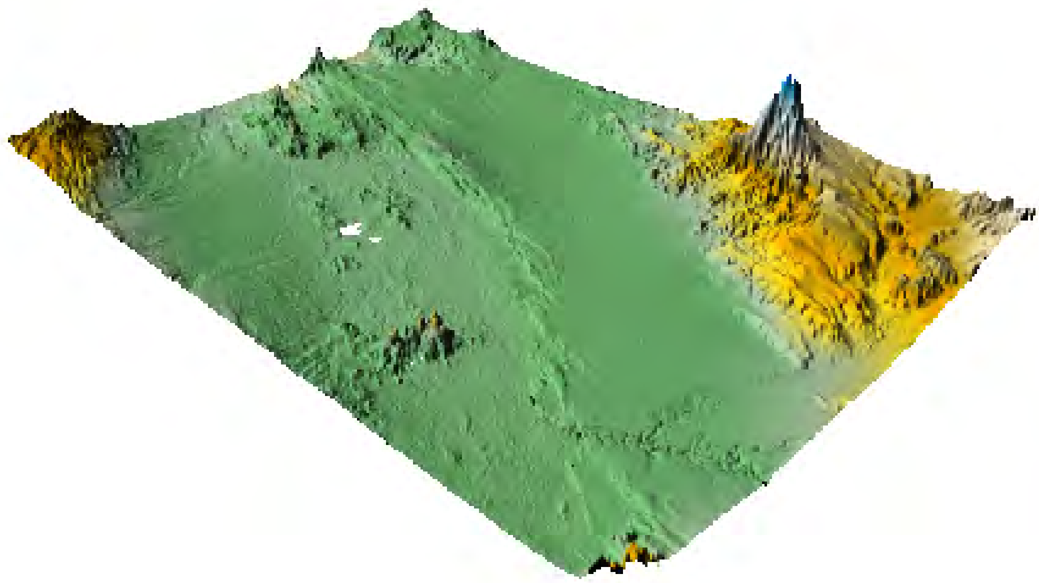
ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF EARTH SCIENCES

HYDROGEOLOGY OF THE ALAYDEGEA PLAIN AND ITS ENVIRONS

(MIDDLE AWASH VALLEY, AFAR REGION)



A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIRMENTS FOR THE DEGREE OF MASTERS IN HYDROGEOLOGY

BY

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Abstract

The Alaydegea plain is an extensive flat south north running plain in the middle Awash valley with an average width of 26-30Kms and length of more than 70kms, situated between 9^{0}- 9^{0} 52’ north and 40^{o} – 40^{o} 30’ east. the average monthly temperature and the mean annual precipitation in the area is around 25.7^{o}c and 597.5mm respectively. Potential evapotrspiration estimation for the area from empirical methods of Penman and Thorenthwaite gives annual PET values of around 1427mm and 1000mm respectively. The arid climatic nature of the area results in the occurrence of high potential evapotranspiration over the precipitation amount. Actual potential evapotraspiration for the area has been estimated from soil water balance and Turc method. Annual AET values (595mm from Turc and 615mm from soil water balance are almost close or nearly equal to the annual precipitation amount resulting in no direct recharge or surplus in the area where almost all the rainfall is lost by evaporation. Deep and shallow ground water systems exist in the area where their flow , occurrence and distribution in general is controlled by the topographic and geologic situation of the area. The Alaydegea plain and related pediments are characterized by a deep ground water system encountered at a depth of 60 to 75 meter. Fractured basalts and ignimbrite interbaded with old outwash plain gravels and volcanic sand is the major aquifer unit in the area. Groundwater recharge to these aquifers is most possibly from precipitation on the eastern mountain range. Areas on the western margin of the plain close to the wonji fault lines are ground water potential sites with aquifer of better tranmissivity (800 m^{2} /d and above) .The observed regional trend for the groundwater flow in the area is north west wards from the eastern highland beneath the Alaydegea plain. The shallow aquifer zones in the river valley system are fed indirectly by percolation or transmission loss from the Awash river where the Awash river loses on annual base a total volume of water nearly 382 Mm^{3} of water between Melka worer and Awash Sebat. Water type on the Alaydegea plain is Na – Ca- HCO_3 type evolving towards more Na –HCO_3 type in the Awash river valley, controlled by Cation exchanges, rock water interaction and evaporation factors along the flow path.

Chapter 1- INTRODUCTION

1.1 Background

It is obvious that groundwater is the major and most feasible source of water supply particularly in areas of arid climatic zones like the Afar region where the study area is found with a limited rain fall in a range of 200 – 600mm annually which is erratic in nature and with minimum associated perennial surface water resource distribution in the area.

Therefore water resource studies on the availability sustainability, purity (contamination) etc of the resource is very important for the effective and safe utilization of the resource in the area.

The Afar area is entirely situated within the main Ethiopian rift between 9^0 – 12^0N and 39^0 – 41^0 E with its triangle form which is a world famous geological feature formed like a funnel within the northern most part of the rift valley. The study area is situated in the southern tip of this region which is found within the middle part of the Awash basin. the Awash River and most of its tributaries from western part drain the Afar area being used as the existing water supply source for most part of the rural community there

From the water supply point of view, the Awash River is the major source of water supply for the pastoral community who make temporal settlement following the river bank especially in times of dry season as the Awash River is perennial through out the year. However to alleviate the water supply problem for other parts of the area where such sources are not near by, groundwater development through hand dug wells and shallow to deep wells is currently on going by the regional water bureau and other funding Agencies. These integrated activities have brought the potable water supply coverage in the region to 31% at this moment.

Similarly, within in the study area which is found in the southern part of the Afar region both surface water and groundwater resource are used for water supply of the pastoral community. Even if the town water supply is from treated surface water (Awash River) most part of the postural community uses untreated surface water directly. Groundwater developments activities through shallow and deep wells in this particular part of the region has also some challenges and constraints with regards to water quality aspects as fluorides, nitrates, chlorides and sulfates are the major ones in most ground water sources.

Therefore these and other related problems needs some further and detail water resource investigations (hydrological and hydrogeological investigations) to indicate some possible ways and mechanisms for sustainable, potable and feasible water resource development programs in the area.
On the basis of this concept this study is proposed to give some detail picture on the hydrogeological characteristics i.e. the hydrogeological nature of the area in the middle Awash basin in particular to areas around the Alaydegea plain which covers most part of the area to the east .The study in general focus and incorporates the evaluation of the hydrochemistry and the ground water flow , Interaction of this system with surface water (Awash), recharge condition and aquifer characterization.

1.2 Objectives and scope of the study

1.2.1 General Objective

The general objective of the study is to describe and give some detail picture on the hydrogeologic feature with more focus on areas on and around the Alaydegea plain. This poses an interest from the hydrogeologic point of view to evaluate its water resource potential in relation to the shallow groundwater resource potential in the Awash river valley to the west of this plain on the basis of aquifer characterization, recharge mechanism, groundwater potential and flow condition and hydrochemical nature of the groundwater.

1.2.2 Specific Objectives

The specific objectives of this study in general includes the description and characterization of the major aquifer systems and units in the area, defining the major structure and lithologic controls on the groundwater flow systems and explaining the origin and mechanism of recharge for the groundwater potential. The objective includes also the description of the hydrochemistry of the groundwater from the analysis of the water chemistry data and discussing the hydrogeologic implications behind the hydrochemical variations.

The scope of the study includes the acquisition and compilation of all the necessary primary and secondary data from previous works in the area and on field assessments. For the hydrologic analysis of the area for instance hydrometeorology and hydrologic (River discharge) data of more than 20 years have been considered for the quantification of the hydrologic components. The collection and compilation of piezometric and groundwater table data of more than fifteen years for piezometers measurements for the shallow groundwater system along the river bank has also been carried out for the interpretation of the interaction of this system with the adjacent river water.

A filed assessment and actual filed observation of the hydro geologic nature of the area and water well data observations and measurements in open wells has also been carried out to further strengthen and filtering the available data source. Hydrochemical data collection and analysis includes on site field measurements of the physical and some chemical parameters and water sample collections at various water source points for furtherer laboratory analysis of the basic cations and anions concentration and other important parameters.

The final scope of the study incorporates the analysis of all available data obtained from multiple sources and interpreting them in accordance with the specific purpose of the study and finally giving some picture about the hydro geology of the area supported with different maps.

1.3 Methodology

To fulfill the various scopes of the study outlined above, multiple methodology and approaches have been used in the area of investigation. Intensive literature review, secondary data compilation and historic data analysis is carried to observe the past trend of the hydrologic and hydrogeologic systems. Data gaps from secondary sources have been filled by supplementing method from data of the same hydrologic year.

Water level measurements was collected and compiled from both open dug wells and shallow bore holes to observe its interaction with the river water and from deep wells of confined system for potntiometric head mapping to show the groundwater flow system.

Field observations was supported with the digital images of the areas analyzed with global mapper- 5 and surfer-8 computer software for the preparation of different maps of the study area. Estimation of indirect recharge from river loss is done from the computation of the channel water balance in the area. The quantification of some components like the evaporasporation was done from both empirical methods and from water balance (soil water balance).

A river flow hydrograph separation at selected gauging is carried out to observe the groundwater component or groundwater run off contributions in the area using graphical method for both the main river and tributaries. The hydraulic parameter of the hydrologic units of various aquifer system and aquifer characterization is determined from pumping test data and lithological logging data complied from a total of 35 wells (shallow to deep wells) drilled in both confined and unconfined system.

For the hydrochemical characterization of the groundwater in the area a hydro chemical data collection from previously drilled wells, existing hot springs and surface water have been made and in addition a new hydro chemical data set has been generated by taking additional samples from different sources and analyzing it for chemical and physical parameters, where more than 50(fifty) newly analyzed water samples have been used for this evaluation.

To observe the field condition of the water samples from various sources field measurements of some parameters like pH, TDS, Temperature, Salinity etc.. is carried out using conductivity meter and pH meter. Therefore the hydrochemical date base used in this study in general includes water samples from fifty(50) water wells three(3) springs, nine(9) hand dug wells and two(2) river water sample. The chemical analysis data is used for classification of water into different hydrochemical groups or water types.

1.4 Previous Works

In relation to Awash River master plan for Awash basin water resource development for irrigation and other purposes the Awash basin on regional level had been studied for its surface water and groundwater potential at different times by the ministry of water resource. Regional hydrogeological studies for the partial valley including the middle and lower Awash basin with the application of remote sensing had also been studied by Mezmure (1981) under the title of the hydrogeology of south afar and adjacent escarpment. Groundwater and soil studies for irrigation potential of the middle Awash valley had also been studied by Currey (1973) and groundwater potential evaluation of the Alaydegea plain by kettema Taddese (1983). all the works carried out are almost general and are of regional level, Regarding some detail hydrogeologic patterns of the study area still there is no clear picture on some detail hydrogeologic natures of the area with respect to aquifer characteristics, groundwater flow systems, detail hydrochemistry ,recharge conditions and the groundwater interaction with the Awash river, Therefore this study is proposed to give some picture in these and other related aspects regarding the hydrogeology of the Alaydgea area and its environs.

Chapter 2: GENERAL OVERVIEW OF THE STUDY AREA

2.1- Location

The Total area i.e. the entire partial catchments is generally located in the middle Awash basin which extends from the Awash town up to Gewane area between latitude of 9^0,00' (0995,850) --$9^0$52' (1,091,201) north and 40^0 (0610000) --40^0 30' (0665000) east. The major focus of the study i.e. the Alaydegea plain is located in the eastern part of this catchment on the main Awash Asseb road (240 – 310 kms) and it is around 70kms long and with an average width of 23 kms which covers an area of almost 1600km^2 running north south.

2.2 - Climate

The climate of the area in general comes under the influence of the Inter tropical convergence Zone (ITCZ) which is a zone of low pressure that marks the convergence of dry tropical easterlies and moist equatorial westerly. The seasonal rainfall distribution is highly controlled by the annual migration of the inter tropical convergence zone across the area. The climate of the area in general fall under the semi-arid or semi-desert climatic zone or based on the Ethiopian Traditional way of agro-climatic zoning it can be grouped as a dry kola climatic zone with altitude ranging from 600 – 1200 m.a.s.l with monthly temperature of 20^0 -25^0c and sparse vegetation type.

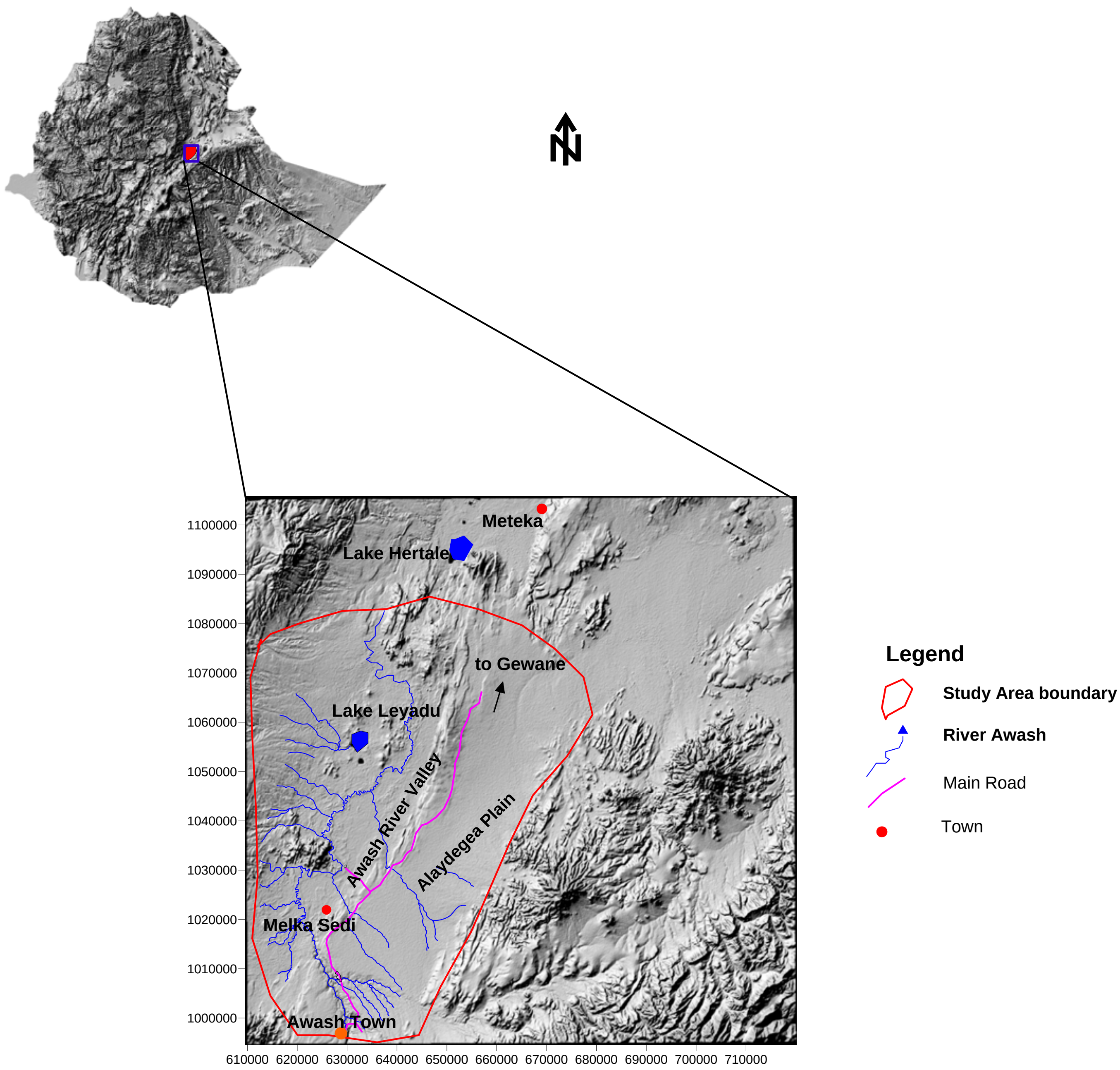


Fig 2.1 Location Map of the Study Area, South Afar (Middle Awash Valley)

2.2.1- Rainfall and Temperature

In general slight temporal and spatial variability of rainfall in the study area is common in relation to some altitude variation and exposure of the different parts of the area to moist air. The Mean annual rainfall for Awash town and Melka Werer areas is around 604mm and 615mm respectively (table 2.1). However escarpment areas to the east and west of the study area could have more than 900 mm of rain fall annually due to altitude effect .The rainfall pattern in the area generally displays a bimodal type which is into two distinct rainy periods. (Fig 2.2)

Temperature also shows slight variation spatially in the study area. At Awash town temperature ranges from a mean monthly maximum of 36.5 ^{0}c to mean monthly minimum of 16^{0}c with mean annual value of 26^{0}c. (Table 2.2) and similarly for Melka Werer areas in the river valley or lower plain areas temperature ranges from a minimum monthly average of 22 ^{0}c in Jan. and Dec. to max average of 29^{0}c in May and June with mean annual value of 25.3^{0}c. In general temperature values are maximum for months of April, May, June and July and minimum for the other months.

Table 2.1 Mean Monthly Rainfall at Gauging Stations in Awash Area

Area/ Station	Jan	Feb	Mar.	Apr.	May	Jun	Jul	Aug.	Sep	Oct.	Nov.	Dec.	Total
Awash Sebat	20.11	41.4	56.1	58.3	40	31	118	134	56.82	24.3	14.8	8.91	604.1
Melka Sedi	32.13	30.5	57.4	59.1	28.1	20	114	132	43.16	9.356	30.46	14.9	571.1
Melka worer	6.98	42.8	87.6	63.3	42.8	21	122	127	55.03	25.52	9.22	12.2	615.2
Average	19.74	38.2	67	60.2	36.9	24	118	131	51.67	19.72	18.16	12	596.8

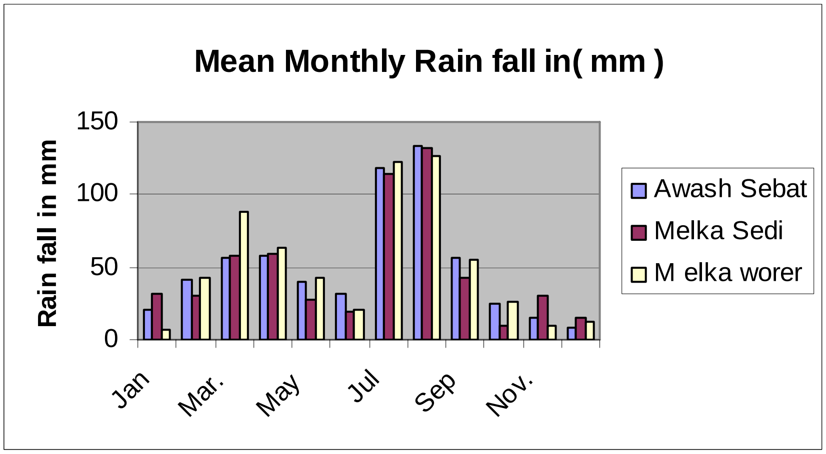


Fig 2.2 Monthly Rainfall distribution for the rain gauges in the study area

2.2.2-Wind speed and relative humidity

As the wind flow pattern is influenced by the seasonal variations of the ITCZ, the predominant wind direction during June to September is southerly to south westerly. the mean monthly wind speed in Awash and Amibara areas range from a minimum value of 0.85 meter/sec or 28.4 miles/day in Dec. to max values of 2.4 meter/sec or 80.4 miles/day in July (See table 2.2) with a mean annual value of 1.36 met/sec or 45.6 miles/day . From relative humidity date available for Amibara area the mean annual relative humidity in the area is around 61.3 %.

Table 2...2 Hydrometeorologic Data for The Awash Area

Parameters	Locat..	Jan	Feb	Marc.	App.	May	Jun	Jul	Aug.	Sep	Oct.	Nov	Dec	Average
Temp(0C) mean monthly	Awash Town	23.4	24.8	26.5	27.4	28.5	29.7	28	26.6	27.2	26.3	24	23.3	26.3
	Melka Worer	22.2	22.8	24.5	26.4	27.9	29.8	28	25.8	26.5	25.3	24	22	25.8
Wind speed(m/s)	Awash	1.15	1	1.25	1.2	1.4	2.3	2.4	1.4	1.2	1	1.2	0.85	1.36
Relat.Hum(%)	Awash	60.6	60.4	60.4	60.5	60.2	60	61	70	60.8	60.7	61	60.7	61.31
Sunshine hours hours/day	Awash	8.9	8	7.9	7.3	8	7.7	7	7.5	7.3	8.1	9.2	9.3	8.01

2.3 Physiography of the study Area

The Awash drains the northern part of the rift valley in Ethiopian from approximately 8.5^0 N to 12^0N. The source Awash lies at an altitude of around 2500m on the plateau to the west of Addis Ababa. The drainage basin is bounded from west by blue Nile from south lake basin, from south east Wabeshebele basin. According to FAO (1969) the basin have been divided into three zones depending on altitude and mean annual rain fall.

i. The upper valley
ii. Middle valley
iii. Lower plains

Physiographically most part of the study area (the Alaydegea plain) lies with in the eastern catchments (i.e. a flat laying plain to the east of Awash River between Awash Arba and near or around meteka. The plain is around 70kms long and 23km width and altitude in the plain ranges from 800 –860 m. a.s.l. The plain is bounded to the west by some part of the study area which is a graben or valley of the Awash River course dropped 100m height from the plain. A north south trending horst separates the plain from this graben and it is believed that this structure diverts the Awash river course to the present valley direction.

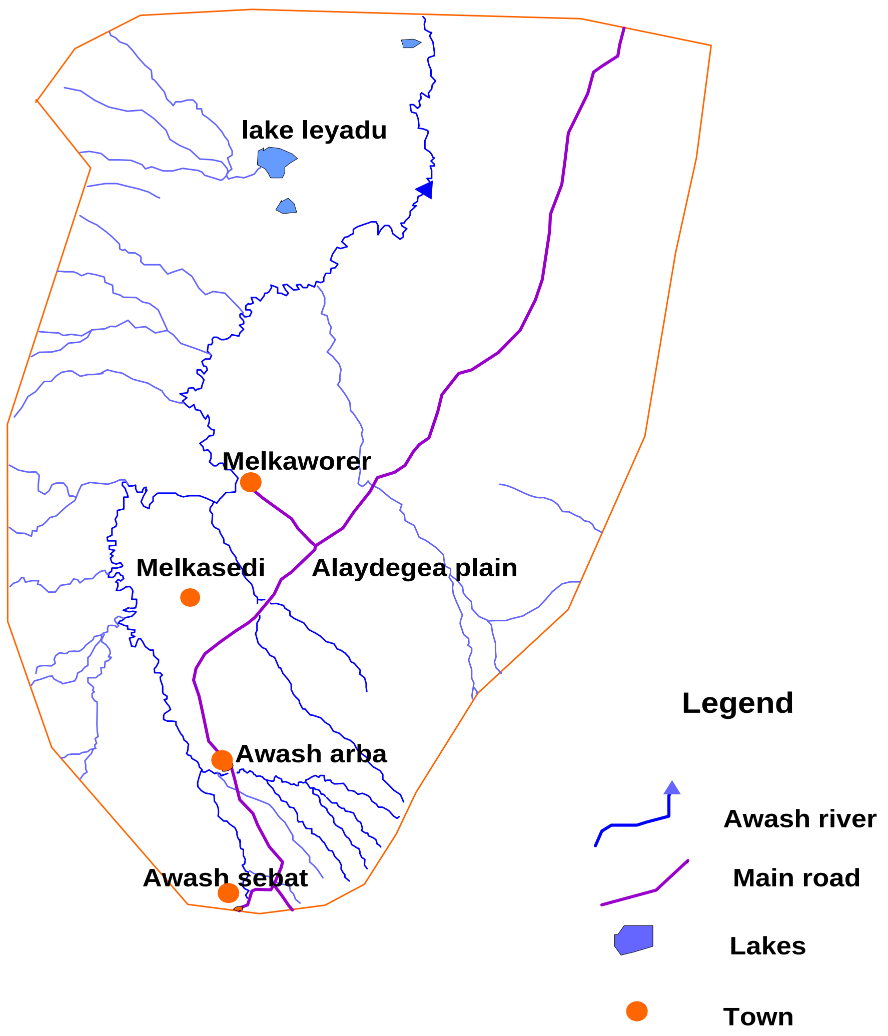


Fig 2.3 Drainage map of the Area

2.4 Land Use Land Cover

2.4.1 Land use

The major land use types in the study area are as follow.

