/11/97
EC	1980	1956	2980	2100	2680	1990	4270	5500	1613	1476
pH	8.7	7.1	7.4	7.6	7.45	7.88	8.83	8.99	7.1	7.6
TDS	1218	1266	1898	1100	1666	1166	2711	3376	1090	782
Na	430	415	570	400	540	460	990	1460	370	270
K	33	17.2	37.5	27	32	120	162	14.8	7.7	6.7
Ca	0.8	30.4	46.4	20	38.4	2.4	1.6	1.6	50.4	36
Mg	0.49	13.6	35	16.5	38.4	2.9	0.49	0	7.78	8.76
Fe	0	0	0	0.02	27.2	0	0.02	0.02	0.02	0.03
MN	0	0	0	0.1	0	0.1	0.1	0.3	0.8	0.2
F	6.9	10.9	5.4	6.3	4.2	5.5	22	29.75	7.4	6.9
CL	128.5	140	368	204.8	280	126	342	408	58	26
NO_3	0.88	4.8	21.12	12	9.2	0.88	154	121	0.88	1.32
CO_3	74.4	0	0	9.6	0	12	129.6	225.6	0	7.2
HCO_3	722.2	817.4	422.1	500.2	678.3	819.8	1298.1	1891	954	700.2
SO_4	130	160	570	300	360	130	400	450	65	210
PO_4	0.45	1.4	0.18	0.4	0.39	1.14	4.75	4.5	1.24	nd
ALKALINITY	716	670	346	426	556	662	1280	1926	782	586
DO	5.3	0.33	4	nd	2.7	nd	nd	nd	0.33	0.67
T	40.8	29	37.2	36.1	36.1	46.2	26.5	30	27	27.5
Total Hardness	4	132	260	118	208	18	6	4	158	126

Annex 7 Groundwater quality at Metehara town

	BH HBH-	BH HBH-	BH HBH-	BH HBH	BH HBH-
Location	38	45	46	26	27
Date	5/2/1998	9/2/1998	7/2/1998	31/12/97	31/12/97
EC	1800	2520	1960	8360	7310
TDS	1232	1728	1285	5818	5250
PH	7.34	8.58	8.6	9.18	8.83
Na^+	375	620	440	2550	2300
K^+	12.8	16.5	29.5	87	305
Ca^{2+}	48	3.2	3.2	1.6	1.6
Mg^{2+}	17.5	0.97	0.49	0.97	0.49
Fe total	0.01	0.6	0.58	0.6	0.1
Mn^{2+}	0.2	0.1	0.1	0.14	0.5
F^-	6	18.5	6	73	63
Cl^-	179	172	145	525	495
NO_3^-	5.72	3.96	3.96	209	149.6
Co_3^{2-}	0	68.2	55.2	609	432
HCO_3^-	695.4	1015	741.76	3111	2976.8
SO_4^{2-}	150	165	110	500	500
PO_4	0.38	0.98	0.26	9	9.2
Alkalinity	570	nd	nd	3550	3160
DO	nd	nd	nd	nd	nd
T	22.4	26.5	33.5	27.5	25.4
Hardnesss	192	12	10	6	8