1. Irrigated Agriculture

It is one of the most kinds of land use for some parts of the study area or zone with flat to almost flat topography (0.2%) of the region with fluviosoils type. This is an area which has potential for crop production where most part is located along Awash river. For the entire basin the net irrigable farm is estimated to total sum of 70,245ha from 48 irrigation schemes where around 82% of these are controlled by state farms, the middle valley around the study area covers relatively less proportion of this compared to the upper and lower valleys. In the study area of middle Awash cotton dominates the cropping pattern with 87% of the irrigated land and other crops like banana citrus tobacco, maize are also some agriculture activities.

2. Extensive Grazing (Seminomadic farming system)

It is also the major land use type in the central and eastern part of the study area. The extent of extensive grazing area in the afar region as a whole is 2,435,942ha which mostly covers the south western, central eastern and central southern part of the region.

3. Bare Land

The largest proportion of the region is occupied by bare land which is mainly located in the north, north east and central part of the region. About 70.8% of the total Afar region is supposed to be bare land where around 54.94% of it is used as grazing and browsing of livestock. Almost much part of the study area in the north eastern and eastern regions is explained by bare land used for grazing.

2.4.2 Vegetation Cover

The vegetation of the region characterized as a major rangeland includes deserts, shrub lands , grass lands and open acacia woodlands (child 1984). The Afar range lands are mainly characterized as savannah, veld, steppy, dry land, native pasture grazing land, bush grassland etc.

As the most part of the study area is categorized as bare land, the dominant vegetation cover of the area is a mixed short savannah grass with woody vegetation predominantly acacia type these vegetation is common in low land areas with annual precipitation usually between 350 to 700mm.In addition to a mixed grass acacia trees of the open savannah range land, the riveriane vegetation is dominant along the course of the Awash River in the study area.

CHAPTER 3 : GEOLOGY

3.1 Regional Geology

3.1.1 Regional Geomorphologic Setting

As the study area is geomorphologically situated within the south eastern and some central part of the middle Awash basin, the regional geological setting of the area is in general a result of the evolution of the Awash basin structure and it is associated or controlled by the regional tecto-volcanic events that evolve the main Ethiopia rift and Afar rift since early Miocene.

The Awash basin is a North ward dipping structure whose margins are block faulted towards the basin center and to the North. Older strata crop out the South and along basin margin. Dips are greater along grabens and basin margin and least toward the center of the basin and younger strata which is a reflection of greater subsidence basin ward and to the North or toward the central Afar (John E .Kalb). The basin is bordered to the west by the Ethiopian plateau and to the East by the Somalia plateau with a plateau surface of around 2400m a.s.l and these two plateaus are moving apart resulting the present morphology.

3.1.2. Major Regional Tectonic Patterns

An important stage in Rift development occurred around 10m.y ago and at that time a Faulted eastern escarpment of the rift was formed on the Nazret area. (V.Kazmin 1978) Faulting in the Ethiopian rift at 10m.y coincide with major faulting of the western and southern escarpment of the Afar (Christeinen et al 1975). The type of tectonics in the Afar Region depends on the attenuation of the crust through tensional movement. The faulting of the Afar shows synthetic and antithetic fractures of tensional type. Strike slip Faults are few the existence of transform faults and big transcurent faults is contested. Mohr (1962).

The main fault trend in the region generally confirms to the NW – SE red sea trend and the NE – SW Ethiopian rift trend. In the southern Afar and in the main

Ethiopian Rift the wonji fault belt (Mohr 1962) came in to being at the end of Pliocene and during lower Pleistocene. In the SW Afar this fault belt shows a SSW/NNE striking fault zones NNW to NW/SE striking faults system also cut through the wonji belt as well through the western parts of the SE plateau. In the main Ethiopian rift the wonji fault belt is younger and began after the Nazrete phase 1.8 to 1.6 m.y ago (Mayer et al 1975).

3.1.3- Regional Stratigraphy

The Regional stratigraphy of the area can be explained can be explained by(table 3.1) where a succession of volcanic and sedimentary formations makes up the stratigraphic sequences. regarding the major lithologic units with their stratigraphy sequence and spatial distribution, the following major units could be correlated to the general stratigraphy of the area (Pilger A. and Rosler, 1974).

A) Volcanic Successions

It has been found that the entire post rift volcanics consists of four series with the 1st three series belonging to the afar group and the last recent series belonging to wonji which are separated from each other by periods of faulting, these series are (from oldest to youngest):-

1. The lower most Afar series of lower Pliocene Age (Ancher basalts).

Forming the lower most part of the lift volcanics these are resulted by the fissural basaltic eruptions in the lower pliocene (10-11 my) mostly flood basalts and siliceous rocks with ignimbrite intercalations. These are exposed along the foot hills of south east escarpments between 40 30 and 41 30 and cover partly conform and partly unconformly various members of the trap series. A sedimentary layer of up to 50m thickness mostly consists of diatomite is intercalated to the stratiform silica rocks. these sediments comprised under the name chorora formation are the oldest known from southern afar. The lower Pliocene silicic volcanic activity is between 10 and 9 m.y

2. Lower afar series of upper Pliocene (Megdela group)

These includes the fursa and dolcha- basalt erupted from flood basalt volcanism of 8 -5 m.y which can be traced nearly continuously along the Afar margin particularly north and central western margins and the Nazrete groups stratoid silicics Ignimbrites, unwelded tuff, ash flows rhyolites and trachytes in the southern middle Awash and upper Awash Valley from Asebot and Afdem volcanics. The silicic volcanoes of Assebot age around 7 and 5.5 m.y. the oldest age of these series is found in the Ethiopian escarpment 12 km west of Eloha, central western Afar near the base of strongly tilted and Faulted block.

3. The Afar Stratoid Series (Plio – Pleistocene)

This is the stratifrom volcanic series of internal Afar, These cover around 2/3 of the rift floor they are plio – Pleistocene volcanic rocks dominantly basalts intercalated with sediments strongly faulted and block tilted. On the basis of clear angular unconformity, the Afar series stratoid was separated from older volcanics sedimentary unit.

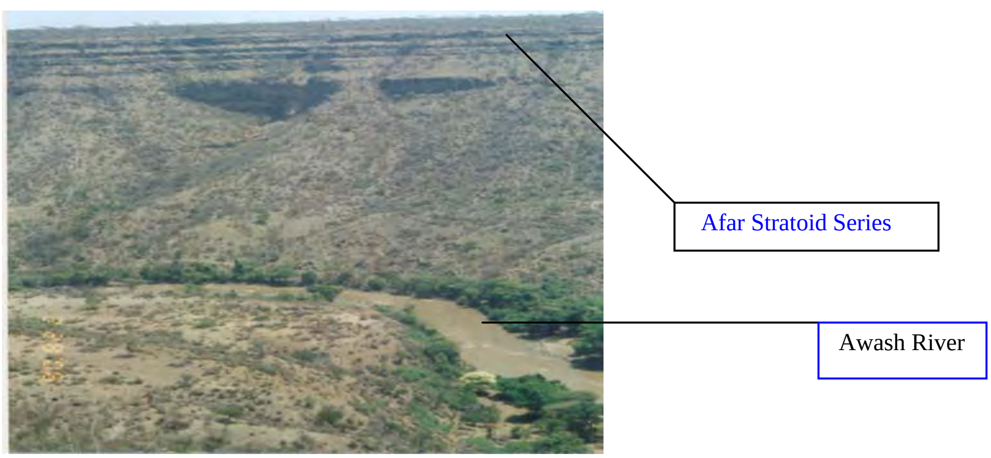


Fig 3.1 The Afar Stratoid Series (photo taken in the Awash gorge)

4. Aden series wonji groups (Pleistocene – sub recent)

The lower Pleistocene faulting affected the entire graben floor and caused a drastic change in the distribution and mode of occurrence of volcanic rocks. In the southern Afar the Aden series volcanic are known from the two segments of the wonji fault belt i.e the hertale and ad ada graben emission basalt, trachyte and rhyolites from central vent here are common. These series also includes the Dino ignimbrite in the southern middle and upper Awash south of mount fentale, Pleistocene basalt of the rift floor which are fissural flood basalts of transitional and ferro basalts located around volcanic centers of hertale, Dofen and Ayelu and also recent basalt with basic lava (picritic and porphyritic type) mezemure (1981).

B) Sedimentary sequences (The Awash group stratigraphy)

The Awash group consists of all late Cenozoic continental sedimentary strata contained within the catchment of the Awash River. The Awash group includes two main units.

1) The late Miocene chorora formation on the SW Awash area escarpment.
2) The Pliocene hadar formation in the northern part of the Awash cachment

The stratigraphic sequence can be explained as follow.

I. Sedimentary Deposite of the upper Pliocene:-

These includes the massive white clay, lacustrine ashes sands, green and white clays covered by cobbles and gravels in the Gewane areas (central part of the region) and the hadar and Ledi regions (Central western parts) where fossiliferous thick sediments covered by conglomerates are found.

II. The Gravel deposite of middle Pleistocene:-Vast detritic deposite at the foot of the Ethiopia slop and which are generally gravelly and extend over the entire pediment stretch toward the East (Bedel 1954). It is related to pluvial of the middle pliestocene. They cover the sedimentary sequence of the upper Pliocene and lower pliestocene by hollowing them out as well as the stratoid basalt where they consist of blocks of cones passing toward the down stream side with finest distribution.

III. The Lacustrine phase of Holocene and recent Pleistocene :-

Here, the Gewane or central valley and Tendaho - Assaita (lower valley) regions represent the last lacustrine phases.

IV. The sediment occurrence of Pleistocene to Holocene

Table 3.1 **Regional Stratigraphic Sequence**

Age	Group of Formation	Rock Type	Place of Occurrence
Recent Pleistocen to Holocene	-Reverine Alluvium -Fluvial and Limnic Sediments	Sand, gravel, Diatomites, Clay & Soil	In the Central and lower Valley grabens
Recent	Afar Plain Deposite	Sands	In the middle and lower Awash Valley Plains
Recent pleistocent to Holocene	Young Lacustrine phase	Clay Silt and Sand	In the central Afar (Gewane) and lower Awash Valley (Tendaho and Aysaita Areas)
Recent to Pleistocene	Wonj group volcanics (Aden Series)	Rhyolites, Ignimbrite and Basalts	In the middle and Lower Awash Valley around Hertale, Dofen, Fentale and Ayelu (Gewane Area)
Middle Pleistocene	Pediment Sediments	Fluvial gravels and Sand	At the foot of Eastern and Western escarpment
Pliocene to Pleistocene	Afar Stratoid Series Volcanics	Stratiform basalts strongly Faulted and block tilted, intercalated with sediments	Covers 2/3 of the rift floor, in central, SE and Northern parts of the Region.
Upper Pliocene	Old lacustrine and fluviatile sediments	Massive white clays, lacustrine ash, green sand, fossiliferous , thick sediment covered by cobbles and gravel	In the central and central western part of the region. Gewane, Hadar and Ledi region
Upper Pliocene 8-5 m.ys	Megdela group of the Lower Afar Series and the Nazret group	Flood basalt volcanic of the Afar group and stratoid silicics, Ignimbrite, unwelded Tuff, rhyolites, Trachite of the Nazaret group	In the North and Central Western Afar margins
Lower Pliocene 9- 11 m.y.s	The lower most Afar group/series	Mostly Flood basalt and Siliceous rocks (Stratiform)	Along the Foot hills of south East escarpment
Lower Pliocene	Chorora group	Old sedimentary formation mostly dominated by diatomite	In the southern and south eastern Afar

3.2 Geology of the study area

3.2.1 Major Stratigraphic units

Regarding the major litho units and their stratigraphic correlation there are in general six major stratigraphic groups that can be correlated to the regional stratigraphic.

These major stratigraphic units and their spatial distribution in the study area are discussed below from old to younger. (Fig 3.3 geologic map)

a) The stratoid silicics, ignimbrites, rhyolites, unwedded tuff and trachites of the Nazrete group: -

These formations are of the upper Pliocene age belonging to the megdela groups of the regional stratigraphy dating around 7 m.y. These formation mainly cover the eastern margin of the study area possibly erupted from the silicics volcanic of Asebot and Afdem mountains that form the eastern rift shoulder. The Garagumbi rhyolitic flows to the east of Awash town at the foot hills of the eastern rift escarps are of this group.

b)The afar stratoid basalts of Pliocene to Pleistocene age interchanged with acidic lava flows: -

These formation covers most central part to eastern part of the study area. These are highly faulted with columnar type of jointing. Particularly the north south running horst structure that separate the Alaydegea plain from the Awash river graben is made up of these acidic lave flows interchanged with staratoid basalt of vascular and scoraceous type.

c) Pediment gravel (out wash plain materials) of plio – Pleistocene age.

These are gravel deposites which contain clay beds and lenses that are derived from the weathering of the adjacent escarpment and transported toward the basin floor to form outwash gravel layers related to pluvial of the Pleistocene period badel (1954).

These materials make up both the eastern and western pediment plains of the area and the deposition of these materials is simultaneous with lava flows of the period as a result these formation are found interbeded with lave flows as observed in bore holes drilled on these plains like the Alaydegea plain. The deposition of these materials is continuous even to recent times as this can be clearly seen in river cliffs or faces or exposures of the Arba River where the Alaydegea plain section is exposed. Fig 3.2

Fig 3.2 out wash plain sediments on the Awash Arba River
Cliffs (Photo taken on the river exposure of the Alaydegea plain)

d) The dino ignimbrites and bofa basalts of the lower Pleistocene of Wonji group.

The bofa basalts which represent the episodes of fissural eruptions make up the lower part of the wonji volcanics (Pleistocene age) dated to 2.5my. Kazmin (1978) these basalt groups are suggested to be uniformly distributed in the rift floor where they are known as old rift floor basalts (UNDP 1973). In the study area this basalts are clearly observed to the east of Awash town in the side face of the Awash River gorge intercalated with scoria formation.

e) Pleistocene to recent basalt, rhyolite, Ignimbrites and trachites of the Wonji group.

These are the recent fissural and centeral type volcanics mostly occurred along the wonji fault belt distributed in different parts of the study area. These includes all volcanics that have been formed after the last major episode of the rift faulting, the ignimbrite flows around mount fentale and Awash town. Around mount fentale there also exists some pentelleritic obsidian, pitchstone lava flows and domes which in general grouped as alkaline to per alkaline undifferentiated volcanics.

The Pleistocene basalts of fissural type (transitional to Ferro basalt and some picritic and porphyritic type recent basalt make up the volcanic centers and domes in the central of the study area that are almost aligned parallel to the wonji fault in the valley floor like mount dofen around Melka worer area and mount Hartale to north east of dofen.

f) Recent River Valley Formation and out wash valley fill sediments

This formation includes the alluvium deposits or reveriane sediments of brown sand silt and clay following the Awash River course and together with some sediments of the lacustrine phase of younger age and black in color existing in area around Lake Leadu and Hertale to the west and north of Angelele and bilen.

The deposition of younger lacustrine phase sediments of sand silt and black clay is related to the damming or blockage of the river as a result of Ehali Mountain down stream or North of Bilen or Angelele and this sediments have been derived from the break down products of this newer volcanics curry(1983) . In relation to the wind gap condition prevailed as a result of this blockage of the river due to recently erupted volcanics, some out wash fan and some deltaic deposited are common down stream of mount Ehali and lake hertale particularly at the slope break of the river valley around gelealo areas where thick fan and deltaic deposits are found before the river drains the gewane swamp.

Recent hill wash and out wash fans of sandy materials are also common at the foot of the escarps and on the adjacent plains. For instance the present drainage system from mount Asebot to the eastern margin of the study area has covered the Alaydegea plain with black basaltic clays and out wash fans of sandy materials.

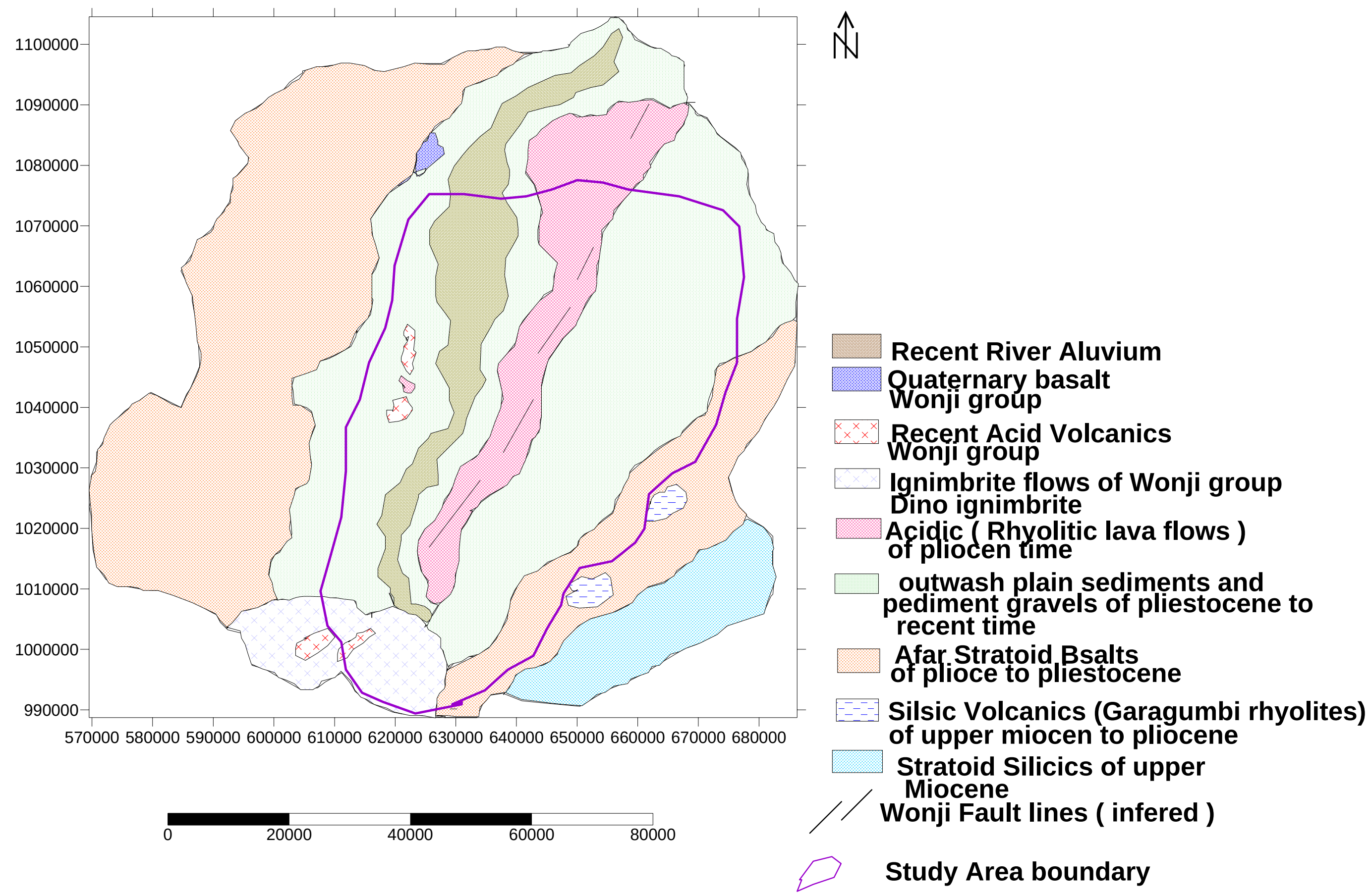


Fig 3.3 Geologic Map of the Study Area

3.2.2 Tectonics In the area

The major structural pattern in the study area is explained by the existence of a belt of numerous “en echelon” fault systems oriented along the NNE to SSW direction parallel to the main Ethiopian rift trend which are suggested to be formed at the end of Pliocene and lower Pleistocene (Mohr, 1962) , where as in the main Ethiopian rift the wonji Fault belt is younger and began after the Nazret phase (meyer 1975).

The existing geomorphologic situation of the study area is possibly the result of this fault belt which forms the existing Awash river valley or graben being separated from the Alaydegea plain rising around 100 meters above the graben with an acidic lava horst running North south in between.

The graben within graben structures existing in the study area like the hertale graben to the North east of Bilen and the Issa graben in middle valley are the result of the wonji fault belt. Columnar Jointing and block faulting of the rocks of the stratoid basalts and the acidic lave horst is most common in areas where these rock units are exposed in particular at the side of the fault escarps around bilen and exposure of the horst structure around berta or Adobtele on the way to melka werer.

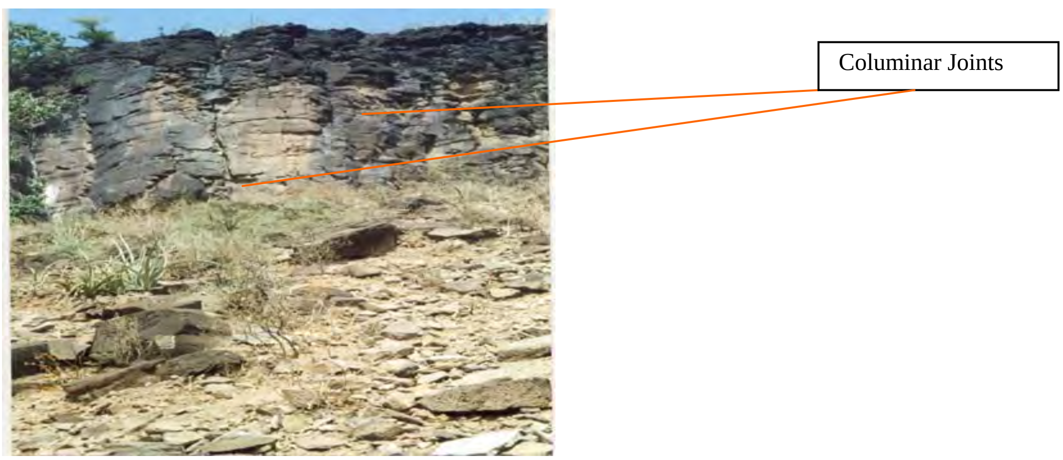


Fig 3.4 Columnar Jointing and Block faulting of the Acidic Lava (photo taken on a Steep Wonji fault escarp at Bilen

At the Northern tip of the Alaydegea plain and near to gewane, and on the Amoisa volcanic series there exists an ESE – WNN alignment of volcanic indicating another important tectonic trend in the area. Regarding the major lineation on which the youngest volcanic activities has occurred in the study area there are two major lineation which trend north – North East coinciding with the major rift faulting.These lineation are approximately 7kms apart (currey 1972) .

Chapter 4: HYDROMETROLOGICAL ANALYSIS

4.1 Determination of aerial depth of rainfall

In order to observe the variation in rainfall within the study area rainfall data was collected from three gauges at Awash Sebat, Melka Werer and Melka Sedi. The data of gauge observation was more or less complete for the first two gauges where data for more than 25 years was compiled and analyzed. However for Melka Sedi gauge the data was incomplete for some years therefore all missing data for the gauges has been filled by supplementing a missing yearly data in relation to the near by gauge. From point measurement data on three gauges there is slight variations in mean annual rain fall for the areas of Awash Sebat, Melkawerer, and Melkasedi with mean annual rainfall of 604 mm, 615mm and 571mm respectively. (table 2.1)

The average rainfall over the area which is the aerial rainfall or aerial precipitation is computed from three point measurements using a simple arithmetic mean method since there is no marked diversity in surface characteristics or much variation in rainfall for the area under study. Therefore, the aerial rainfall for the study area is computed to be 596.7 mm annually.

The distribution of rainfall is observed to be of the bimodal type with relatively high rainfall amount for the months of March and April with monthly mean of 67 mm and 60mm and similarly the heavy summer rains for July and Augest with monthly mean of 118 mm and 131mm respectively.

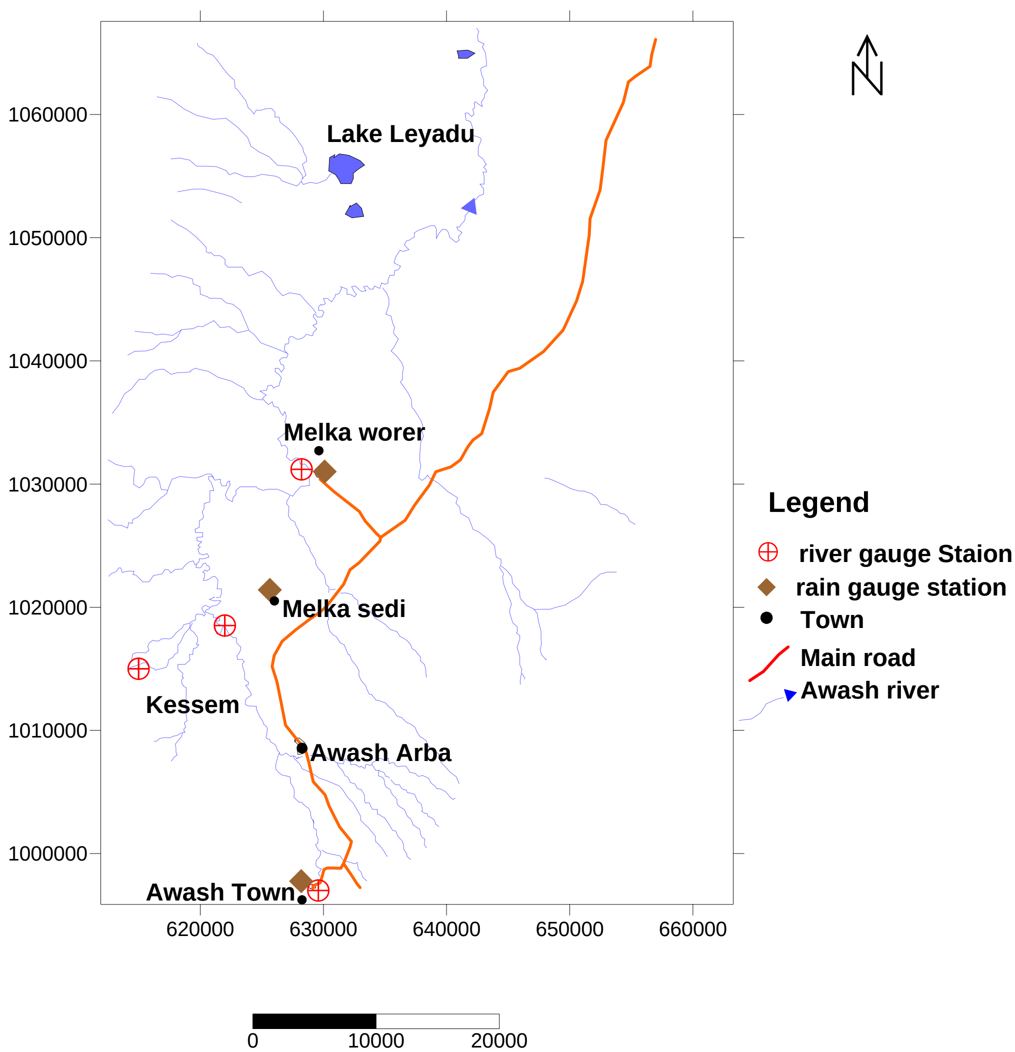


Fig 4.1 Location Map for Hydrometeorogy Stations in the Study Area

4.2 Evapotranspiration

Under field condition it is not possible to separate evaporation from transpiration. Indeed we are generally concerned with the total water lose or evapotranspiration from a basin. Whether the loss is due to free water evaporation, plant transpiration or soil moisture, evaporation is of little importance. Fitter (1996)The term potential evapotranspiration was introduced by

Thornthwait (1944) as equal to the water loss which will occur if at no time there is a deficiency of water in the soil for the use of vegetation, the majority of the water loss due to evapotranspiration takes place during summer months with little or no loss during the winter. Because there is often not sufficient water available from soil moisture the term Actual evapotranspiration is used to describe the amount of evapotranspiration that occurs under field condition. Fitter (1996).

4.2.1 Estimation of of Evapotanspiration

As the area is found in Semi arid Climatic zones with high temperature values raising the potential evapotranspitation much higher than the annual PPT, Evapotranspiration is an important and major factor for the water loss in the catchments leaving the area under moisture deficit where precipitation could not satisfy soil moisture. This is supported with a significant correlation of PET with altitude in the previous studies (Halcrow, 1989) made for the entire Awash basin where evaporation values are observed to be over twice the mean Annual Rainfall for the upper Awash Valley (around Wonji).

For this study of the partial catchment, Analysis of potential evapotranspiration i.e. the potential Water loss from a vegetated land surface by evapotraspiration plus transpiration in unlimited moisture supply (Shaw, 1988) has been carried out using two empirical methods which are the Penman modified method and Thorethwaite method.

A) The penman modified method

The Penman combined method, penman (1948) which was developed by combining the mass transfer and energy balance approaches for calculating the open water evaporation based on the fundamental physical principles with some empirical concepts that enable the use of standard meteorological observation, was later modified by the ministry of agriculture Fisheries and Food (MAFF,

1967) to allow the conditions under which evaporation plus transpiration takes place from a vegetated surface. (shaw, 1988)

The basic equation for PE is given by

$$PET = \frac{\left(\frac{\Delta}{\gamma}\right)H_T + E_{at}}{\frac{\Delta}{\gamma} + 1} \qquad (4.2.1)$$

Here to signify the inclusion of transpiration effect in this equation an extra subscript **t** is maintained unlike the same equation for the open water evaporation of (Penman 1948)

H_T = is the available heat which is more often calculated from incoming radiation (r_i) and out going addition (Ro) determined from sunshine records temperature and humidity using;

$$H_T = 0.75R_I - R_o \qquad (4.2.2)$$

Where r is the Albedo, i.e. the reflective coefficient for incident radiation which is taken as 0.25 for a short grassed surface (assuming the grass and pasture land of study area)

Hence, $H_T = 0.75R_I - R_o$ (4.2.3)

R_i is a function of Ra, the solar radiation (fixed by latitude and season) and modulated by function of the ratio n/N of measured to maximum possible sunshine duration using r=0.25.

$$R_I(1-r) = 0.75R_a f_a\left(\frac{n}{N}\right) \qquad (4.2.4)$$

For the study area with in latitude to the south of 54 ½ north;

$$f_a\left(\frac{n}{N}\right) = \left(0.16 + 0.62\frac{n}{N}\right) \text{ (Maff, 1967)} \qquad (4.2.5)$$

R_o – the out going radiation explained by the empirical equation

$$R_0 = \sigma T^4\left(0.47 - 0.075\sqrt{e_d}\right)(0.17 + 0.83n/N) \qquad (4.2.6)$$

$$E_{at} = 0.35\left(1 + \frac{u_2}{100}\right)(e_a - e_d) \qquad (4.2.7)$$

E_a = the saturated vapor pressure at air temp- T_a

e_a= vapor pressure of the air , i.e. the saturated vapor pressure at dew point T_a

(e_a – e_d) the saturation deficit

U_2 = mean wind speed at 2m above the surface miles/day

γ – hygrometric constant, which is obtained from the nomogram

Therefore, based on the basic equation (4.2.1) above, the calculated annual potential evapotraspiration of the study area according to penman is 1427mm.

Table 4.1 Calculated PET Values of Awash Area according to Penman Method

Months	Jan	Feb	Mar	App	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (^oc)	22.8	23.7	25.5	26.9	28.2	29.7	27.6	26.1	26.8	25.5	24.1	22.6
n hrs/day	8.9	8.0	7.9	7.3	8	7.7	7	7.5	7.3	8.1	9.2	9.3
N hrs/d	11.6	11.8	12	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.4	11.2
Wind speed, mile/day	38.5	33.5	41.8	40.2	46.9	77.0	80.4	46.9	40.2	33.5	40.2	28.4
n/N	0.76	0.67	0.66	0.59	0.63	0.60	0.55	0.60	0.60	0.68	0.79	0.80
$e_d - e_a$, mm/day	9.3	9.35	9.35	9.32	9.4	9.44	9.28	7.08	9.26	9.26	9.25	9.28
Ra (mm/ day)	12.8	13.9	14.8	15.2	15	14.8	14.9	15	14.8	14.2	13.1	12.5
Ri (1-r), mm/d	4.56	5.85	6.31	5.85	6.19	5.9	5.6	5.92	5.9	5.31	6.38	6.15
R_o (mm/day)	2.37	2.13	2.10	1.94	2.04	1.97	1.84	1.74	1.97	2.15	2.42	2.44
H_t	2.19	3.72	4.21	3.91	4.15	3.93	3.76	4.18	3.93	3.16	3.96	3.71
σTa4 mm/day	15.5	15.5	15.9	16.1	16.4	16.7	16.3	16	16.15	15.95	15.6	15.3
Δ/γ	2.64	2.67	2.88	3.06	3.2	3.36	3.12	2.94	3.03	2.91	2.7	2.52
Eat, mm/day	4.49	4.35	4.61	4.56	4.83	5.84	5.84	3.64	4.54	4.32	4.53	4.17
PET (mm)	83.4	116	129	122	130	132	129	121.2	122.4	103.74	123	114.6
Total Annual PET												1427mm

B) Thornthwaite method

This formula relates potential evapotransiration to temperatures and the number of hours of day light to the consumptive use of a short closed vegetation and is strongly based on Temperature as an index of energy available for evapotraspiration

This equation is given by;

$$PET_m = 16 N_m \left(\frac{10 \bar{T}_m}{I} \right)^a mm \qquad (4.2.8)$$

where T_m- is the monthly mean temperature ^{0}c and N_m is the monthly adjustment factor related to hours of day light and m_c… is the months 1,2,3,4, …12

I –the heat index for the year, it is given by

$$I = \sum i_m = \sum \left(\frac{\bar{T}_m}{5} \right)^{1.5} \quad \text{for m=1…1 2} \qquad (4.2.9\ )$$

And: $a = 6.7x10^{-7} I^3 - 7.7x10^{-5} I^2 + 1.8x10^{-2} I + 0.49$

Then, given the monthly mean temperature from the measurements at a climatologically station an estimate of potential evapotranspiration for each months of the year can be calculated (Table 4.2)

Based on this the Annual PET from thorenthwaite for the Awash area i.e. South Central part of the partial catchments or study area with mean monthly temperature of 25^{o}c from is around 1000mm annually. In comparison to the result from the penman modified this has underestimate the value. From the two methods i.e penman and Thorenthwait, an average value of Annual PET = 1211 mm (Table 4.3)

Table 4.2 Monthly Potential Evapotraspiration (PET) computed for Awash Area according to Thorenthwaite Method

Parameters	Jan	Feb	March	App.	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (mm)
Temp.	22.8	23.7	25.5	26.9	28.2	29.7	27.6	26.1	26.8	25.5	24.1	22.6	
(Tm/5)1.5	9.7	10.3	11.5	12.47	13.4	14.4	12.9	11.9	12.4	11.5	10.58	9.6	
N M	0.96	0.98	1	1.025	1.05	1.06	1.05	1	1	0.98	0.97	0.96	
PET	56.1	63.5	79	93.1	108.4	125.8	102.4	83.9	90.1	77.3	65.78	54.7	1000.00
I= 140.6													
a=2.68													

Table 4.3 Average potential evapotranspiration value of Awash Area from Thorenthwaite and Penman

Methods	Jan	Feb	March	App.	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (mm)
Penman	83.4	116	129	122.1	129.7	132.6	128.7	121.2	122.4	103.7	123	114.6	1427
Thorenth.	56.1	63.5	79	93.1	108.4	125.8	102.4	83.9	90.1	77.3	65.8	54.7	1000
Average	69.8	90	104	107.6	119	129.2	115.6	102.6	106.3	90.52	94.4	84.65	1213.59

C) Actual Evapotransiration (AET)

AET is used to describe the amount of evapotranspiration that occurs under field condition when there is often not sufficient water available from soil moisture. Fitter (1996)

Turc (1954, 1955) is a widely used empirical formula to estimate the Annual values of AET for catchment areas which could be applied in both humid and arid climate's either hot or cold.

$Et = P/(0.9+ (P/L)^2)^{1/2}$ mm per annum

Where p is the mean annual precipitation (mm)

$L = 300+25T+0.05T^3$ (mm)

T= the mean air temperature (^{o}c) of the area

In this method, these results demonstrated that precipitation and Temperature could be the dominant factors in evapotranspiration (Shaw, 1988)

For the Area under study this method has been used to estimate the actual evapotranspiration.

For this computation, an average values of mean annual rainfall and Temperature values have been considered for the entire Area , so that mean Annual Rainfall amount for the area is obtained by averaging the values obtained for the three localities (table 2.1) from the rain fall analysis computed which gives a value of 596.8mm annual for the entire study area . And similarly an average or mean value of Temperature (26 ^{o}c) is computed and assumed by a similar approach for the entire area.

Based on this

L (26^{o}c) = 300+25(26) +0.05(26)^{3} and from this

AET = 595.6 mm annually

D) Soil Water balance computation

A value of the actual evapotranspiration (Et) over a catchment is more often obtained by first calculating the potential evapotranspiration (PET) i.e assuming an unrestricted availability of water and then modifying the answer by accounting for the actual soil moisture content. Using the method outlined by Thorenthwaite and Mather (1957) soil water balance model computation.

Since water loss from a catchment area does not always proceed at the potential rate as it is dependent on a continuous water supply, the actual evapotranspiration becomes less than potential when the vegetation is unable to abstract water from the soil (Shaw 1988)

When the soil is saturated, it holds no more water. After rainfall cease, saturated soil gave up water and becomes unsaturated until it can just hold a certain amount against the force of gravity; it is then said to be at field capacity. In this range of condition AET = PET. If there is no rain to replenish the water supply, the soil moisture gradually becomes depleted by the demands of the vegetation to produce a soil moisture deficit (SMD), viz the amount of water required to restore the soil to Field capacity. As SMD increases, Et becomes increasingly less than PE the value of Et and SMD vary with soil type and vegetation. Penman (1950) introduced the concept of a root constant (RC) that defines the amount of soil moisture (mm depth) that can be extracted from a soil without difficulty by given vegetation.

It is assumed that AET=PET for a particular type of vegetation until the SMD reaches the appropriate root constant plus a further 25mm approximately which is added to allow for extraction from the soil immediately below the root zone. Thereafter AET becomes less than PET as moisture is extracted with greater difficulty, (Shaw 1988).

A soil moisture budget can be made on a monthly basis for various types of vegetation classified according to their root constant. Accordingly soil moisture budgeting for the eastern part of the study area which is the Alaydegea plain, is made by considering a soil type i.e clay soil with vegetation type of deep rooted crops (alfalfa, pasture grass and shrubs) and rooting depth of 0.67m with available water capacity of the root zone 200mm.

Table 4.4 AET values from Soil Water balance Model (Thorenthwaite and Mather Water Balance) For clay soil with deep rooted pasture grass and shrubs type vegetation of rooting depth 0.67 And available water capacity of 200mm that covers much part of the area.

mm	Jan	Feb	Mar	App	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
PPT	7.0	43	88	63	43	21	122	127.0	55	25	9	12	615
PET	83	116	129	122	130	133	129	121	122	104	123	115	1427
P-PET	-76	-73	-41	-59	-87	-112	-7	6	-67	-79	-114	-103	-812
Acc.Pot W.L	- 1125	- 1198	- 1239	- 1298	- 1385	- 1497	- 1504	-686	-753	-832	-946	- 1049	
SM	1	1	0	0	0	0	0	6	5	3	2	1	
SM change	0	0	-1	0	0	0	0	6	-1	-2	-1	-1	
AET	7	43	89	63	43	21	122	121	56	27	10	13	615
D	76	73	40	59	87	112	7	0	66	77	113	102	
S	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0

Therefore, based on this input data and available metrological data like the monthly Rain fall data and PET values estimated from Melkawrer areas the

Actual evapotranspiration (AET) is calculated for this particular part of the study area using Thorenthwait and Mather (Dingman 1994) standard soil water balance model.

Alley (1984) found that if in a given month

P_m>PET, the value of the soil moisture at the end of the month, S_m found as

$$S_m = \min\{[(P_m - PET_m) + S_m - 1], S_{\max}\} \qquad (4.2.10)$$

If Pm<PET, a soil moisture deficit develops where S_m is given by

$$S_m = S_{m-1} \exp\left[-\frac{(PET_m - P_m)}{S_{\max}}\right] \qquad (4.2.11)$$

Finally, the monthly actual evapotaqnspiratopn AET_m is then found as

AET = PET if $P_m > PET_m$

AET = $P_m + S_{m-1} - S_m$ for $P_m < PET_m$

Where AET is the actual evapotranspiration

PET – Potential evapotranspiration

P_m – Aerial PPT

S_m – change in soil moisture i.e ($S_{m-1} - S_m$) or soil moisture difference for two consecutive months under consideration.

According to this balance computation, AET value is calculated to be 615 mm (Table 4.4). From this computation it can be observed that except for the month (August where PPt> PET value the rest shows lower values of PPT below PET values. since the balance shows that Annual AET values obtained (615 mm) is equals to the annual PPT values ,all the Rain fall annually received goes out or lost as evapotranspiration resulting no surplus values (zero surplus) for the whole months of the year. This condition is due to the the arid nature of the study area.

According to David. N. (1990) soil moisture budgeting is developed for humid climate and have less validity in arid and semi arid zones and they work best for seasonal patterns of recharge, well developed soil which do not dry completely and when PET and AET are of similar size and with PPT relatively uniform. But for semi Arid and Arid zones, the model normally underestimates recharge often giving zero value.

4. 3 River Discharge Analysis

To observe the River flow pattern and the hydrographic characteristics of the River Catchment, River discharge Analysis has been made for the main Awash River in the Partial Catchment. This includes the observation and Analysis of peak river flows, patterns of River flow or River Regimes and Hydrograph Analysis i.e separation of ground water Runoff and surface Runoff at selected gauging station.

For the observation of the flow pattern of the Awash River along its course in the study area. Flow discharge data on daily and monthly basis have been used on selected gauging stations at upstream (Awash Station) and down stream (Melka worer) gauging station. River discharge data are obtained from stage – discharge relation ship recorded at gauging stations.

The mean annual total flows and mean monthly discharge of the river Awash for a specific time period of 25 years (1973 – 1998) including tributaries inflow amount is shown in Table 4.5 and 4.6

Table 4. 5 Mean Monthly discharges of Awash River and its Tributaries averaged for long years

Location	Jan	Feb	Mar	App	May	Jun	July	Aug	Sep	Oct	Nov	Dec
at Awash Sebat	46.5	42.3	55.0	62.2	60.4	44.8	93.7	160.8	150.6	85.0	42.0	40.0
at Melka -Worer	39	43	59.0	54.6	48.9	33.5	92.6	160.9	132.6	72.9	402	31.7
at Hertale	49.25	50.69	65.56	70.98	63.65	57.48	142.3	229.9	173.2	71.3	41.6	45.1
Kessem Stream	5.383	5.28	10.60	7.654	4.882	11.76	93.58	129.93	67.12	16.2 9	8.52	7.76
Kebena Stream	2.47	2.87	2.73	6.33	3.82	2.87	13.25	44.36	18.7	6.11	4.77	2.15

Table 4 .6 Summary of Mean Annual Total flows of Awash River and its Tributaries at gauging Stations

Gauge Station	Drainage Area in Km^2	Period	Mean Annual Flow in Mm^3
Awash at Awash Sebat	18568	1973--1998	1725
Awash at Melka Worer	25860	1973--1998	1854.86
Awash at Hertale	33875	1965--1975	2752
Kessem Tributary	3135	1970--2004	411.83
Kebena Tributary	1300	163--1980	286.4

4.3.1 Peak Discharge and River Hydrograph Regimes

From the river hydrograph pattern based on daily discharge data at Melkawerer gauge, the peak discharge for the months of July and August (=200 m3/s) is observed that signifies the flood periods of the year Fig 4.2

Irregularities in the hydrograph pattern is a reflection of the catchment response to rain fall, where the peak flows are the effect of summer Rains both from the Western upland areas and upstream River catchment. The expected pattern of river flow during a year from monthly mean discharge data is known as River Regime (Shaw 1988).

The monthly mean discharge for the River Awash observed at the two gauging station for records of more than 20 years (i.e from 1973 – 1998) at Melka werer gauge exhibit a distinctive seasonal pattern with the highest values occurring in July and August months >200m3/s and relatively higher values also in march is 180 m3/s.

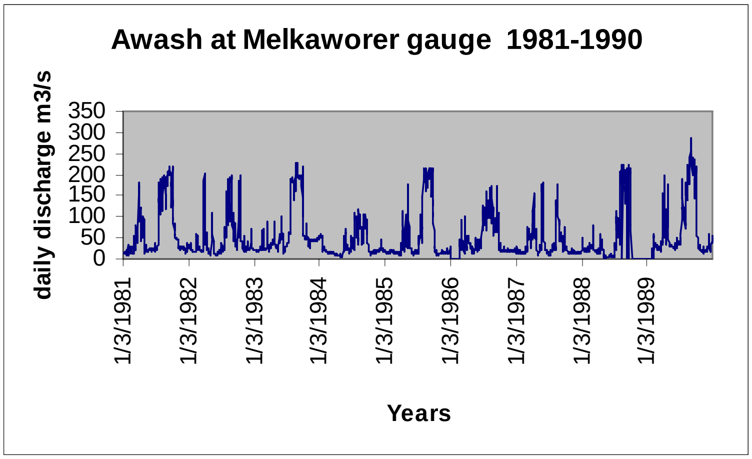


Fig 4.2 Awash River Hydrograph for long years from daily discharges

As the River Regime is the direct consequences of the climatic factors influencing the catchment Run off, the observed regime is consistent with the bimodal type of Rainfall pattern for the entire partial catchment. Therefore in general the river regime is of rain fall dependent.

From the mean annual total flow computed at the three gauge stations along its course down stream, the Awash River in general shows an increasing tendency in flow amount (Table 4.6) (i.e.Up to Hertale gauge). Further down stream however flow amount could be minimized as the river drains in the Gewane or Meteka swampy areas.

The increase in flow amount for the above trend is totally related to the run off contribution from the western uplands tributaries inflow to the main Awash Channel.

4.3.2 Base flow Separation

Separation of the different flow components, especially the base flow is essential to evaluate the ground water potential and it also provides knowledge in the Rain fall run off relation ship of a given river catchment.

The hydrograph of discharge against time has two main components. i.e the surface runoff which is produced by a volume of water derived from storm event and the base flow contributed from the ground water (Shaw 1988)

Base flow separation is made for the river Awash at three gauging stations, at Awash Sebat, Melka werer and Hertale gauging station in the study area using a graphical method of separation. This is a method where the lower parts of the hydrograph have to be connected and the area below is an approximation of the volume of base flow.

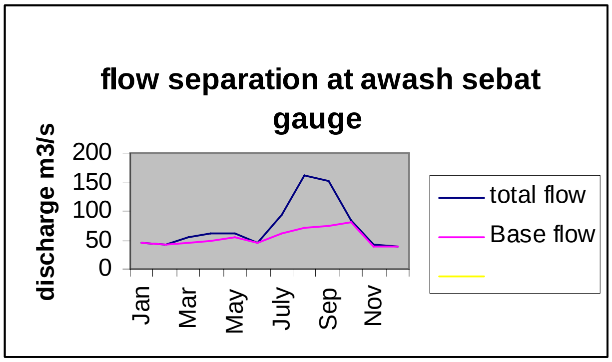
At Melka worer gauging station, the mean annual total flow is 1854 Mm^3 and adding the Irrigation abstraction upstream with mean annual amount of 158Mm^3 the naturalized or gross flow at this gauge is 2012 mm^3 from base flow separation at this gauge, the base flow component obtained is around 633Mm^3 (31 % of the total flow) and surface run off is in the order of 1379Mm^3 or 68% of the total flow. The proportion of Irrigations is considered in both components.

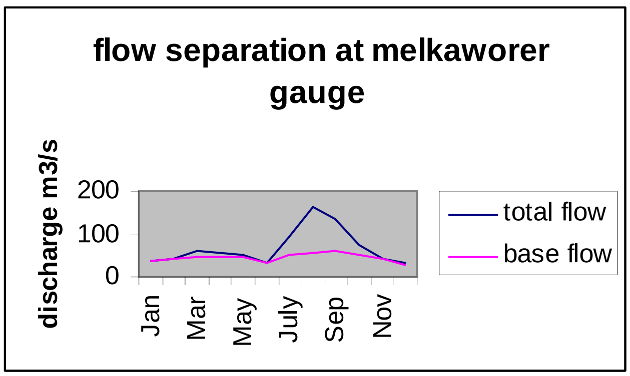
Similarly, base flow separation is made for the upper and lower reaches of the river at Awash Sebat and Hertale gauging points using the same method. From this Hydrograph separation, it has been observed that the upper and lower parts of the river i.e at Awash Sebat and Hertale have relatively higher base flow components than the middle part which is Melka worer. The highest value is for Hertale gauge down stream of melka worer. This surface run off amount separated at the gauge includes both the run off contribution from the partial catchment and the surface inflow from the upper catchment at the upstream gauge.

Hydrograph separation for the tributary Kessem River has also be done to observe the ground water run off condition for the Western part of the catchment. From the hydrograph separation it has been observed that ground water run off is in the order of 22% of total flow for this sub catchments. the mean annual total flow at Kessem gauge is 411 Mm3 with base flow component of 90.4Mm^{3}and for Kabena tributary which has similar catchment characteristic as Kessem ,the Mean Annual total flow (from records of 1965 – 1980) is around 286.4 Mm^3 with base flow component of around 63 Mm^3.