Annex 8 The ground water quality of some boreholes in the Wonji area

Reference Number	TDS (mg/l)	Co_3^{2-} (mg/l)	Hco_3^{2-} (mg/l)	CL^- (mg/l)	SO_4^{2-} (mg/l)	No_3^- (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	sio_2 (mg/l)	Co_2^- (mg/l)	PH
BH-1	1859.43	nd	1250	38	1	1.1	390	11	50	16	91	11.9	7.22
BH –2	1126.93	nd	609	66	56	1.1	250	12	35	6	79	25	7.63
BH-3	1770.53	nd	976	70	144	2.7	310	24	125	40	74	114	7.14
BH-4	1180.06	nd	669	49	73	0.6	240	18	35	11	79	16	7.82
BH-5	1201	nd	646	67	54	0.58	290	18	20	5	86	28	7.57
BH-6	617.17	nd	366	19.9	0	0.5	61.2	11.6	60.9	nd	85.5	nd	7.9
BH-7	1880.26	nd	864	58	466	8.1	260	21	80	45	76	142	6.98
BH-8	828.69	nd	478	30	20	30	118	13	44	18	76	22	7.56
BH-9	679.13	nd	256	23	12	11	45	8	47	17	66	22	7.29
-BH-10	1148.87	nd	610	69	88	2.2	230	17	30	16	81	24	7.63
BH-11	Nd	ND	488	28.4	69.9	30	102	11.2	65.7	33	nd	nd	7.5
BH-12	Nd	nd	366	26.9	0	2.5	39.1	13	19.2	44.8	98.3	nd	7.5
BH-15	779.65	nd	439.2	42.5	25.1	0.5	113.9	12.5	43.3	20.4	80	nd	7
DW -1	1314.2	0	675	86	60	25	345	16	9	2	79	7	8.07
DW-2	1411.2	6	774	70	44	23	365	18	6	3	86	nd	8.45

Nd=no data

Source : Teshome Dechasa, 1999,Thessis

DECLARATION

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

Name: **Ahmed Abduletif**

Signature:

Date of submission:

Annex 3 - Rainfall record of Metehara station, source N.M.S.A

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Oct	Nov	Dec	Yearly total Rainfall (mm)
6.3	0	29.6	76.6	104.5	12	167	154	4.4	0.05	0	553.85
0	41.6	43.2	25.9	13	51.8	64.3	67.1	4	0	7	317.9
0	24.6	71.2	78	74.8	0	53.6	110	2.8	0	0	415.4
12.6	29.6	11.3	23.7	7.8	11.3	154	136	18	0	11.9	415.8
0	28	104.8	101.3	7.5	82.1	48.7	92.7	5.6	0	12.7	483.4
0.5	220.8	58.1	62.9	1.8	0.9	146	76.9	2.1	0	0	570.4
0	54.3	56.1	46.7	53.3	15.4	137	132	11.7	0	0	506.5
25.8	50.3	0	75.8	16.8	62.6	90	158	49.6	5.7	2.3	536.5
43.8	59.5	0	139.6	57.3	23.7	100	104	21.9	_	56.9	606.7
_	0	6.5	21.4	55.4	38.6	248	132	0.1	12.7	1.9	516.6
0	43.5	81.9	44	10.5	28.5	47.3	144	0.5	0	0	400.3
27.6	0	97.3	35.1	80.5	26.5	205	101	1.6	7.5	0	581.7
29.7	0	12.6	44.3	11.5	34.5	140	53.8	112	14.6	0	453.1
0.8	18.1	76.6	34.2	14.9	4.7	78.2	136	78	0	0	441.1
0	0	73.6	6.2	15.9	16.7	136	151	76.2	2.2	0	478.1
0	0	1.8	20.7	36.9	29.6	136	153	47.3	11.9	9.4	446.2
_	_	_	_	_	_	_	_	_	_	_	
2.6	0	73.3	19.3	9.3	10.2	43.2	80.8	_	_	_	
8.81	33.54	46.94	50.33	33.63	26.42	117	116	27.3	3.64	6.38	