Table 4. 7 Flow characteristics at gauging stations for Awash River catchments with its tributaries and related base flow contribution

Location of Stations	Length of record	Mean Annual total flow Mm3	Total Annual Base flowMm3	Surface run off
Awash River at Awash Sebat	1968-2001	1812.65	656	1156.6
Awash River at Milkworer	1973-1998	2012	633	1379
Awash River at Hertale	1964-1975	2752.93	1272	1480.9
Kessem stream at Kessem gauge	1970-2000	411.00	90	321
Kebena stream at Kebena gauge	1963-1980	286.43	63	223.43





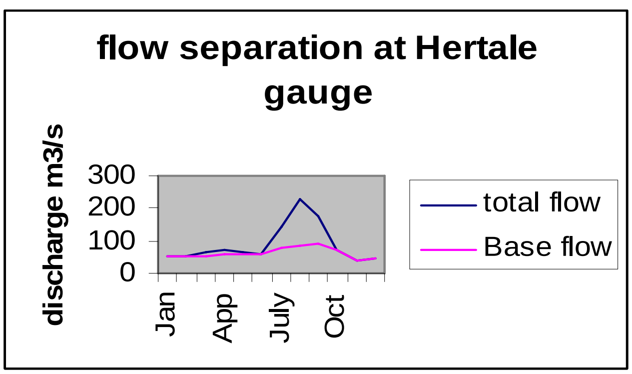


Fig 4.3 base flow Separation for Awash River at three gauges

4.4 Channel Water balance and Indirect Recharge from Awash River

The area in particular the shallow river valley Aquifer system gets some indirect recharge from percolation of the Awash River channel which is the most possible mechanism as the area is situated in a limited rain fall distribution.

Channel water balance computes recharge from straight forward estimation of transmission loss and by careful consideration of river bed process, this can be further extended to estimate recharge or percolation in the area. (David 1990)

All the significant inflow and outflow components to the upstream and down stream parts of the river channel including along its path (for the tributary inflow) would be considered.

Recharge from channel water balance is computed (Table 4.7 and 4.8)

Recharge (Ro) = $Q_{up} + Q_{inR} - Q_{down} - Q_{out} - Ea$

Where Q_{up} = upstream inflow (i.e river discharge measured Upstream)

Q_{inR} tributaries inflow to the channel

Q_{down} = down stream out flow(i.e Q measured down stream)

Q_{out} = out flow by abstraction

Ea = Evaporation from River surface (open water evaporation) Which is considered insignificant due low channel surface area

Table 4 . 8 Mean Monthly Awash River Loss and Gain Computation (BALANCE) From mean monthly flows in Mm3 for the time period (1973—1983)

Gauging Pt.	Jan	Feb	Marc	App	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Mm3
Awash at Awash Sebat	91.68	81.11	91.97	94.2	95.83	80.48	169.48	286.6	316	151.8	86.87	89.95	1636.13
Awash river at M. Worer	79.62	73.6	96.17	99.6	78.27	67.23	230.47	432.22	336.3	149.7	79.6	76.3	1799.42
Kesem Inflow	5.582	4.86	6.6	6.8	4.2	8.9	107.95	176.63	66.4	17.5	7.3	5.5	418.68
Kebena Inflow	6.42	7.46	7.1	11.44	9	8.28	39.14	113.3	56	16	10.9	4.75	289.79
Kes+Keb	12	12.32	13.79	18.3	13.2	17.2	147.09	289.93	122.4	33.5	18.2	10.32	708.47
Irrigat. Abstraction	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	158.4
River Loss b/n Awash sebat and Worer	10.2	6.63	-3.6	-0.7	17.56	17.29	72.81	131.08	88.95	22.49	12.18	10.68	385.57

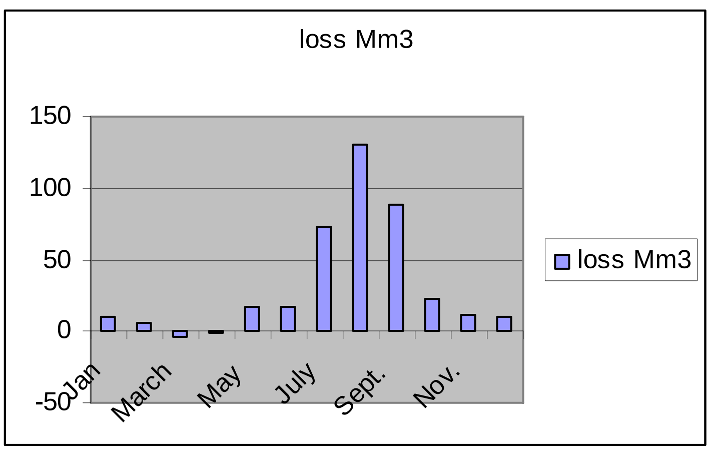


Fig 4.4 Mean Monthly loss of Awash river b/n Awash Sebat and Melkaworer

Table 4.9 Net Annual Loss of Awash River between Awash town and Worer for the same time period (1973—1983)

Year	Awash at M.Worer gauge	Awash at Awash Sebat gauge	Kessem and Kebena inflow	Water loss between Awash sebat and M. Worer considering irrigation use of 158.60Mm3 annually
1973	1285.16	1013.08	909.2	473.57
1974	1723.27	1477.27	1006.11	601.56
1975	2243.99	1986.64	805	389.18
1976	1693.50	1337.49	578.82	64.26
1977	2344.81	1984.84	700.99	182.47
1978	1873.38	1846.25	694.21	508.53
1979	1624.20	1508.54	535.56	261.35
1980	1156.39	896.70	751.93	333.69
1981	2121.20	2152.60	755.58	628.43
1982	1551.87	1358.82	540.6	189.00
1983	2230.05	2435.37	533.56	580.30
Average	1804.35	1636.15	710.14	382.94

From table 4.9 showing the Awash River channel water loss and gain from Annual total flows in Mm^3/year of the Awash, Kessem and Kebena River contributing to the channel and also considering Irrigation abstraction with mean annual value of 158 Mm3/year and also assuming channel evaporation the transmission loss is computed for the part of the channel between Awash Sebat and Melka Worer

Q_{up}= the mean annual total flow at Awash Sebat Gauge considered as upstream inflow is 1636.14 Mm3

Q_{inR} = Tributary inflow, i.e. kessem + kebena = 697 Mm3

Q_{down} = downstream out flow, i.e mean annual river discharge at Melka were gauge = 1804.34 Mm^3

Q_{out} = Irrigation abstraction, mean value 158 Mm^3/year

Therefore, Transmission Loss (Recharge) is given as ;

Recharge (Ro) $= Q_{up} + Q_{inR} - Q_{down} - Q_{out}$

$= 1636.14Mm^3 + 709.69\ Mm^3 - 1804.34\ Mm^3 - 158\ Mm^3$/year

$=$ 382.85.14Mm^3 Annually

Note: Since transmission loss might be reduced by bank storage, evaporation from surface, temporary pools before becoming deep percolation which again might be reduced by perched water table and under flow before becoming recharge, the amount obtained could not be an actual recharge to the shallow ground water, therefore the actual recharge would be some amount less than this value depending on the channel bed and subsurface conditions.

Chapter 5 : HYDROGEOLOGY

5.1 Regional Hydrogeology

With the rapid evolution of the basin through the plio – Pleistocene, a reasonable thickness of the alluvium and volcanic accumulated in the bottom of the Awash valley (Halcrow 1989).

As much of this material is unsaturated and in consequence groundwater gradients from the escarpment are not necessary analogous to topography and the further suppression of the groundwater head distribution is probably accentuated by faulting. As a result very deep groundwater could be possibly encountered on some parts of the basin in addition to the shallow groundwater.
The Hydrogeology is intimately associated with the geological evolution of the basin. The regional groundwater flow is obviously from the escarpment in to the valley and north east ward to lake Abe (243 m.a.s.l) and possible further to Danakil depression (-114m.a.s.l).

Regarding the hydrogeology of the pediment slops where thick pediments are present that are formed from Miocene to recent locally interbedded with volcanic, they from an aquifer of extreme in homogeneity. These areas include Eastern catchment, middle valley and lower plateau slops north of kessem. Groundwater condition in the eastern catchments is related to the situation adjacent catchment of Dire dawa where Mesozoic lime stone, dolomite and sand stone occur in the escarpment and recharge the pediment.

5. 2 Hydrogeology of the Study Area

5.2.1 Aquifer Characterization

5.2.1.1 Aquifer Systems in the Area

Major Aquifer system classifications has been made from the hydrogeologic patterns of the area for the depth of groundwater level in wells and aquifer units in relation to the prevailing hydrochemistry of the groundwater. This is based on the observation and analysis of all the compiled well log data and pumping test data for the existing wells in the study area.

There exists in general both a shallow groundwater or aquifer system and deep groundwater/aquifer system in the study area. The spatial distributions of these aquifers and their depth of occurrence and lithologic make up of this system are discussed as follow.

a) Shallow aquifer system

This aquifer system in general extends through out the Awash River valley (or relatively few depth below the Awash River course) in the river alluvium sediments of sand and gravel with clay. The aquifer unit in most places consists of sand and gravel and in most cases it is found in a semi confined nature below a sandy clay layers and sometimes found in un confined system. This situation is observed from the different shallow wells and open dug wells drilled on the river banks of Awash like the shallow wells observed at Bilen, Sheleko , Melka worer and Melka Sedi (kerensa) where a shallow sand and gravel aquifer system are encountered at a depth of around 30 meters and below in a semi - confined nature. The water level in these well rises to a depth 10 – 15 meters.

The shallow wells of Melka Worer, Sheleko, Ambush, Melkasedi and Bilen with a depth of around 50 meters penetrating this aquifer system in general yields water in the rate of 5.7 lit/sec with relatively lower draw down of around 2 meters and high transmissivity values. However the transmissivity values for the same aquifer system but with more clay intercalation is relatively lower like the Hassoba deep well with transmissivity value of 31.88m^2/d and relatively higher drow down of 14m. Permeability of aquifer is reduced due to the existence of clay material in the aquifer units. for the unconfined shallow aquifer system as observed from the open dug wells close to the river bank of Awash at Hassoba, Ambash, sheleko and melka sedi water level in the clayey sand (very low permeability aquifers) exists at relatively very shallow level i.e 5 – 7 meters below ground surface.

In addition to the river sediments, the shallows aquifer system in the Awash River valley also exists within the volcanics erupted in the valley floor in relation to recent wonji faults. The shallow aquifers of scoracious basalts and scoria encountered through shallow wells at Ambash and Melka Worer areas around the recently erupted dofen volcanic is a good example. Water level in this wells rise up to 8 meter depth with wells yielding 7 – 10 l/s . The possible mechanism of recharge condition for this Aquifer system is percolation from the Awash River bed and seepage from irrigation Canals particularly for the very shallow unconfined Aquifer units.

b) Deep Aquifer system

Most of the wells both (shallow and deep) however tap water from deep Aquifer Systems i.e fractured volcanics and volcanic sands particularly for areas adjacent to the Awash River graben i.e the Alaydegea plain and related pediment plains and upland areas to the west and east of the river valley. This is a highly weathered and fractured Aquifer interbedded with old pediment gravel existing at a depth of 80-100 m depth confined between massive volcanic units. From Deep Wells drilled on the Alaydegea plain, Awash Arba Town and adjacent to the horst structure on Berta Areas, with depth ranging from 100-140 meters, water level in the well exists between 60-75 meter depth with very low draw down in the range of 1 to 3 m and . this aquifer has relatively higher transmissivity value in the range of 400-800 m2 /day with productivity of 6-8 lit/sec. the out wash old pediment gravels and course sands interbeded with fractured Aquifers are also

encountered at depth between 100-150 meters in wells at Awash Arba town i.e the southern tip of the Alaydagea plain.
The depth to water level in a well drilled at berta area close to the foot of the horst that separates the plain from the river graben rises up to 34m below ground surface. Here transmissivity value is relatively higher up to 800m^2/d with well yielding above 5 lit/sec with a draw down of less than two meter. This aquifer system (scoraceous basalt) is highly fractured due to the recent tectonic events (wonji fault) that forms the near by horst structure separating the plain from the western Awash River valley. The increased transmissivity values in this area is due to the induced secondary porosity or fracture porosity in relation to the tectonic event .

There exists a small variation in the depth of occurrence and types of aquifer units in this aquifer system on the plain along the south north direction. The major aquifer units of this system includes the weathered and fractured basalts, ignimbrite and trachites interbaded with volcanic sand and old pediment gravels. the depth to this aquifers in the southern tip of the plain around the Awash Arba area is beetwen 80 – 90m and extending up to a depth of 150 meter and it exists in confined system with its upper section consisting of thick pyroclastic and massive volcanics of trachites and ignimbrites as observed from the Arba town deep wells. Depth to aquifers toward north east direction on the plain is between 60 – 70m and extending up to depth of 120 meter. The aquifer system dominantly consists of the fractured aquifers of scoraceous basalt and ignimbrite or trachy basalts continuously interchanged with volcanic sands and well rounded out wash gravels . The depth below 120m is mainly of massive volcanic units as this can be more explained by well logs of Elfora and Andido areas.

Regarding the groundwater level along the plain, it declines north eastwards, where for instance, from Awash Arba(south tip of the plain) toward northeast on the plain water level in the ground declines from a depth of 60m for Awash Arba well to 75m depth in areas around Elfora camp which is around 25km north on the high way from Arba town and further toward north in Andido areas which is around 45 kms from Arba town on the high way, groundwater level declines to a depth of around 80m below ground surface as observed from Andido deep wells.

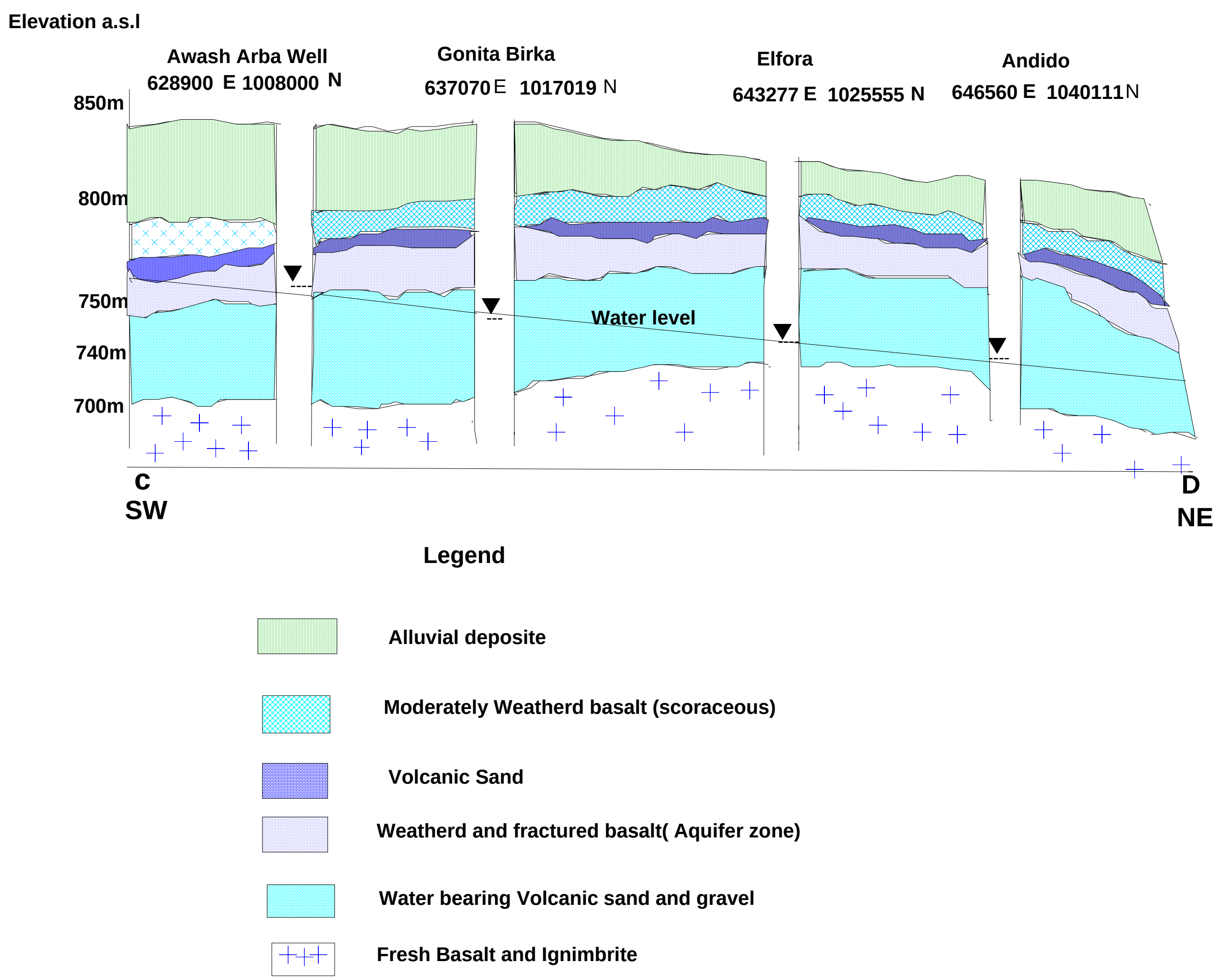


Fig 5.1 Hydrogeologic Section on the Alaydegea Plain along SW – NE direction

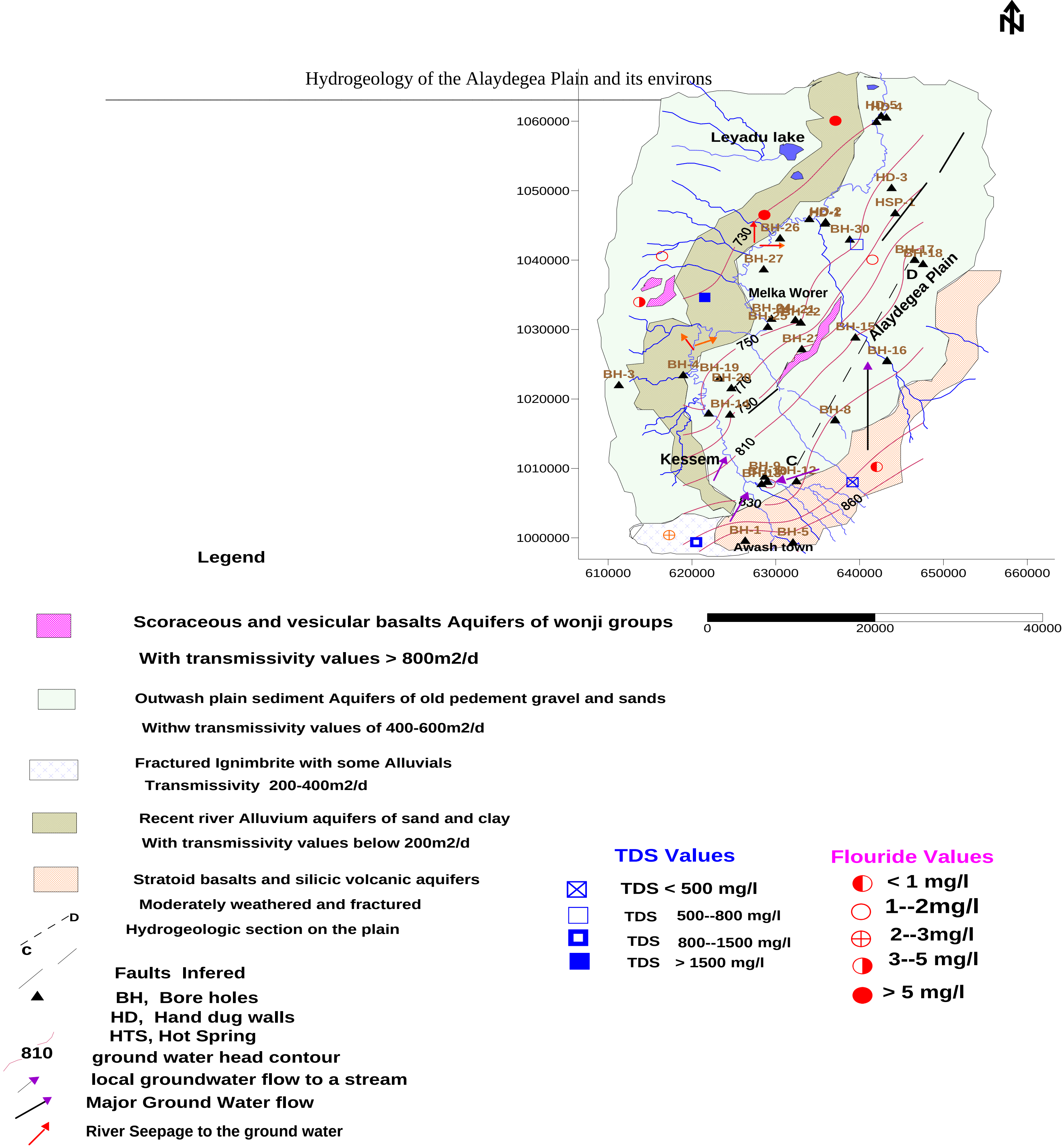


Fig 5. 2 Hydrogeologic map of the study Area

5.2.1.2 Review of Resistivity survey values in the area

From resistively survey conducted previously on the plain to the north western part of the plain around Andido area, the survey had identified 5 – 6 layers with their apparent resistivity which is almost consistent with the bore hole log data on the area. Apparent resistively values for the identified layers in general range from 30 to some high values around 900 (Ώ -m) where the bottom 5th and 6th layers exhibit resistivity values ranging from 30 – 150 (Ώ – m) which signifies the major aquifer zones of highly weathered and fractured basalt and the water bearing sand with gravel. the depth to this aquifer zone is below 80m. the massive basalt layers exhibit values ranging from 500 – 900 (Ώ – m) making almost the top layers where as the non water bearing formation with moderate resistivity values of 75 – 200 (Ώ – m) characterizes the intermediate layers of slightly weathered rocks existing below 20 meter depth up to 80 depth.

For the south eastern part of the plain to the east of Arba town, Resistivity survey results had shown the existence of a high resistive thick alluvial of sand and gravel which is dry or non water bearing with values around 400 (Ώ –m) and this units occurs at shallow depth (below 20m) and extending downwards at depth. The dry well or abandoned well resulted for deep well drilled around Awash Arba town, a dry well in Asbodune (165m depth) and a dry well close to the Arba tributary (145m depth) as far to the east of Arba town close to Arba tributary in gumaeba locality prevails this situation where a high resistive thick dry alluvium is encountered at shallow depth.

Resistivity survey results for the river valley formations (valley fill) along the Awash River had also prevailed some consistent values to the shallow wells drilled in the area. Resistivity values for Awash Sheleko area down stream of Melka worer and at the right bank of Awash shows the existence of very low resistive layer of very fine alluvium with resistivity values of less than 15 Ώ – m at the top (1 –10m thick) overlaying an aquifer zone of thick sandy Alluvium with resistivity value of 50 – 200 Ώ-m extending below 10m depth. However resistivity survey values for areas far to the east of the river on some upland areas like Berta locality which is close to the horst structure near Alaydegea plain show somewhat different values than the river basin fill formation. In Berta areas resistivity survey results had shown the existence of highly weathered and jointed volcanic rock with resistivity values of 20 – 80 (Ώ – m) below a depth of 25 meters down wards and this is overlain by dry non water bearing highly weathered volcanic and alluvium with resistivity values of less than 20 (Ώ – m).

Table 5.1 Summery of Resistivity Values Alaydegea

Area	VES No	Resistivity Ώ -m Depth (m)	Layers					
			Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
Awash Arba Southern end of Alaydegea Plain 628683 E 1008918N	1	Resistivity Ώ-m	24.4	95.7	24.4	16.4		
		Depth (m)	1.3	4.9	30.0	Infinite		
	2	Resistivity Ώ-m	39.2	201.6	116.9	25.7		
		Depth (m)	1.3	4.6	31.8	Infinite		
	3	Resistivity Ώ-m	6.0	4.6	49.9	31.6		
		Depth (m)	1.0	14.2	48	Infinite		
Gumaeba Area south west of Alaydegea plain 638000E 1010000N	1	Resistivity Ώ-m	16.9	3041.6	139.4	398.9		
		Depth (m)	0.5	3.6	17.0	Infinite		
Andido area north east of Alaydegea plain 646560 E 1040111N	1	Resistivity Ώ-m	80.0	892.2	488	39.5	67	
		Depth (m)	2.7	6.4	36.1	42.2	Infinite	
	2	Resistivity Ώ-m	6.9	11.7	39.1	159.7	79.3	31
		Depth (m)	4.2	5.3	8.3	21.4	51.5	-
	3	Resistivity Ώ-m	8.6	12.8	141	75.5	140.1	30
		Depth (m)	2.6	4.9	24.8	70.6	97.3	-

Table 5.2 Summery of Resistivity Values Awash Valley

Area	VES No	Resistivity Ω-m Depth (m)	Layers					
			Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
Berta close to the River graben margin 633107E 1027266N	1	Resistivity Ω-m	8.8	1.76	9.6	13.2	-	
		Depth (m)	1.2	2.1	10	-	-	
	2	Resistivity Ω-m	1.18	29.5	66	11.6	22.5	
		Depth (m)	1.1	2.5	11	32	-	
	3	Resistivity Ω-m	5.8	23.2	3	13.5	11	88
		Depth (m)	0.7	4.3	4.9	12	100	-
Sheleko Area Close to Awash Coarse on the flood plain 628562 E 1038760 N	1	Resistivity Ω-m	23	5.75	0.37	5	250	
		Depth (m)	1.3	3.4	4.7	10	-	
	2	Resistivity Ω-m	11	27.5	4.3	12.5	1.45	70
		Depth (m) Ω-m	0.7	3.5	7.6	28	40	
	3	Resistivity Ω-m	24	1.6	4.6	36	1.26	54
		Depth (m)	0.89	2.9	11.5	28	35	69

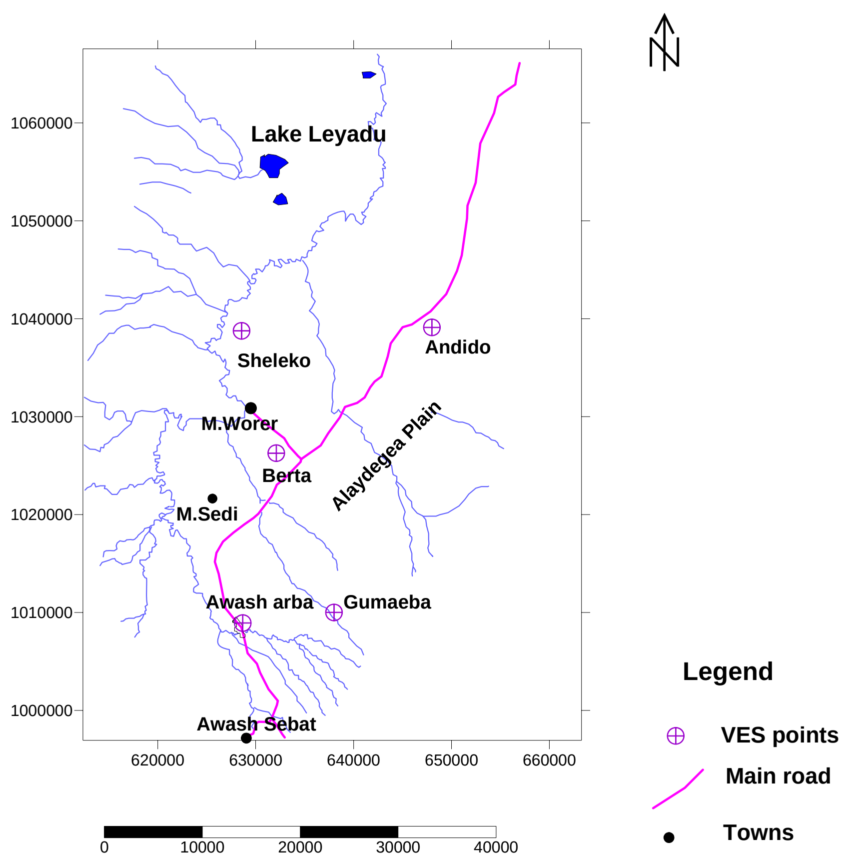


Fig 5.3 Map for the location of VES Points

5.2.1.3 Major Hydrostratigraphic or Aquifer units in the study area

From both the shallow and deep aquifer system for the entire study area, there exists in general 5 (five) major Hydrogeologic units which differ each other on the basis of the degree of the hydraulic nature (permeability and transmissivity) and watar yielding capacity. the spatial distribution of this aquifer units and their stratigraphic correlation to the major rock units of the study area is also discussed .

The major aquifer units are discussed as follow (with best aquifers first)

a) The scoraceous and vessicular basalt aquifers.

This aquifer units belong to the recent wonji volcanic group spatially distributed within the Awash river valley close to recently erupted volcanic center and along the wonji fault belt. Deep wells drilled in berta areas very close to this fault belt and wells drilled in Ambash area very close to dofen volcanic center in general tap water from this aquifer unit which is 15 – 30m thick. these are good aquifers in relation to water productivity yielding 7 – 10 l/s with transmissivity values of around 800 m2/d (from berta wells). Transmissivity value of aquifers for areas close to kessem and kebena rivers to the west of Awash town in the valley rather show a relatively higher valve of 800 – 1000m^2/day yielding water with a rate of 5- 6 lit/sec with very low draw down.

b) Fractured and weathered aquifer of trachy basalt and ignimbrites.

These aquifer units belong to the Afar stratoid silicic and stratoid basalt groups of plio-Pleistocene age most probably down faulted from the eastern margin areas. these aquifer units as discussed earlier are situated in the deep aquifer system of the Alaydegea plain occurring at a depth of around 60 – 70 meters and below with a possible thickness of around 40 to 60 meters. These aquifer units have a transmissivity value of 200 – 600 m^2/day with a minimum draw down. wells drilled in these aquifers yield water up to 10 lit/second.

c) Old Pediment sands and out wash gravels.

These aquifer units exists being interbeded with the above aquifer units in the pediment areas like the Alaydegea plain.These are deposited simultaneously with the lava flows forming the above rock units. This aquifer is observed to be good aquifer as observed from well on Awash Arba town with an aquifer thickness of around 20 meter being confined below a massive basalt unit . Well tapping from this aquifer yields water at around 7 lit/sec with low draw down of around 3m. Transmissivity value for this aquifer is moderate (400 m^2/d). The existence of out-wash volcanic sand at relatively shallow depth is encountered at kerensa well at a depth of 54 meters and below.

d) Fractured Ignimbrite of the Awash area.

This aquifer unit belongs to the dino-ignimbrite of the recent wonji group volcanics covering the Awash area. The aquifer is encountered at a depth of 200 meter and extends below to a depth of 234m as observed from a deep well drilled in kurkura camp (Awash station) with well depth of 242 meter. The aquifer occurs in association with gravel and boulders.

Well drilled in similar aquifer in the nearby well of kurkura with 139m depth has moderate productivity with a yield of 5 lit/sec. the well is situated in the kurkura river valley or gorge and hence the aquifer is at relatively lower depth (70 – 80m).

f) Recent River Alluvium of Sand and Gravel Aquifers (Pleistocen to Holocene)

This are aquifer units that make up the shallow aquifer system existing within the Awash river graben formation. The depth to this aquifers is relatively shallow at around 20m and variable thickness ranging from 15m at Sheleko wells to 40m thick for Melka Worer and Serkemo deep wells. The highest depth to these Aquifers is encountered at Hassoba well down stream of Melka Worer where the aquifer (sand with some clay) exists at a depth of 82m and extends up to 100mts depth. Since this aquifers are found in association with clays in most aquifer zones , their productivity and trasmissivity is reduced . The aquifer most possibly gets their recharge directly from the Awash River. Wells drilled in this aquifer yields 2-5 l/s with lower transmissivity values of 20-30m2/day (in Hassoba and Kerensa or Melka Sedi wells).

g) Weathered Acidic Rhyolitic flows.

This aquifer unit is also important and exists close to the acidic lava horst structure that forms the Awash river graben. This aquifer unit with its interflow gaps as good primary porosity is observed around Berta areas in a well depth of 134m with the aquifer unit existing at a depth of 64 to 82 meter. Since primary porosity of inter flow gaps are reduced due to filling or deposition of some detrital and unsorted pyroclastic materials, there is no observed appreciable well productivity for this aquifer.

Table 5.3 Summary of Major Aquifer units with their hydraulic parameters and spatial distribution

Major Aquifer Type	Depth (met.)	Thickn. meter	Transmissivity m2/d	Water yields(l/s)	spatial distribution
Scoracious and Vesicular basalts	30-60	15-30m	800-1000	7-10	Ambash, Berta, Melkasedi and Kebena areas .
Trachybasalts and Ignimbrite (weathered and fractured)	60-70	40-60	200-600	10	Alaydegea plain
Old Pediment gravel and volcanic Sands	50-100	54	400	7-10	Alaydegea Plain
Fractured Ignimbrite of Wonji group with old Alluvial	70-100	34	200-400	5	Around Awash area
Recent River Alluvium	20-50	15-40	20-30	2.5	Hassoba,Kerens and Melkasedi

5.2.2 Groundwater Recharge and Discharge

5.2.2.1 Recharge zones and mechanisms of groundwater recharge

a) Recharge zones Groundwater recharge can be defined as the entry into the saturated zone of water made available of the water table surface together with the associated flow away from the water table within the saturated zone.

A recharge area can be defined as that portion of the drainage basin in which the net saturated flow of the ground water is directed away from the water table, Freez (1979). In recharge area there is a component to the direction of ground water flow near the surface that is down ward. Here the water table usually lies at some depth.

For most groundwater potential of the study area in the Awash catchment particularly for the pediment areas close to the ranges of mountain to the west and east of the valley, the uplands or mountain ranges are the zone/areas of groundwater recharge from direct precipitation in the area where as for the valley bottom aquifers beneath the Awash river coarse the river seepage is an indirect source of recharge in the area.

b) Groundwater Recharge Mechanism

1- Recharge from precipitation on the mountain range

Due to the relatively higher Annual potential evapotranspiration over the total Annual precipitation in the river valley, a direct and local recharge from PPT for this lower valley part i.e the Alaydegea plain and the river graben is very rare.

As mountain front system prevails on the study area where much part of the study area consist of the large pediment plain with alluvial fan and deltaic formation adjacent to the mountain ranges to the east of the Awash river, the major source of recharge to the aquifer systems is often along source of recharge boundary where the groundwater is recharged by precipitation on the mountain range. This is an area which relatively get better rain fall over the evapotrarspiration in the area and this recharge feeds the valley aquifer through sub surface flow. As a result recharge to the deep ground water system of the lower plains and valley bottoms occurs in two ways.

1) As sub surface in flow from mountain mass to the basin aquifer and

2) Infiltration to or loss of surface run off from most ephemeral streams running down from the elevated uplands/escarpments where they loss much of their water in the Alluvial fans and in the pediment gravels and sands. The localized indirect recharge (david 1990) mechanism is most common for the eastern pediment plain (Alaydegea area) where much of the run of from the eastern

highlands is soaked and disappears in the pediment formations and minimum reaching to the Awash river channel.

There fore based on the above recharge considerations, the deep aquifer system in the Alaydegea plain gets some part of its recharge more possibly through the above mechanisms.

2- Indirect and some localized recharge from the Awash River

Most part of the shallow aquifer system (river valley aquifer system) is fed by direct and localized percolation from the Awash river channel and flood water. From water table observation and groundwater head distribution along the river channel the depth to groundwater along the river course for most part of the river is below the river bed where the Awash river is a loosing river for most part of the river reach in the area feeding the shallow aquifer beneath. However from the groundwater level contour map constructed it has been also observed that the river gain some local inflow from the groundwater at its upstream parts around upstream around kesem, kebena and Awash area. On monthly or seasonal bases the river gets some groundwater run off as base flow particularly in time of dry period. However the net Annual loss from the river to the groundwater in general is positive. This net Annual loss to the groundwater for the part of the river section in the study area is computed by river channel water balance in (Table 4.8) previously.

1.2.3 Indirect recharge from Awash River through Fault lines

Fault zones can act either as barriers to groundwater flow or as groundwater conduits depending upon the nature of the material in the fault zone, particularly faults in poorly consolidated rocks with low displacements exhibited very good permeability (fitter 1996) . In the study area, there exists a number of en -echelon type fault belts or wonji faults which results the prevailing direction of the Awash river course. The possibility of groundwater recharge is maximum through this fault lines.

Particularly in areas around the upstream of melka Sedi and down stream of the Arba town, the Awash River gorge crosses at the break of fault lines i.e the structure that dropped the river graben below the Alaydegea plain. Geologic formations around these area is of scoracious basalt group of the recent pleistocene time outcroped following the tectonics. Therefore this part of the river reach could be the possible zone of groundwater recharge to the shallow and deep groundwater system in the area.

5.2.2.2 Groundwater Discharge

A discharge zone or area can be defined as that portion of the drainage basin in which the net saturated flow of the groundwater is directed toward the water table. In this area there is a component to the direction of groundwater flow near the surface that is upward (cheery 1979).

In the study area in general topographic and structure controls play a major role for the occurrence of groundwater discharge zone in various ways in the area.

As topographic highs like the mountain range are the recharge zone, the topographic lows or the valley bottom of the study area is considered to be a groundwater discharge zone. The topographic low and marshy areas of meteka at the southern tip of the Alaydegea plain where there exists a sharp slop break or land drop of more than 100 meters can be considered as local discharge zone where the ground water discharges through numerous hot springs aligned at the foot of north south running basaltic ridge. Most part of this groundwater discharge in the marshy area of meteka is lost by evepotranspiration.

The regional and local fault lines in the study area running SSW – NNE play a major role for the occurrence of this discharge point as hot springs at the foot of these fault escarps where all the spring identified in the study area are fault springs(fig 6.3). The wonji fault belt is a major geologic control creating some barrier condition to the local and regional groundwater flow particularity from the eastern upland/mountain ranges. The existence of hot springs discharging along the foot of this fault belt at meteka, Bilen, dofen and the Filwoha hot springs around Awash fentale in the lower kessem catchment which get its groundwater recharge from the upper Awash valley all these hot springs prevail or explain the effect of the existing fault on the springs development or fault spring in these Areas.

Fig 5.4 Bilen hot spring areas forming local discharge Zones for the ground water (Swampy Areas)

The other from of groundwater discharge in the area is the groundwater run off to rivers as base flow. The groundwater run off from eastern part of the catchments to the Awash river could be minimum due to the flat topographic nature of the area where much of the groundwater and surface run off from the eastern highlands is lost in the Afar plains.

5.2.3 Groundwater flow

on the basis of the potentiometer head distribution from various deep wells drilled in the confined aquifer system, potentiometer contour map has been constructed and from this the groundwater flow direction is indicated. The general trend of groundwater flow is toward north west from the eastern mountain range (fig 7.4) along which there exist a general potentiometer head decline as observed from the groundwater contour distribution.

This groundwater flow could be further controlled by the regional north south running fault lines. Most local flows from the eastern and western uplands to the valley bottom may join this major zone of groundwater circulation towards north.

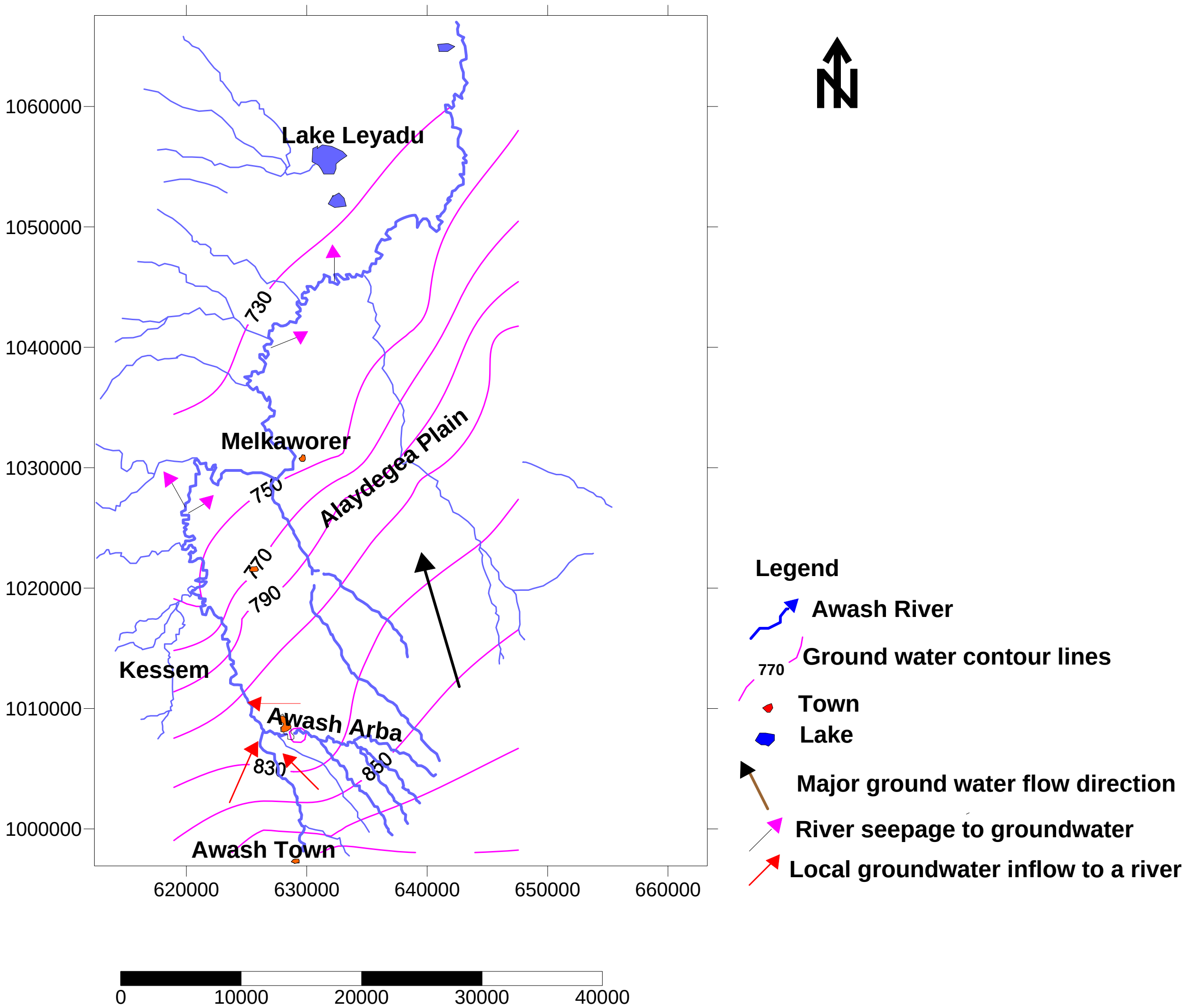


Fig 5. 5 Groundwater flow direction Map

5.2.3.1 Geologic controls on the groundwater flow condition

The heterogeneity or anisotropy in the aquifer systems and the prevailing major geologic structures in the area have their own controls and effect on the groundwater flow direction and rate of circulation. The Wonji fault belt in the area is the major control for the groundwater flow direction . Wells tapping water through deep wells on and close to this belt like the Berta and kerensa wells which are close to this structure shows better transmissivity values than other

wells located far on the plain and in the valley. These wells are sunk in weathered and highly fractured volcanic lava.
Groundwater condition in both the western and eastern pediments is similar with respect to the groundwater recharge and flow mechanisms to these plains where groundwater flow to this area is assumed to be as through flow from the escarpment areas.

From the groundwater head distribution in the areas close to the upstream reaches of the awash river the groundwater head is above the river surface and as a result there is some ground water inflow to the river (fig 5. 5). The regional groundwater flow which is indicated in the flow map from the eastern up land areas toward the valley floor would be further controlled towards north by the major tectonic lines following the rift trend.

For the lower plains in general it can be said that groundwater is derived from the escarpments, the upper Awash valley, some localized flows and river losses. the effect of lithologic controls on the groundwater circulation is relatively higher for the groundwater condition in the Alluvial aquifers of the valley formation. The low transmissivity values for most shallow aquifers of clay, sand and gravel due to the prevailing clay and silt formation retards the rate of groundwater circulation in these areas which give rise to the high salinity of the groundwater due to long time residence or rock water interaction.

5.2.3.2 Topographic controls on the groundwater flow

The effect of topographic controls on the groundwater flow relies on the immutable law which states that the highlands are recharge areas and lowlands are discharged zones. The existence of a number of Artesian or flowing wells south west of Meteka swamp at Buremedaitu locality shows the effect of this topographic control. These flowing wells are found close to the hot springs and this topographic low forms a local discharges zone for the groundwater flow both from the eastern mountain range and the upper Awash valley section and it had been resulted from recently occurred tectonics in the area that form the Gewane and Metake swampy zone forming an internal drainage system.

The occurrence of artesian wells is directly related to the hydraulic head difference between the aquifer beneath and the surface elevation. Any hydrogeologic system that leads to hydraulic head values in an aquifer that exceed the surface elevation will result in flowing wells. freez and cheery (1979)
If an aquifer out crops in an upland and is recharged there, an equipotential net can develop where by the hydraulic head in the aquifer down dip from the recharge area is higher than the surface elevation. A well tapping the aquifer at such location and open at the surface will flow.

Therefore aquifer conditions around Meteka and Buremedaitu which is located at the northern tip of the study area (Alaydegea plain) prevails this situation where drilled shallow wells at Buremedaitu , Gefrem and Meteka result in Artesian wells.

5.2.4 Groundwater and surface water interaction

The major objective of this part of the study is in general to develop an understanding of the temporal interaction i.e the seasonal patterns of the interaction between the shallow groundwater system in the Awash river valley of the study area and the Awash river water and identifying the areas where groundwater and surface water interactions are likely to be occurring

5.2.4.1 Basic principles:-

Groundwater and surface water are not isolated components of the hydrologic system but instead interact in a variety of physiographic and climatic landscapes (sophocleous 2002) . In many regions groundwater and surface water resources are connected and most surface water resources (rivers, lakes, dams, wetlands) generally interact with groundwater.

Rivers generally interact with groundwater in three basic ways (winter etal 1998) streams gain water from inflow of groundwater through the stream bed (gaining stream) they lose water to groundwater by out flow through the stream bed (losing stream) or they do both gaining in some reach and losing in other reaches. For groundwater to discharge into a stream channel the elevation of the ground surface in the vicinity of a stream must be higher than the elevation of the river stage conversely for surface water to seep to groundwater the altitude of the water table in the vicinity of the stream must be lower than the elevation of the stream water surface.

5.2.4.2 Groundwater surface water interaction in the study area.

The interaction of groundwater and surface water in river valley like Awash could be affected by the interchange of local and regional groundwater flow system with the rivers and by flooding and evapotranspiration. As the Awash river is a big river valley system, the interaction of groundwater and surface water usually is more spatially diverse than it is for smaller stream which receives ground water flow primarily from local flow that show high seasonal variability.

However in the river system like Awash groundwater from local flow system discharges to the river and at various places across the flood plain and at the foot of fault escarps adjacent to the flood plains where there is a slope break on water table configuration and surface typography in relation to recent tectonics in the valley.

To observe the seasonal patterns of this interaction in the Awash river valley in the study area two approaches have been followed, the first is a base flow separation and observation, in order to observe the degree of base flow contribution to the river Awash and its variation down steam, for the upper and lower reaches of the Awash river at Awash Sebat , Melka worer and at the down stream of the study area.

The second approach is a well hydrograph Analysis where pizometric water level fluctuations have been analyzed in comparison with the adjacent river water hydrographs to observe the seasonal patterns or relationships of the between the river discharge and the neighboring groundwater system at shallow depth. For this, the Awash river hydrograph at Melka worer gauging station is compared with the piezometers situated close to this area.

Therefore to observe this temporal relationships between the river and the groundwater, water elevation data on monthly bases from piezometere observation had been compiled for the hydrologic year from1973 –1989 for three piezometers located in the Awash river bank in the irrigation farms between Melka Sedi and Melka worer (Amibara) areas(Fig 5.7). The piezometers are selected for their relatively continuous data source at least for the considered hydrologic year.

a) Analysis on long term fluctuations in piezometer and river hydrograph

From piezometery well hydrograph and river hydrograph regimes analyzed, The long term piezometric water level fluctuation trend or hydrograph regime for successive years from 1976 – 89 had been compared with the corresponding river hydrograph regime for the same hydrologic year. Two piezometer data (pizometer No. 3 and piz. No 10) have been used for this analysis. Regarding this long term hydrograph regime, both the piezometer shows a declining trend water level (recession in the well hydrograph) starting from the hydrologic years of 1983 and 1984 on wards for piezo No. 10 and from 1985 on wards for piezo. No 3. This recession trend is comparative and there is some coincidence in relation to the river hydrograph where values for the hydrologic years particularly for the years of 1984 and from1986 – 1989 (Fig 5.6).