Annex 4 - Rainfall record of Nura-Era station, source N.M.S.A

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Oct	Nov	Dec	Yearly total Rainfall (mm)
nd	nd	16.4	21.9	nd	33.9	66.2	61.4	122	nd	nd	321.6
26.9	15.5	18.2	73.3	19.4	nd	nd	132	133	0	39.5	457.6
nd	0	39.8	1.3	48	42.9	55.1	nd	nd	nd	nd	187.1
nd	nd	42.6	10.5	nd	nd	nd	nd	nd	nd	nd	53.1
nd	nd	nd	nd	nd	nd	128	30.8	7.1	0	0	166.2
0	54.5	36	32.3	2	60.9	85.4	103	6.1	0	nd	380.3
0	11.3	57.1	47.5	134.6	3.2	45.8	211	3.8	0	0	514
13.3	23.2	4.5	45.3	0	23.1	128	194	11	0	4.7	447
0	46	89.8	160.3	1.4	57.1	115	174	8.9	0	16.2	668.2
1.4	302.8	73	107.8	2.3	2.7	200	118	_	0.5	0	808.4
0	47.2	130	17.3	17	17.8	210	138	11.6	0	0	588.1
45.2	6.7	nd	59.2	14.2	21.5	147	205	35.3	10	18	562.2
118.4	20.6	0	100.5	41.2	9.6	118	125	34.8	0	6	574
0	0	77.5	28.1	58.1	73.3	211	131	12.5	20.5	12.1	623.6
0	31.2	40.7	103.8	14.1	52.3	74.2	158	0	0	0	474.1
158.7	0	11.7	94.2	82.1	42.8	110	144	12.2	30.8	0	685.7
21.2	0	14.6	6	0	0	41	37.5	164	nd	nd	284.7
nd	nd	31.3	0	14.8	39	126	153	141	4.4	0	508.8
0	0	0	30.7	31.5	14.8	108	181	79.6	2.8	13.6	461.2
0.3	26.5	31.8	22.3	28.3	31.6	143	103	0.8	0	0	387
25.7	0	71.9	24.7	18.4	8.3	74.8	133	24	0	34.8	415.6
25.69	34.44	41.42	49.35	29.3	29.71	115	133	44.8	4.06	9.06	516.01

Annex 5 - Rainfall record of Sodere station, source N.M.S.A

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Oct	Nov	Dec	Yearly total Rainfall (mm)
nd	nd	nd	nd	0	17.5	203	213	101	0	0	
nd	nd	78.4	2.9	10.4	68.7	182	223	110	0	0	
0	0	2.9	16.9	0	19.2	nd	179	20.5	29.5	19	
0	0	99.9	10.8	111.6	92.3	293	226	nd	nd	9.2	
14.6	7.3	17.8	15.1	63.1	24.8	107	158	0	0	4.7	4459.9
4.87	3.43	49.75	11.43	37.02	44.5	196	200	57.8	7.38	6.58	
	_ no data										

Annex 6 -Geochemical data of some borehole in Metehara area
Source:- MoWR, 1998

Location	BH Ilala clinic	BH at metehara ortho. Ch.	Bh at Second Camp	BH at third camp	BH at fourth camp	BH gudina foundation	BH at Mosque, Metehara	BH at Catholic Church	BH at Met ehara town	Bh at Met ehara town
Date	18/11/97	19/11/97	20/11/97	20/11/97	20/11/97	21/11/97	25/11/97	25/11/97	26/11/97	26/11/97
EC	1980	1956	2980	2100	2680	1990	4270	5500	1613	1476
pH	8.7	7.1	7.4	7.6	7.45	7.88	8.83	8.99	7.1	7.6
TDS	1218	1266	1898	1100	1666	1166	2711	3376	1090	782
Na	430	415	570	400	540	460	990	1460	370	270
K	33	17.2	37.5	27	32	120	162	14.8	7.7	6.7
Ca	0.8	30.4	46.4	20	38.4	2.4	1.6	1.6	50.4	36
Mg	0.49	13.6	35	16.5	38.4	2.9	0.49	0	7.78	8.76
Fe	0	0	0	0.02	27.2	0	0.02	0.02	0.02	0.03
MN	0	0	0	0.1	0	0.1	0.1	0.3	0.8	0.2
F	6.9	10.9	5.4	6.3	4.2	5.5	22	29.75	7.4	6.9
CL	128.5	140	368	204.8	280	126	342	408	58	26
NO_3	0.88	4.8	21.12	12	9.2	0.88	154	121	0.88	1.32
CO_3	74.4	0	0	9.6	0	12	129.6	225.6	0	7.2
HCO_3	722.2	817.4	422.1	500.2	678.3	819.8	1298.1	1891	954	700.2
SO_4	130	160	570	300	360	130	400	450	65	210
PO_4	0.45	1.4	0.18	0.4	0.39	1.14	4.75	4.5	1.24	nd
ALKALINITY	716	670	346	426	556	662	1280	1926	782	586
DO	5.3	0.33	4	nd	2.7	nd	nd	nd	0.33	0.67
T	40.8	29	37.2	36.1	36.1	46.2	26.5	30	27	27.5
Total Hardness	4	132	260	118	208	18	6	4	158	126