Similarly to observe the degree of long term relationships or correlations between the river discharge and the piezometres water elevation fluctuations on monthly averages, Some correlation has been made for the piezometre No.20 and piz. 10 with the river hydrograph on monthly average bases . This analysis shows the occurrence of positive correlations for both piezometers with the river discharge with a relatively better correlation for piezo. no. 20 and slight correlation for piezo.no 10.

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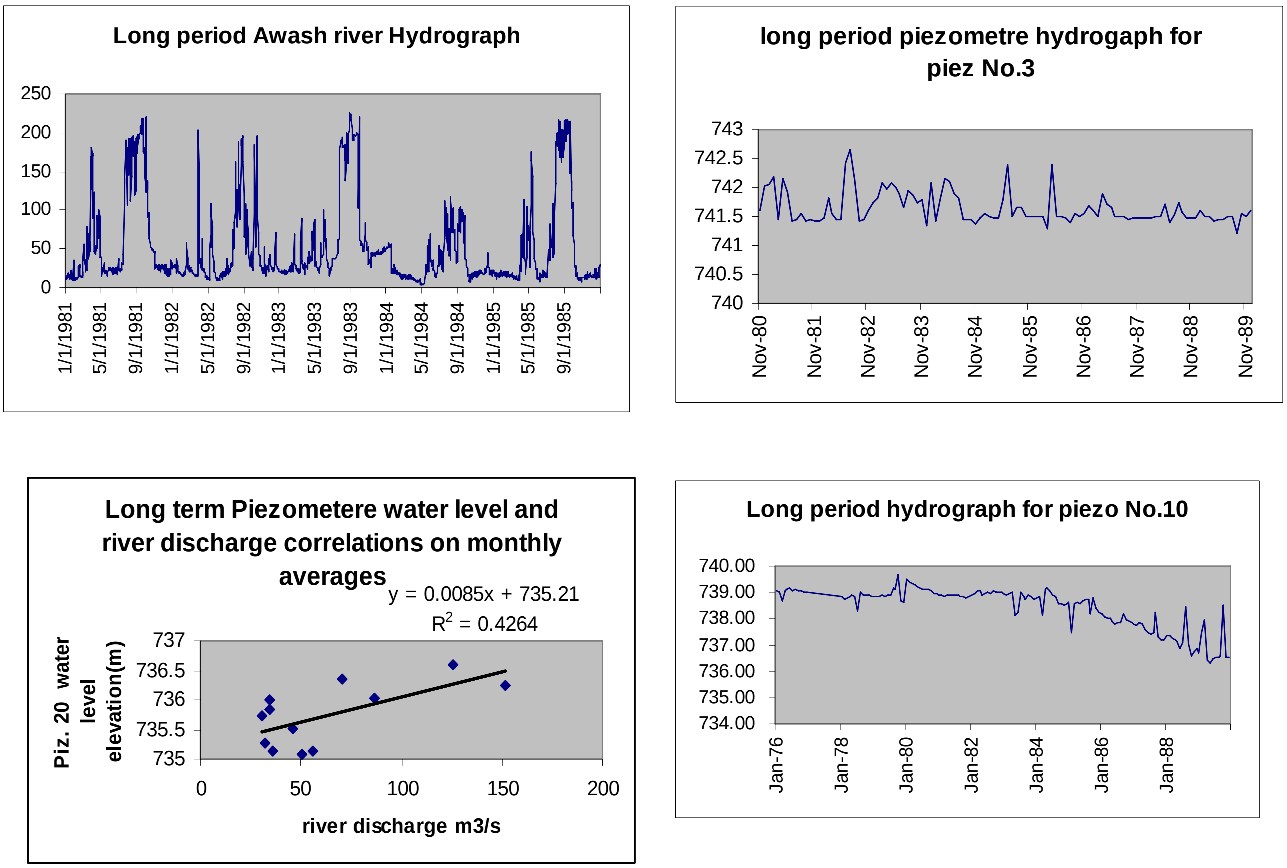


Fig5.6 Comparisons and correlations for long period hydrograph regimes for Awash River and adjacent piezometeric water elevation

This long term coincidence of the two hydrograph regimes shows that the two systems, the shallow groundwater system and the Awash River have strong hydraulic connection (interaction) where the Awash River directly feed the aquifer system or in another way the water level in the shallow aquifer system is strongly dependent and controlled by the Awash River hydrograph regime.

b) Analysis on Seasonal hydrograph regimes for the Piezometers and River discharge

Seasonal hydrograph regimes for separate years for the piezometeric records and river discharges had also been analyzed to observe the seasonal coincidence or relationships for the groundwater and Awash river system.

For these analysis, the piezometre (i.e pizo No. 20) had been used and the hydrograph of this piezometer for selected separate years of 1982 and 1984 had been analyzed and correlated with the river hydrograph for the same hydrologic year. The seasonal patterns of the piezometere hydrograph show good coincidence or relation ship with the river hydrograph regimes as observed from a single year hydrograph regimes.

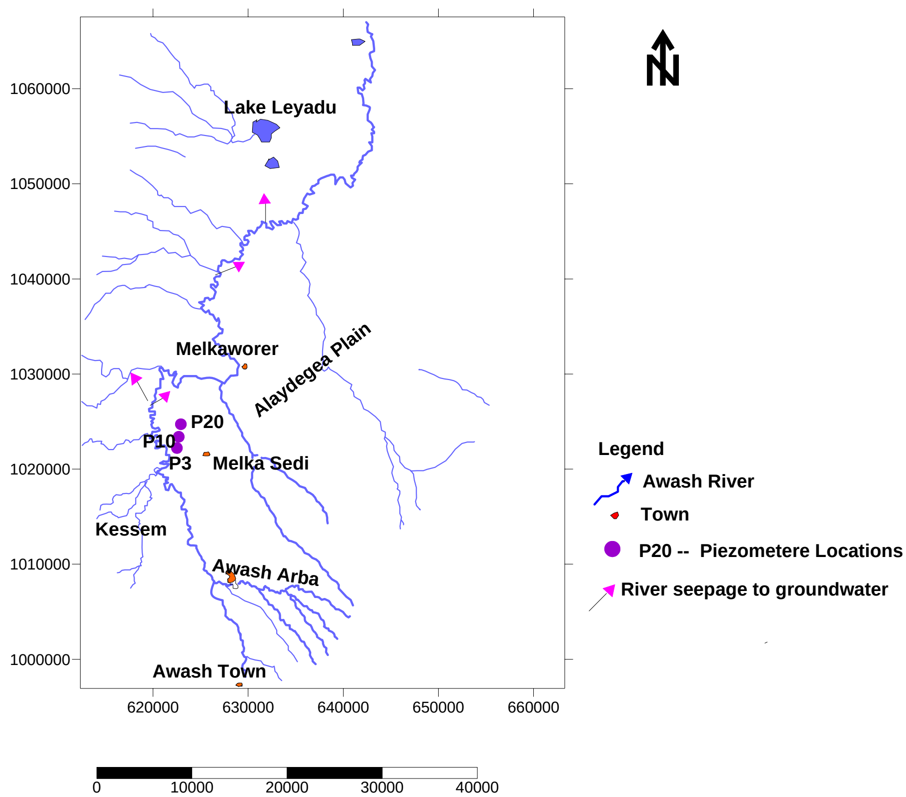


Fig 5. 7 Locatin of Piezometers

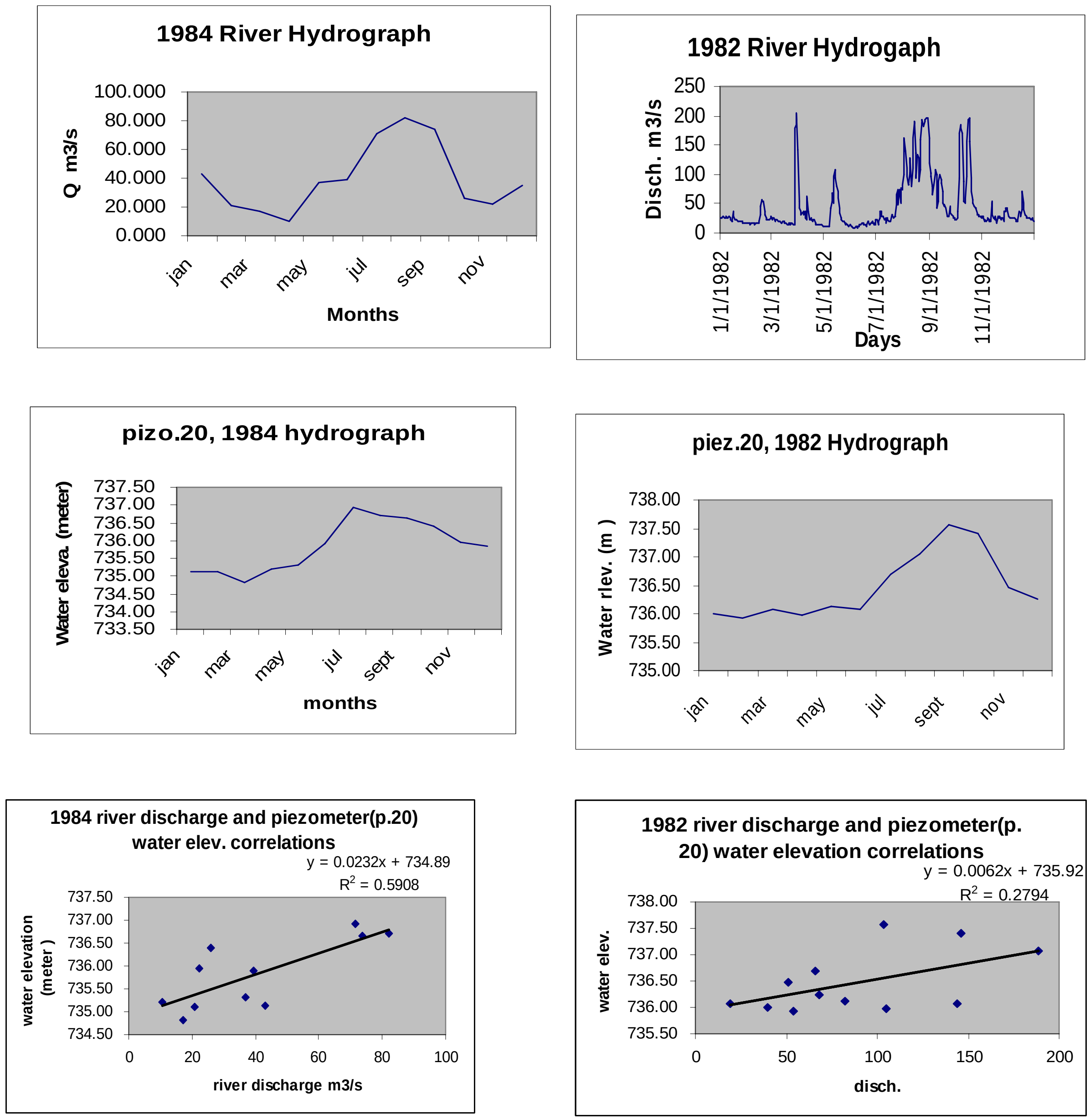


Fig 5.8 Single Year Correlations between the river discharge and adjacent piezometer

There exists a relatively better correlations for the year of 1984 in comparison to the slight correlation observed for the year 1982. In their hydrograph section a steep rising limb occurs for the July and august followed by a steep depletion or recession of the hydrograph for the months of September and October which is coincidental with the hydrograph regime of the river which shows a peak discharge in august.(Fig 5.7)

Therefore all the hydrograph analysis results shows the existence of strong relation ship between the shallow groundwater and the awash river showing that the Awash river is a loosing river feeding the shallow aquifer system beneath. This net annual loss has been calculated in the previous chapters in the channel water balance part.

From this balance computation the river is loosing in most months of the year except for march and April where the river loss is minimum which most likely be the period where the river is fed by the ground water.

c) Analysis from base flow separation

To identify areas or river reaches where this interaction is most likely occurring, the extent of base flow contribution to the Awash River at different gauging point of the river has been considered from the hydrograph separation method at the gauging station of Awash Sebat, Melka worer and Hertale from upstream to down stream reaches of the river. Flow characteristics and base flow contributions for the three stations is shown on table 4.3 in the previous chapter of river hydrograph Analysis. this base flow contribution or groundwater run off is higher for hertale (down stream) with highest value and relatively higher for Awash sebat and lowest for the middle reach (Melka Worer) with respective values of 656 (38%), 633 (31%) and 1272 (43%) annually.

Chapter 6: HYDROCHEMISTRY

For the purpose of the hydrochemical characterization of the ground water and explanation of the major geologic controls on the hydrochemical variations and concentrations, a water quality Analysis has been done on water samples collected from 50(fifty) water points in the study area. This water quality analysis in general includes water samples taken from 38 deep and shallow well including wells from the eastern highland or recharge zone ranging in depth from 40 to 270 meters, water samples taken from 8(eight)hand dug wells and three (3)springs and two river water samples.

In addition to the laboratory chemical Analysis of the above samples. On site or field measurements for some water quality parameters like ph, water temperature and TDS (salinity) has been performed to observe the behavior of the physical and Hydrochemical behavior of some parameters at the time of sampling.

6.1 Discussion on Field measured Water Quality Parameters

To evaluate the field conditions of the water Chemistry with respect to some physical and chemical parameters like TDS, water temperature, salinity and ph, some field measurements on different water source i.e boreholes, Hand Dug wells springs and River water sources in the study area has been carried out using Water Quality measuring kits.

Water Temperature, Salinity and pH

Water temperature for groundwater from deep and shallow wells in both the Alaydegea plain and river graben is observed to be in the order of 30 – 33 ^{0}c. Some highest value is observed for Berta deep well around 40 ^{0}c. both river water samples from Awash river and Hand dug wells show similar temperature values of 29 – 31 ^{0}c.

The extreme highest values or hot water condition is observed for the hot springs and artesian well in the local discharge zones situated very close to the Wonji Fault belts. The artesian well in buremedaitu around meteka, the Bilen hot spring and the meteka hot springs shows water temperature of 37 ^{0}c, 40 ^{0}c and 47 ^{0}c respectively.. Heat from deep thermal source in these area is the major factor or cause for the high temperature values of these sources. Regarding the salinity and TDS conditions the boreholes and springs display almost similar conditions with salinity ranging between 0.5 – 1 g/l and TDS values of 400 – 700 mg/l except for Awash Town Deep Wells which is close to 1000 mg/l. The close similarity in TDS for the springs and artesian wells in the local discharge zones with waters from the upland Alaydegea plain boreholes shows that there occurs some mixing of relatively fresh ground water flow to these source from the eastern mountain range which is the recharge zone for the plain. On the contrary, bore holes and Hand Dug Wells on the valley floor situated in the river graben alluvium rather shows a relatively higher salinity and TDS values ranging from 1500 – 3000 mg/l (melka worer, sheleko, Ambash, Hassoba).

Awash River sample measurements made at upstream part around Awash Town shows TDS values of 259 mg/l increasing to values of around 431 mg/l down stream at Melka Worer. This increment could be related to the inflow of Kessem and Kebena Tributaries to the river Channel downstream of Awash town which could have some ground water run off in their flow from the Western sub catchments zone.

Almost all the Deep Wells and hot springs display pH values close to 8 of Alkaline condition and some amount above where as the hand dug wells displays pH values of near neutral to Alkaline condition of 7 – 8 values.

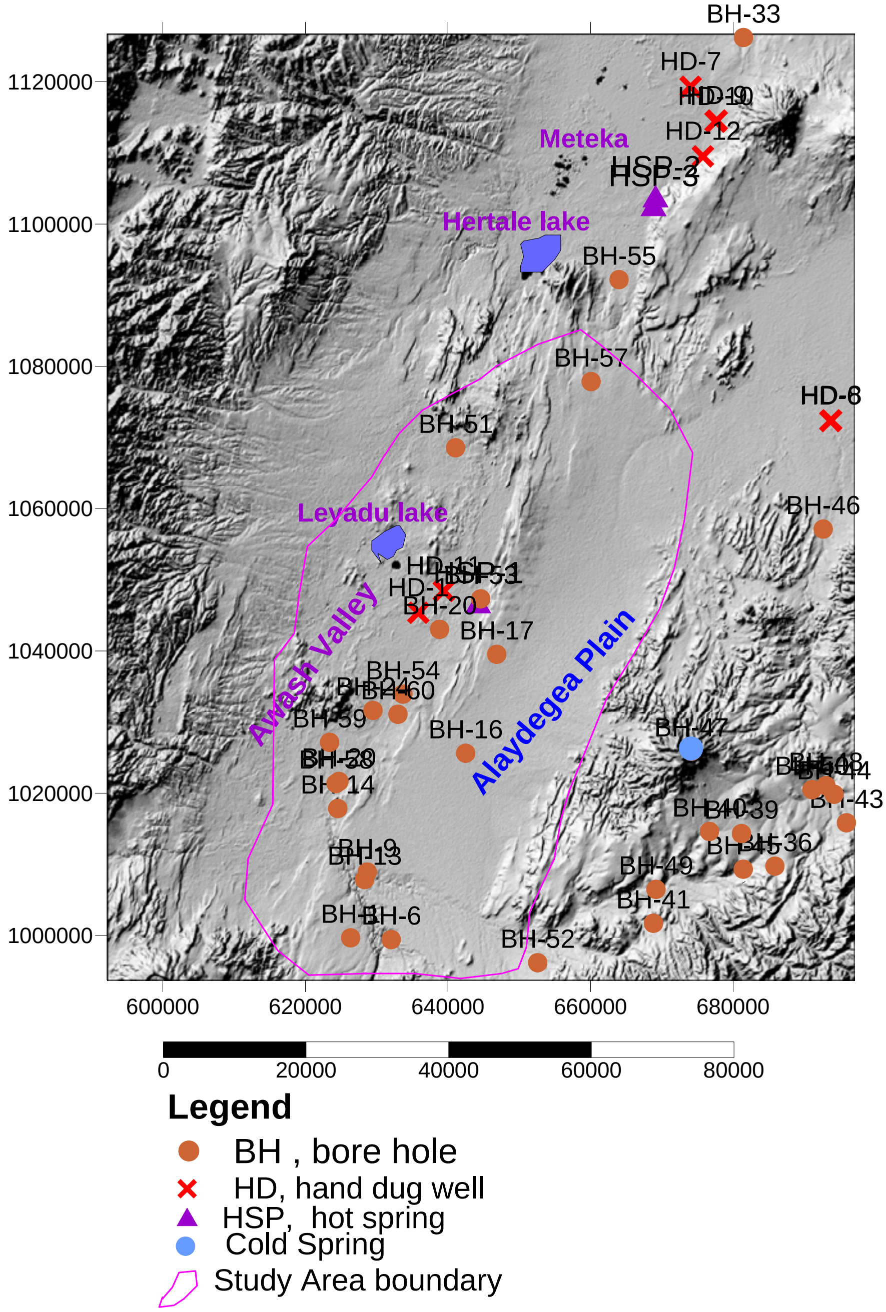


Fig 6.1 Map for the distribution of all water sample sources Analysed in the labratory

Table 6.1 Field Measured Water Chemical Parameters

Site	Location (UTM)	Sample source	Water Temp ^{0}c	TDS Mg/l	Salinity g/l	Conductivity m s	ph
Buremedatu	0668700E 1102550N	Artesian Well	37.2	874	0.8	1.433	8.60
Meteka Spring	0668821E 1102656N	Spring	47.3	841	0.89	1.362	8.70
Awash Town Dudub	0626351E 0999671N	Borehole	32	1016	0.9	1.7	7.62
Awash River Sample upstream of melkasedi	Upstream of melkasedi	Awash River	25.7	234	0.4	0.397	8.27
Awash Sebat	At Awash Town	Awash River Sample	29.3	259	0.5	0.43	8.48
Bilen	0644235E 1046853N	Spring	39.9	622	0.7	1.03	8.12
Hassoba (1)	0638824E 1043036N	Dug Well	30.6	2720	2	4.52	7.23
Ambash (1)	0630277E 1042299N	Hand dug Well	30.9	1967	1.5	3.26	7.61
Sheleko	0628562E 1038760N	Dug Well	32	1429	1.2	2.39	7.83
Awash River Upstream of Melka worer	Upstream Of Melka Worer	Awash River Sample	28.2	431	0.435	.711	8.2
Kerensa	0624546E 1017845N	Deep Well	30.4	702	0.7	1.16	8.4
Berta	0633107E 1027266N	Deep Well	40	614	0.54	0.894	8.3
Undelisea	0639500E 1028942N	Deep Well	33	571	0.49	0.79	8.0
Kurkura	0632047E 0999422N	Deep Well	31.6	448	0.37	0.6	7.9
Andido	0646837E 1039522	Deep Well	32.3	488	0.4	0.68	7.9

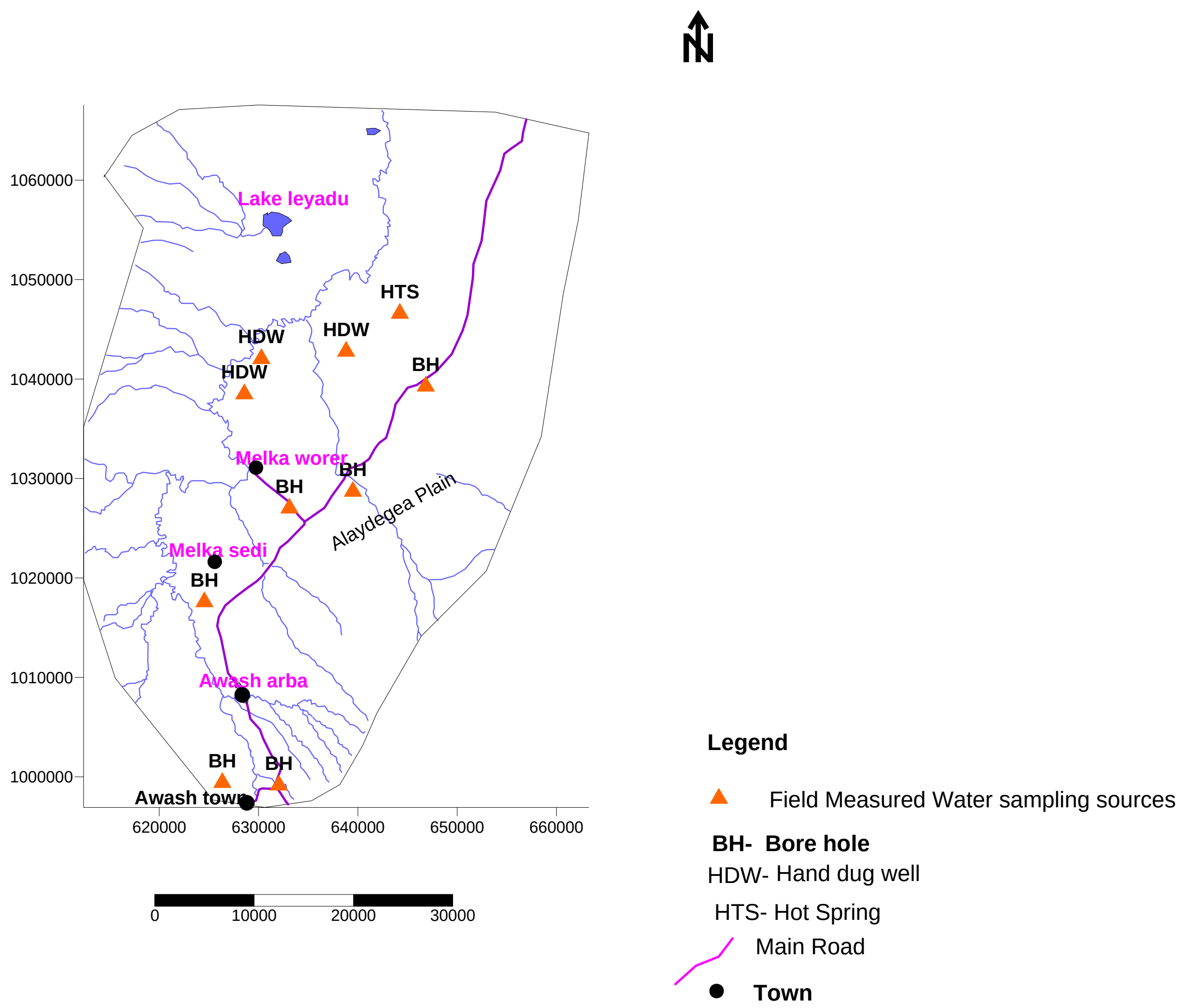


Fig 6.2 Map for the distribution of Field measured water sample Sources

6. 2 Discussion on Chemical analysis results from the Laboratory

From the water quality Analysis results of the above samples, the following discussions on the ranges of the concentration of some major Cations and Anions with their trend of variations is made as follow.

6.2.1 Cations (Na^+ and Ca^{++})

Out of the major cations that constitute the ground water chemistry in the study area, calcium (Ca^{+2}) and Sodium (Na^+) are the most dominant cations where sodium in particular shows a significant variations spatially through the study area. As chemical weathering of silicate mineral in Acidic rocks which are the dominant rock units in such parts of the Ethiopian rift is major source of these ions in ground water. The sodium (Na+) concentration ranges from a minimum values of 30-150 mg/l in the upper parts of the catchment around recharge areas to maximum values of 1259 mg/l in the valley bottom of Awash. The pediment plain in between relatively shows intermediate values of 100-200 mg/l.

Therefore the Na+ shows in general an increasing tendency from the uplands toward the Awash river valley where the samples from the hand dug wells at Hassoba shows some highest value up to 1250 mg/l. As sodium is retained by absorption on mineral surfaces, especially by minerals having high cation exchange capacities such as clay, this high Na^+ concentration is attained in the shallow valley sediment Aquifer system, in relation to long time water rock interaction, Silicate weathering and slow ground water circulation rate to accumulate the sodium in the clay sediment.

On the contrary, the calcium concentration which ranges in the area between a minimum values below ten (10) mg/l in the lower valley bottoms and plain area up to maximum values of 150 – 200 mg/l in the eastern upland areas of the catchment around Bordede and Meiso which in general shows a decreasing trend toward the valley bottom. There fore from the samples analyzed in the study area sodium and calcium in general show a negative relationship (fig 6. 3)

The decrease in the concentration of calcium is possibly related to its precipitation along flow path which relatively gives lower concentration in the valley formations in comparison to the higher Sodium concentration.

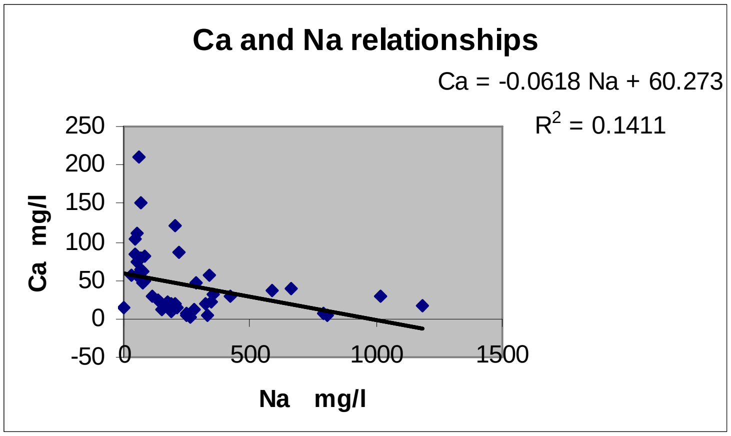


Fig 6.3 Na – Calcium correlations for the water sample Analyzed

6.2.2 Anions

Out of the major Anions in the Ground Water chemistry, bicarbonates, Fluorides and Chlorides are the most dominant and major Anions that characterizes the chemistry of the ground water in the study area. The concentration of these two Anions in ground water is strongly controlled by the Co_2 gas circulation or emission from the deep geothermal sources in the study area.

The two Anions shows a positive correlation in the ground water system of the rift zones. The occurrence of high Hco_3 concentration in such systems is due to the reaction of dissolved carbon dioxide released in the rifts systems or $C0_2$ in soils with Acidic rocks to produce Mica or Clay minerals and bicarbonate ions, with the following mechanism UN (1973).

$Co_2 + H_2O$ + Na, K – Silicates ----- Hco_3 + Na, K + H – silicates

H^+ ions in the system are fixed by silicate (Metasomatism / Hydrolysis) resulting in a near neutral to Alkaline Solutions (Gizaw, 1996) and this creates an environment conductive to the formation of high HCO_3 and Na.

From the water samples collected in the study area ,samples from water sources in the upper recharge zones and pediment plains of Alaydegea area out side the valley generally show bicarbonate concentration in the order of 200 – 500 mg/l where as the river graben shows some higher values of more than 500 mg/l.

Fluoride (F^-)

The situation of relatively high Fluoride concentration in the ground water of the lower valley system in the study area is also related to the geochemical controls in relation to the rift nature. Fluoride concentration in the lower river valley graben of the study area in Melka werer, Melka sedi, Serkemo) areas ranges from 2-4 mg/l where some maximum values have been observed around Awash Sheleko and Hassoba around 10 mg/l and relatively higher values in Gewane area 6-8 mg/l. Fluoride concentration in the Alyadegea plain and around Awash towns ranges from 1-2 mg/l and for upland areas the value decreases from 1 mg/l to some trace amount .

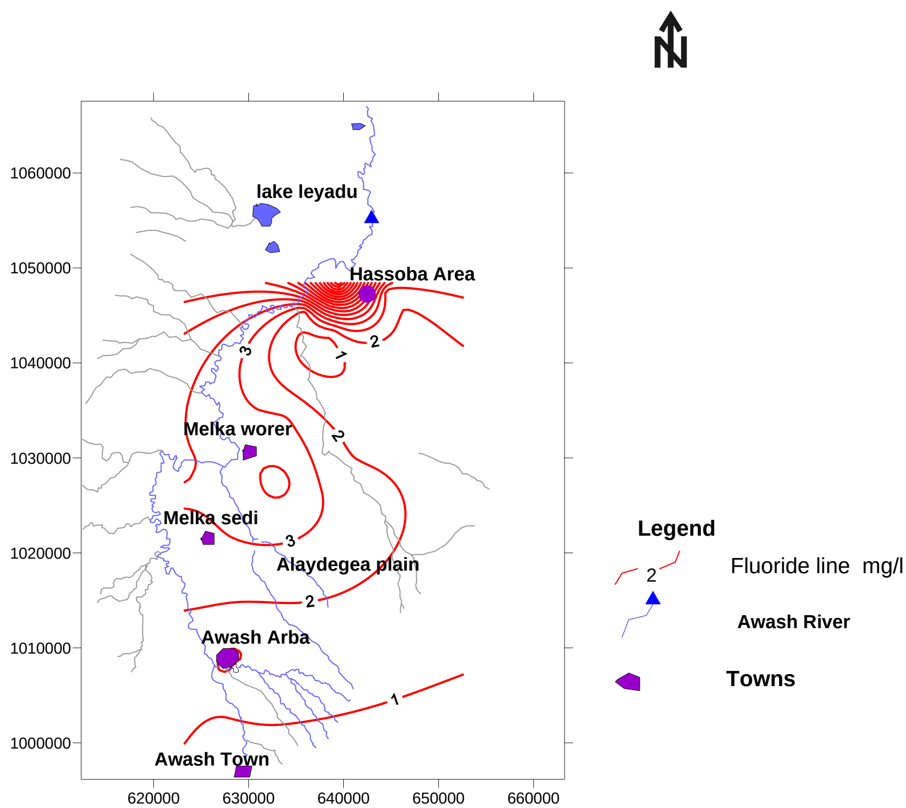


Fig 6.4   Fluoride Map of the study Area

The possible source of Fluoride concentration is a chemical weathering on Acid Volcanic rocks and magmatic emission.). Fluoride is commonly associated with volcanic or fumarolic gases, and in some areas, these may be an important source of fluoride in natural water. The major controlling factor for fluoride concentration are the temperature of interaction between the rock and water, the concentration of Ca^{+2} in the water and the pH of the water (Gizaw 1996).

From water quality analysis results in the study area, the high Fluoride concentration in Dufen (Melka Worer), Sheleko and Hassoba localities is most possibly related to the above facts where the situation of these areas close to Wonji fault belt and Dofen recent volcanics shows the occurrence of high Co_2 gas emission and high temperature inducing a deep chemical wheathering on the Acidic type Wonji volcanic in the area. The low Ca^{++} concentration in these area favors the mobility and increment of the Fluoride ion. In addition to this chemical weathering, deep magmatic source could also contribute to the high fluoride concentration.The occurrence of Acidic Volcanics of rhyolite, Ash and Welded tuff in Berta area as observed from the upper section of deep well log in Berta Shows that ground water circulating on this Aquifer systems attain high fluoride concentration which is observed to be around 4.4 mg/l for this well. The occurrence relatively higher fluoride values above standards for the hot springs of bilen , Meteka and Gewane areas better supports the deep magmatic source of fluoride in the areas.

Chloride

From the water quality analysis result on the study area, chloride ion shows slight variation in concentration. The source to chloride concentration is most commonly the solubility of some Halite or evaporates in sedimentary formations, associated with lacustrine sediments. As a result a relatively higher chloride concentration is observed in swampy or marsh areas around gewane down side of the study area with values (400 – 800 mg/l) from hand dug well and extremely high values of around 3800 mg/l in the Hassoba Hand dug well (on Awash flood plain).

In both cases, the possible source of chloride could be the solubility from evaporates of the lacustrine sediments of the top shallow Aquifer and local evaporative enrichment particularly for the Gewane or Meteka areas as these areas are local ground water discharges zones.

Therefore, groundwater sampled from very shallow depth through the hand dug wells in valley sediments of Amibara (Hassoba and Angelele) and further down stream around Gewane swamps which in general are associated with lacustrine deposits shows high chloride concentration .

Sulphate (So_4) and Nitrates (No_3)

In most of the samples analyzed, these two Anions have relatively low concentration particularly in most deep wells sampled in the study area. The relatively high concentration of these Anions is observed in some hand dug wells in the Hassoba and Awash Sheleko areas including Gewane areas.

In general, the Nitrate concentration for the most ground water is nearly 10 mg/l and below. But the hand dug wells mentioned in the above localities range from 15 – 20 mg/l with some highest values of 800 mg/l at Hassoba hand dug well. This highest values for the Hand dug well could be related to some Anthropogenic source in relation to Agriculture fertilizers (Inorganic) and Animal manures (Organic source).

Similarly the sulphate values show relatively lower values of ranging from 30 – 100 mg/l except few deep wells at Awash Town and Melka Worer (200 – 300 mg/l) where as the Hand Dug wells show higher concentration ranging from 200 mg/l to some highest value of 2780 mg/l for Hassoba Hand Dug Wells. This extreme high values are most possibly related to some Anthropogenic source, dissolution from evaporates in the clay sediment and some volcanic source (Dofen Volcano)

6.2.3 Total Dissolved Solids (TDS)

Total Dissolved Solids includes all solid material in solution, whether ionized or nor. As it is related to the sum of the concentrations of all ions, it is directly related to the electrical conductivity.

From the water quality analysis result of the Area, the TDS values in general ranges from a minimum values for a relatively fresh ground water of 300 to 500 mg/l from boreholes in the eastern upland areas around Asebot and Meisso which are close to the recharge zone for the pediment plains to some high values which is saline water with a value ranging from 600 mg/l to 2000mg/l in most hand dug Wells around Awash flood plain and Gewane discharge zones (Meteka Areas). Some extremely high values up to 14,000 mg/l of very saline water is also tapped in the Hand Dug well of the Hassoba Area. Most Deep Wells in the Alaydegea plain and the Hot Springs of Bilen Meteka and Gewane including the artesian wells in Buremedaitu and around Meteka local Discharge zones, in general display similar values ranging between 500 – 800 mg/l of moderately fresh water.

The similarity in TDS values of the hot springs and the Artesian Wells of this areas with TDS values for Deep Wells in the Alaydegea plain shows that the ground water system in this water points is a part of the ground water flow system in the plain which have a local meteoric origin in recharge zone of the eastern upland or mountain ranges. The relatively higher temperature values of 45- 60^0c for these hot springs and artesian wells shows that there is deep heat source for these waters as there is ongoing volcanic activities in the Area. The short flow path of this ground water from the local recharge zone could most probably control the further evolution of the ground water to different higher values since the TDS values for ground water is strongly controlled by the time of contact or rock water interaction along the flow path.

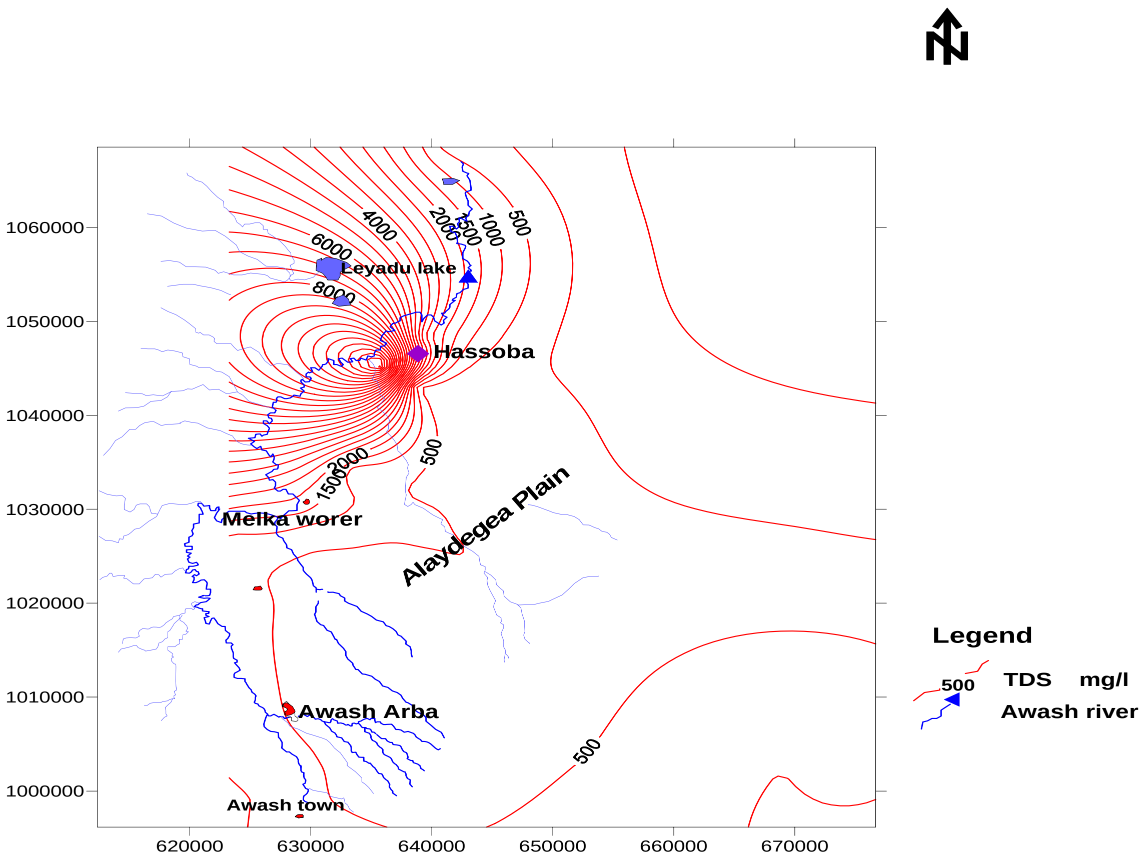


Fig 6.5 Total Dissolved Solid (TDS) Map of the Study Area

The extremely higher values of TDS for the shallow Aquifer (sediments) in the river valley fill alluvial formations as observed from Hand Dug Wells in Hassoba areas could be the result of long time rock water Interaction of the ground water with valley sediments in relation to slow ground water circulation. Some additional factors for high TDS values in the area could also be the dissolution of some salt minerals associated with lacustrine sediments of the Alluvium in the Area, evaporative enrichment where the rate of concentration of this minerals increase from the continuous evaporation of the Water ponding on the flood plain of Awash. And also to some extent the ion exchange between the ground water and the shallow Alluvial Aquifer in the valley which might contribute to the higher TDS due to concentrated and enrichment in the major ions of Na , bicarbonate and slight increase of K ions to the valley. From the above explanation it can be generalized that both the geology (lithology) and the topographic and climatic factors along the flow path together with the mentioned geochemical process control the geochemical evolution or spatial variation of the ground water chemistry from the eastern recharge zone to the valley bottom of Awash river and some local discharge zones.

6.2.4 Alkalinity

Alkalinity

The Alkalinity of a solution may be defined as the capacity for solutes it contains to react with and neutralize acid. In almost all natural waters the alkalinity is produced by the dissolved carbon dioxide species, bicarbonate and carbonate and the most important non carbonate contributors to Alkalinity include hydroxide and Silicates. The Co_2 gas from Atmospheric gas present in the soil as well as Co_2 from local magmatic source is the primary source for the production of Alkalinity in Natural water.

From the water quality analysis result of the study area it has been observed that the Alkalinity of the ground water in general ranges from a minimum value of 200 – 400 mg/l for the most deep wells on the Alaydegea plain and Eastern upland areas including the Awash town to some highest values of 1000 – 1400 mg/l for the Hand Dug Wells in Awash Valley bottoms in Amibara and Gewane. Most deep Wells and shallow wells drilled in the fractured rock Aquifers within the River Valley like (Berta, Melka werer, Kerensa) show some intermediate values ranging between 400 – 800 mg/l.

The highest values attained for the Valley bottom areas is most possibly resulted from Calcite Dissolution in the Clay Sediments of the Alluvial together with the local Co_2 source for excess bicarbonate production from magmatic systems in relation to the active tectonic events in the low graben structures of these areas (Meteka and Dofen hot springs).

6.3 Spatial variation of the Groundwater Geochemistry and relation ship with different Aquifer Types

In order to observe the geochemical trend or spatial variation of the Ground Water Chemistry along flow paths in the study area, all samples collected from different sources and depth or Aquifer units have been categorized in to five(5) sampling groups according to the spatial relationship of sampling point to Aquifer systems from which the samples are taken. The spatial distribution of these groups follows the topographic flow paths for the local ground water flow from recharge zone to discharge zones in the study area. Based on this; a total of 45 samples have been grouped as follows;

Group 1 Samples: include around eight(8) deep well samples from fractured Aquifer system in the areas close to the recharge zone (Eastern mountain front), this includes wells from Asebot, Meisso and Bordede area.

Group 2 samples: includes around nine(9) deep well samples from both fractured Aquifer and Alluvial Aquifer system of the Alaydegea plain.

Group 3 samples: includes around sixteen(16)deep and shallow wells from both volcanic and Alluvial Aquifer in the Awash River Valley formation i.e in the river graben which includes water wells from Berta, Kerensa, Melka Werer, Melkasedi, Serkemo and Shelko.

Group 4 Samples :includes around 7 Hand Dug well samples from very shallow Aquifer of the River Alluvium (Clay and Fine Sand) close to the River bank (From Hassoba, Sheleko, Angelele Gewane areas)

Group 5 Samples:- includes five (5) Hot springs and Artesian Well from the local discharge zone around Bilen, Meteka and Gewane.

Table 6.2 Spatial variation of the Ground Water Chemistry and its relation ship with different Aquifer system for sample groups

	Chemical Constituent (mg/l) range of concentrations						
Sample Group	Na^+	Ca^{++}	cl^-	F^-	Hco_3^{--}	TDS	So_4^{--}
Group I Deep Wells from fractured Aquifers in recharge zone	30-150	50-200	20-180	0.5- 0	200-500	300-600	5-100
Group II Deep wells from fractured and Alluvial Aquifer in Alaydege Plain	40-200	20-80	20-60	1-3	250-400	400-600	20-170
Group III Shallow to Deep wells from volcanic and Alluvial Aquifers in the River Valley of Awash	100-700	4-40	50-350	1-4.5	200-1000	600-1900	30-300
Group IV Hand Dug Wells from recent River Alluvium Aquifers close to the flood plain in the valley bottom.	400-1250	7-45	170-3800	1.6-10	500-1700	1000-14000	200-2700
Group V Artesian Wells and hot springs from local discharge zones in Bilen, Meteka and Gewane Areas.	170-250	2-15	60-130	2-3	350-450	600-700	50-100

6.4 Water Types

Water Types classification of the water samples collected from all sources is made to observe the major water groups, their relationship and evolution along the flow path by using a graphical method. The piper diagram (Piper 1944) is the most widely used graphical form. The diagram displays the relative concentration of the major cations and Anions on two separate trillinear plots, together with a central diamond plot where the points from the two trillinear plots are projected.

According to this classification and presentation, the water samples from the study area which has been grouped previously into five samples groups according to their spatial relation ships and source type, have been classified into different water types. Fig 8.6 and Table 8.3 the first sample group (S_1) which contain deep wells from eastern upland areas close to the Recharge zones shows in general a Ca – bicarbonate to (Ca-Na- Hco_3) water type.

Similarly group two samples (S_2) that includes the deep Wells on the Alaydegea plain in general shows a water type of Na –Ca- bicarbonate to Na – bicarbonate type further to north of the plain and similarly the group three (S_3) samples that includes the Deep and shallow Wells drilled in the River Valley (Awash River graben) in general show a sodium – bicarbonate to some mixed type of Na – bicarbonate – sulfate--chloride water type with a relatively higher sodium concentration toward the valley bottom.

The group four samples (S_4) which includes the Hand Dug wells in the river valley bottom of Alluvium (in Amibara, Sheleko, Hassoba, Gewane) generally show some mixed type i.e. Na – bicarbonate sulphate – chloride water type with high concentration of the Anions.

Finally, the fifth sample groups (S_5) which includes water samples from springs and Artesian well (Bilen spring, Meteka and Gewane Springs and Buremedaitu Artesian Well) in generally show a sodium – bicarbonate (Na Hco_3) .

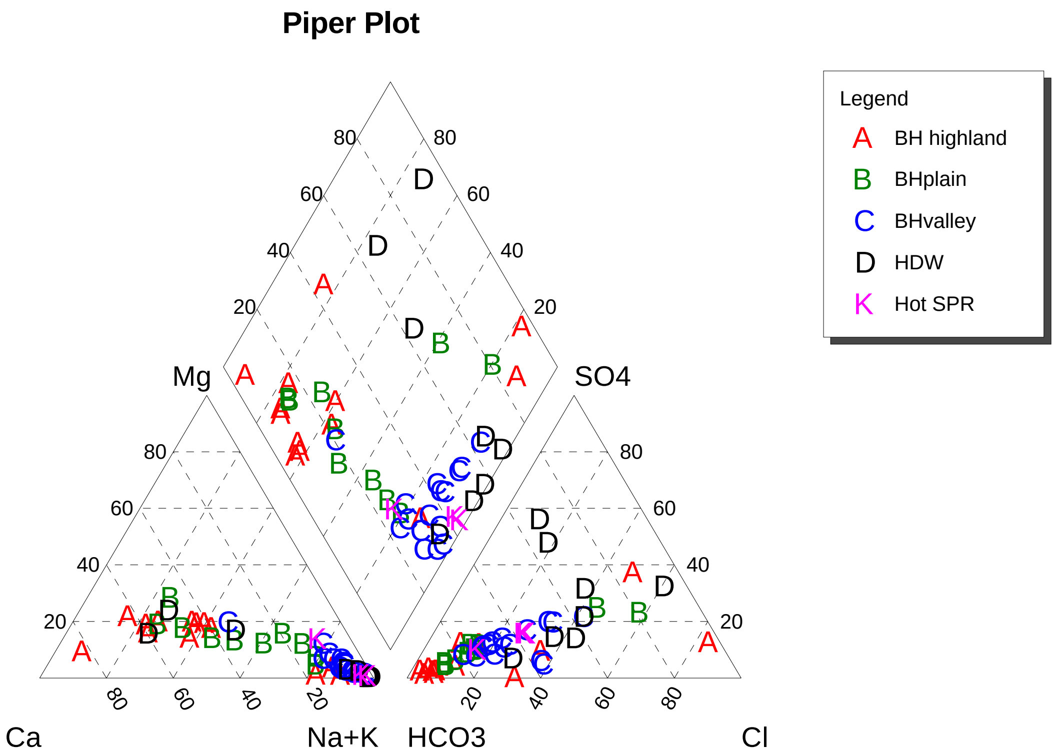
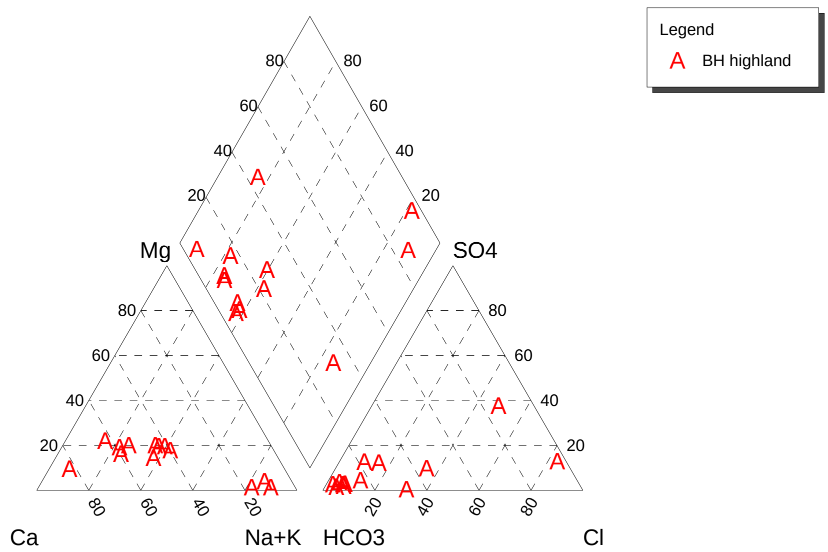


Fig 6.6 Piper plot for all Water Samples analyzed from different Sample sources (Boreholes, hand dug wells and springs) which are spatially grouped into five sample groups in the Study Area.