Annex 7 Groundwater quality at Metehara town

	BH HBH-	BH HBH-	BH HBH-	BH HBH	BH HBH-
Location	38	45	46	26	27
Date	5/2/1998	9/2/1998	7/2/1998	31/12/97	31/12/97
EC	1800	2520	1960	8360	7310
TDS	1232	1728	1285	5818	5250
PH	7.34	8.58	8.6	9.18	8.83
Na^+	375	620	440	2550	2300
K^+	12.8	16.5	29.5	87	305
Ca^{2+}	48	3.2	3.2	1.6	1.6
Mg^{2+}	17.5	0.97	0.49	0.97	0.49
Fe total	0.01	0.6	0.58	0.6	0.1
Mn^{2+}	0.2	0.1	0.1	0.14	0.5
F^-	6	18.5	6	73	63
Cl^-	179	172	145	525	495
NO_3^-	5.72	3.96	3.96	209	149.6
Co_3^{2-}	0	68.2	55.2	609	432
HCO_3^-	695.4	1015	741.76	3111	2976.8
SO_4^{2-}	150	165	110	500	500
PO_4	0.38	0.98	0.26	9	9.2
Alkalinity	570	nd	nd	3550	3160
DO	nd	nd	nd	nd	nd
T	22.4	26.5	33.5	27.5	25.4
Hardnesss	192	12	10	6	8

Annex 8 The ground water quality of some boreholes in the Wonji area

Reference Number	TDS (mg/l)	Co_3^{2-} (mg/l)	Hco_3^{2-} (mg/l)	CL^- (mg/l)	SO_4^{2-} (mg/l)	No_3^- (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	sio_2 (mg/l)	Co_2^- (mg/l)	PH
BH-1	1859.43	nd	1250	38	1	1.1	390	11	50	16	91	11.9	7.22
BH –2	1126.93	nd	609	66	56	1.1	250	12	35	6	79	25	7.63
BH-3	1770.53	nd	976	70	144	2.7	310	24	125	40	74	114	7.14
BH-4	1180.06	nd	669	49	73	0.6	240	18	35	11	79	16	7.82
BH-5	1201	nd	646	67	54	0.58	290	18	20	5	86	28	7.57
BH-6	617.17	nd	366	19.9	0	0.5	61.2	11.6	60.9	nd	85.5	nd	7.9
BH-7	1880.26	nd	864	58	466	8.1	260	21	80	45	76	142	6.98
BH-8	828.69	nd	478	30	20	30	118	13	44	18	76	22	7.56
BH-9	679.13	nd	256	23	12	11	45	8	47	17	66	22	7.29
-BH-10	1148.87	nd	610	69	88	2.2	230	17	30	16	81	24	7.63
BH-11	Nd	ND	488	28.4	69.9	30	102	11.2	65.7	33	nd	nd	7.5
BH-12	Nd	nd	366	26.9	0	2.5	39.1	13	19.2	44.8	98.3	nd	7.5
BH-15	779.65	nd	439.2	42.5	25.1	0.5	113.9	12.5	43.3	20.4	80	nd	7
DW -1	1314.2	0	675	86	60	25	345	16	9	2	79	7	8.07
DW-2	1411.2	6	774	70	44	23	365	18	6	3	86	nd	8.45

Nd=no data

Source : Teshome Dechasa, 1999,Thessis