Highland Borehole Samples



Plain Borehole Samples

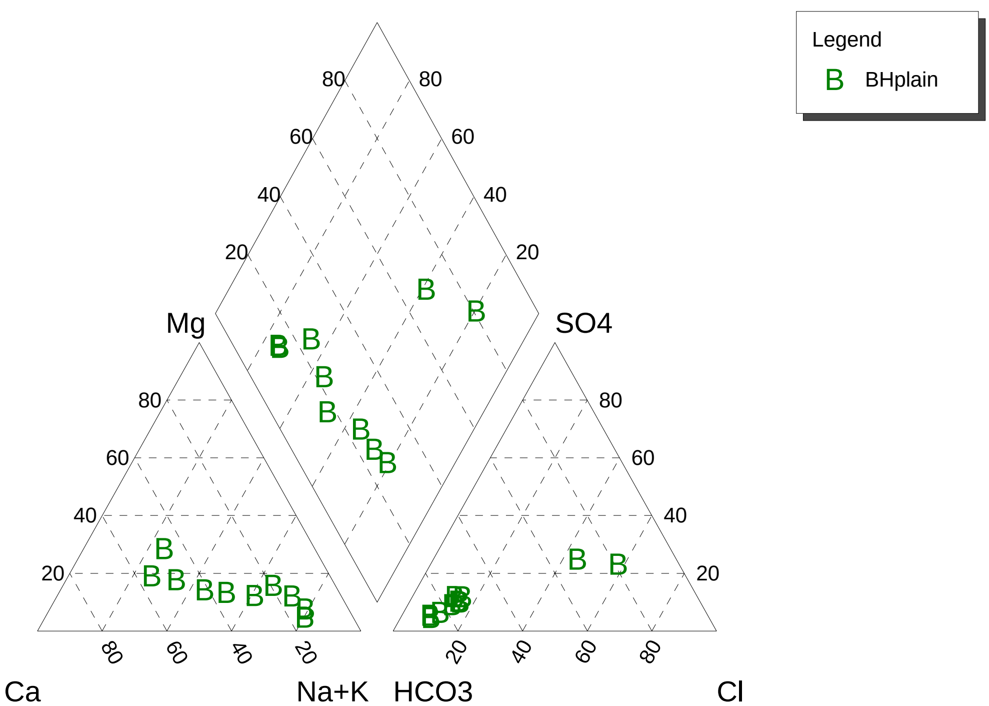
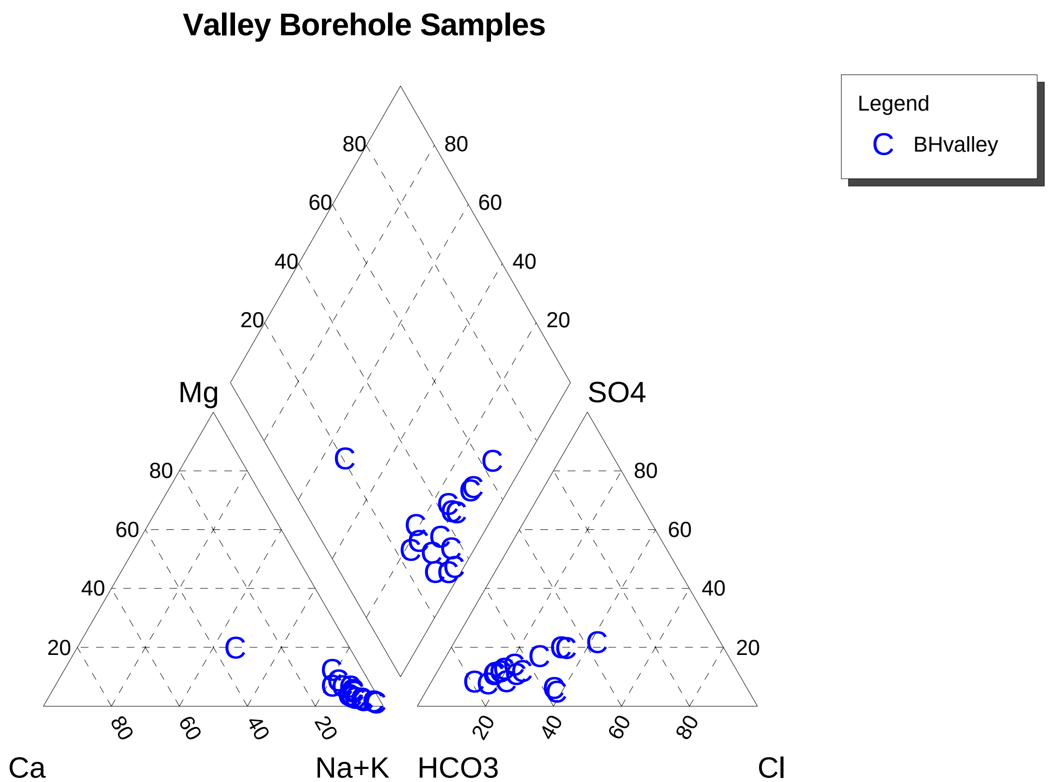


Fig 6.7 piper for boreholes from recharge zone and the Alaydegea Plain



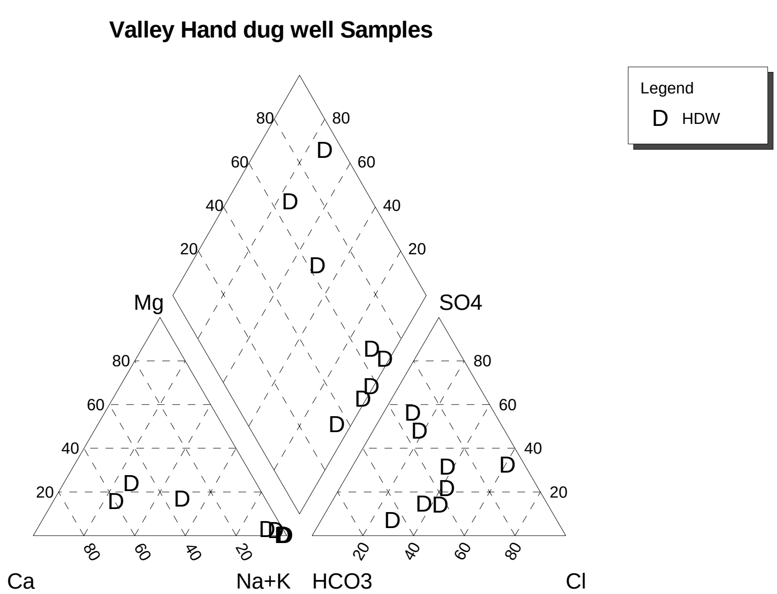


Fig 6.8 piper plot for boreholes and hand dug wells in the river valley

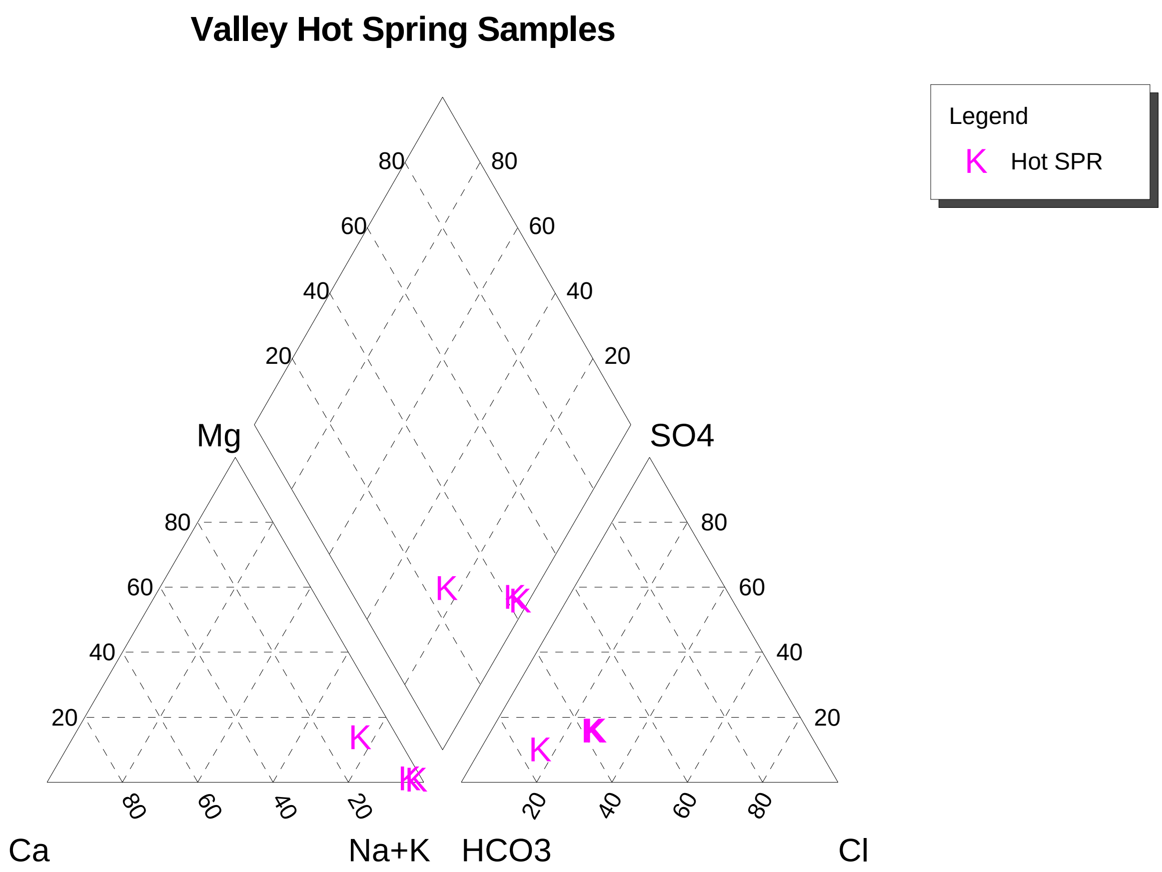


Fig 6.9 Piper plot for hot springs in the valley

Table 6.3 - Spatial Distribution of the Water Types classified and their Relationship with Hydrogeologic Units (Aquifer Zones)

Samples location	Source Type	Aquifer zone	Water type
S1. Eastern upland Area (Recharge Zone) at Meisso Asebot, Bordede.	Deep Wells	Weathered fractured Rock	Ca – bicarbonate
S2. Alaydegea Plain	Deep Wells	Weathered and Fractured Rocks and old Alluvial	Na – bicarbonate and Na – Ca - bicarbonate
S3. Awash River Valley (Graben) Melka Werer, Melka Sedi, Kerensa, Berta	Shallow and Deep Wells	Recent Volcanics and Alluvium	Na – bicarbonate ($NaHCo_3$)
S4. River Valley Floor or Flood plain, Hassoba, Gewane, etc	Hand Dug Wells	Very Recent Riveriane Sediment	Mixed type (Na- HCo_3-So_4-Cl)
S5. Discharge zones in the River valley Bilen, Meteka (Gewane)	Springs and Artesian Wells	Basalts and Piroclastic sediments	Na- bicarbonate (Na- HCo_3)

6. 5 Geochemical Trend along flow paths

From this table therefore it has been observed that there is a general increasing trend along the topographic flow path for the Sodium, Chloride, Fluoride and Bicarbonate ions attaining higher values in the river valley aquifers of group III and IV and similarly there is also an increasing trend for the total dissolved solid (TDS) as expected and most possibly controlled by the rock water interaction along topographic flow paths. The higher TDS values in the valley alluvial will be further enhanced from evaporative enrichment and salt dissolution and some cation exchange, since the alluvium is rich in clay sediment in association with some lacustrine sediment that give rise to higher Na^+ and Cl^- ions raising the TDS value.

On the contrary, the Ca^{++} cation in general shows a decreasing geochemical trend toward the valley bottom. This is related to the early precipitation of the calcium in areas around recharge zones and some cation exchange.

The cation exchange is a reaction in which the calcium and magnesium in water are exchanged for sodium that was absorbed to Aquifer solids such as clay minerals resulting in the higher sodium concentration and softer water (i.e decreased Calcium and Magnesium Concentration).

The generalized equation is

$$Na_2\,x + Ca^{+2} \leftrightarrow Ca\,x + 2Na^{+}$$

$$Na_2\,x + Mg^{+2} \leftrightarrow Mg\,x + 2Na^{+}$$

Where Na^{+} = Sodium ion

Ca^{+} = Calcium ion

The decrease in the Calcium ion is one important geochemical control for the increment of the fluoride ion in the down valley systems. In addition, the high fluoride concentration in the valley results from rock dissolution and some magnetic sources in the Areas.

Therefore, from the above discussions of the spatial variation of some major cations and Anions along flow path and from discussions of major water types, the general geochemical trend or evolution of the groundwater from Eastern Recharge zone toward the Awash Valley bottoms can be explained as follows.

$Ca – HCo_3 \longrightarrow Ca – Na – HCo_3 \longrightarrow Na\text{-}ca – HCo_3 \longrightarrow Na – HCo_3 – So4 – Cl$

(Recharge Zone) (Discharge Zone

Eastern uplands **Alaydegea Plain** **Awash river Valley**

6.6 Evaluation of the hydrochemistry with respect to Drinking Water Quality standards in the Study Area

The chemical analysis results for the water samples from various sources in the study area have been evaluated and compared with WHO and EU water quality standards to observe the level of potability of the water with respect to some major ionic constituents like Flouride, Sodium, Chloride, Sulphate and Nitrate that are the major threat in relation to health problem. For this evaluation the water quality analysis results from 42 water sample i.e 26 bore holes, 11 hand dug wells and three hot springs which all fall in the area of interest which includes the Alaydegea plain and the Awash River valley (Awash Town to Gewane) excluding the Eastern upland recharge zone.

Concerning the chemical quality of drinking water and health issues, the most problematic element in the study area is fluoride (F) for which 73% of the samples analyzed exceeds the WHO guide line (> 1.5 mg/l). Out of this, 80% of the hand dug well (9 out of 11), and 73% of the bore holes (19 out of 26 samples) and all the three hot springs exceeds the WHO and EU guide line for Flouride. The incidence of medical problems in relation to dental and skeletal fluorosis is well observed in the study area particularly in Melka Worer, Melkasedi Sheleko and Gewane where this fluoride concentration is highest > 3 – 10 mg/l and above.

Even if it is not a major health threat, next to Flouride, Sodium (Na) is also another major element that displays some higher values above the WHO and EU guide line (>200 mg/l) in some samples analyzed. From this it has been observed that around 54.7% of the samples show sodium concentration above the guide line (>200 mg/l). Out of this 63% (7 out of 11) from the hand dug wells, 53% (14 out of 26 bore hole samples) from wells two out of three hot springs show higher sodium concentration above the guide line.

TDS values for some water samples also show conditions above the WHO and EU guide line where 28% of the total samples exceeds the guide line (>1000 mg/l) out of which 63% of the hand Dug Wells (7 out of 11) from Worer, Sheleko, Hassoba and Gewane exceeds the guide line and 19% of the bore holes (5 out of 26 Wells) exceeds the guide line. The hot springs, bilen meteka, gewane are below the guide line (< 1000 mg/l)

Regarding the major Anions like Chloride, Sulphate, few samples show values above the WHO guide line, for chloride for instance 23.8% of the samples analyzed exceeds the WHO guide line (>250 mg/l) out of which 45% of the hand dug wells and 19% of the bore hole samples show this condition. Similarly for Sulphate (So_4), 12% of the samples exceed the WHO guide line (>250 mg/l) out of which 2% of the bore holes and 4% of the hand dug wells show this situation. For Nitrate (No_3) only one hand dug well (Hassoba) show higher values (>50 mg/l) than WHO guide line

Table6.4 – Comparison with Water Quality standards for drinking Water

Element/ Parameter	WHO guide Line mg/l	Total % of Samples Above WHO guide line	Hand Dug Wells % above WHO	Bore holes % above WHO	Hot Springs % above WHO
Flouride	1.5	73%	80%	19%	100%
Sodium	200	54.7%	63%	53%	66%
TDS	1000	28%	63%	19%	-
Chloride	250	23.8%	45%	18.5%	-
Sulphate	250	12%	36%	2%	-
Nitrate	50	2%	9%	-	-

CHAPTER SEVEN : SYNTHESIS

7.1 Result from analysis of hydrometrology

From the meteorological data analysis in order to observe the temperature and rain fall and other climatic characteristics of the study area a meteorological data of long years have been used for the analysis. From this the effective annual depth of precipitation has been determined from gauge data of more than 20 years from three gauging stations of Awash Town, Melka Sedi and Melka werer. Since there is no much variation in rainfall and marked diversity in surface characteristics for these areas the average rain fall over the study area is estimated to be 596.7 mm annually from simple arithmetic methods.

Temperature in the area in general varies from a mean minimum monthly value of 19 ^{o}c to mean maximum monthly values of 32.5 ^{0}c with average values of 25.7^{o}c. Temperature values are in general maximum for the months of April, May, June and July. Similarly, the estimated mean annual values for wind speed is 1.36 m/sec and the mean annual relative humidity in the area is around 61.3%. The potential evapotranspiration for the area is computed from Penman modified method using the necessary metrological data and the Thorenthwait method using mean monthly temperature values.

The annual PET value for the area from Penman modified method is estimated to be around 1427 mm. With relatively higher values for the months of May, June and July with potential evapotranspiration values of 129.6 mm, 132.6 mm, 128.7 mm respectively. The potential evapotranspiration values from Thorenthwait are relatively underestimated with total annual amount of 1000 mm.

The actual evapotranspiration of total annual value has been also empirically estimated from Turc's method using mean annual temperature and precipitation values. From this the annual actual evapotranspiration is estimated to be 595.6 mm.

An equal values of AET with the annual precipitation has been obtained from Thorenthwait and Mather water balance which gives around 615 mm annually. In general actual evapotranspirations value is almost closer or nearly equal to the annual precipitation values showing that evaporation is the principal cause of all water loss from precipitation leaving no direct recharge to the area.

In the study area the Awash river is the main Perennial river which gets some run-off from the perennial tributaries of Kebena and Kessem from West and seasonal tributaries of Arba from east including some ephemeral streams from West and east. From three gauges at Awash Sebat, Melka Werer and Hertale the average annual flow for the period of 1973 to 2004 is calculated to be 2110 Mm3 with total annual flow increasing down stream since additional tributaries are included from Western sub catchments zones.

From the river Hydrograph pattern of Awash at Melka Werer gauge the peak discharge for the months of July and August is around 200 m3 /sec and the extremely low discharge for May and June is around 10 m3 /sec. The monthly mean discharge for the river Awash observed at Awash Sebat and Melka Werer gage station for more than 20 years (1973 – 1998) show seasonal pattern with highest values occurring in July an August months which is greater than 200 m3 /sec and also in March around 180 m3 /sec.

From the Hydrograph separation made for the river Awash at the Awash Sebat Melka Werer and Hertale gauges shows an estimated ground water component of 656 Mm^3 , 633 Mm^3 and 1272 Mm^3 respectively with relatively higher values at down stream showing more ground water inflow at this part of the river.

Transmission loss or channel water loss has also be estimated considering the upstream (Awash Sebat) and down stream (Melka Were) gauges to estimate the indirect recharge to the shallow Aquifer system in the river valley from peculation at river bed. For this the total net annual loss of Awash river for the period of 1973 to

1983 is calculated to 382.85 Mm3. This amount could be considered as a potential indirect recharge to the shallow alluvial aquifer depending on river bed conditions.

7. 2 Results from Analysis of Hydrogeology

Aquifer system and distribution

From well logging data and local geology of the study area both the shallow and deep aquifer systems and six hydrostratigraphic units have been identified.

The shallow aquifer system extends through out the Awash river valley existing below a depth of 30m consisting of sand and gravel with some clay. Most shallow wells and hand dug wells in the river valley tap water from this aquifer zone. Water level in this aquifer zone stands between 10-15m below ground surface.

The deep aquifer system on the contrary is encountered at a depth of 80-100m existing on areas of pediment plains on some parts of the river valley system. Fractured volcanic aquifers and volcanic sand aquifer in general make up this system. depth to water level in this system stands between 60-75 meters below ground surface. The major aquifer units of this system on the Alaydegea plain includes the weathered and fractured basalts, ignimbrite and trachites interbaded with volcanic sand and old pediment gravels. And the depth to the water level on the Alaydegea plain in general decrease from south to northeast direction where depth to water level around awash Arba i.e south of the plain is around 60m and toward north at Andido it is around 80 m deep below ground surface.

On the bases of hydraulic characteristics and water yielding capacity , in general six hydrostratigraphic units had been identified in both the shallow and deep aquifer systems.

Groundwater recharge and discharge

The deep aquifer system of the Alaydegea plain gets indirect recharge possibly as sub surface in flow from eastern mountain mass and also from loss of surface run off from most ephemeral streams running down from the elevated uplands/escarpments where they loss much of their water in the Alluvial fans and in the pediment gravels and sands. However local direct recharge from precipitation is very insignificant due to the prevailing higher potential evapotranspiration over the precipitation. The shallow aquifer in the river valley system also gets indirect recharge from the Awash river bed percolation as computed from the river channel water balance where the Awash river loses around 382.5Mm3 annually of water between Awash town and Melka worer areas.

Local fault lines like the wonji faults close to the Awash river are also good mechanisms or conduits for local groundwater circulation and recharge from the river to the Adjacent aquifer system. Topographic low areas are groundwater discharge zones in the study area where some hot springs emerges at the foot of fault scarps local depressions . Meteka areas around gewane and Bilen hot springs are local discharge zones.

Groundwater flow

Both topography and geology plays a major role for the groundwater flow in the area. There is a regional groundwater flow from the eastern mountain range towards north west or topographic lows in the valley floor as observed from the Potentiometric head map constructed. This regional flow is most possibly controlled by the regional tectonics which trend north wards following the main rift trend . Local tectonics like the wonji faults play some major roles controlling the local flow pattern where most hot springs emerges at the base of these local fault lines at Bilen and Meteka areas.

Groundwater surface water interaction

The shallow aquifer system in the river graben is observed to have some close hydraulic connection with the Awash river. From potentiometric head distribution, it is observed that there exists some ground water inflow to the Awash river in its upstream reaches. A piezometere water elevation observations around Melka worer and Melka sedi areas shows that the groundwater table is few meters 10-15mts below the river surface and as a result the Awash river shows a loosing nature feeding the groundwater .The moderate relationships for the seasonal and long term piezometeric hydrograph regimes with the Awash river hydrograph at melka worer shows this hydraulic connection between the river and the ground water.

7. 3 Results from Analysis of Hydrochemistry

Field measured parameters

Water Temperature :

Water temperature for most deep and shallow wells sampled in the field shows value between 30 to 33^{0}c where as the hot springs of bilen and Meteka shows some highest water temperature values ranging from 37^{o}c to 47^{o}c.Heat from deep thermal sources is the major cause for this high temperature.

Total dissolved solid (TDS) and Salinity

Regarding the salinity and TDS conditions the boreholes and springs display almost similar conditions with salinity ranging between 0.5 – 1 g/l and TDS values of 400 – 700 mg/l except for Awash town deep Wells which is close to 1000 mg/l. The close similarity in TDS for the springs and artesian wells in the local discharge zones with waters from the upland Alaydegea plain boreholes shows that there occurs some mixing of relatively fresh ground water flow to these source from the Eastern mountain range which is the recharge zone for the plain, boreholes and Hand Dug Wells on the valley floor drilled in the alluvium relatively shows high TDS values ranging from 1500-3000 mg/l (Melka worer sheleko, Ambash areas)

Laboratory Analysis results

Out of the major cations analyzed sodium and calcium ions in general show some relationships spatially along ground water flow path from eastern upland recharge zones toward the river valley. As a result the sodium (Na+) concentration ranges from a minimum values of 30-150 mg/l in the upper parts of the catchment around recharge areas to maximum values of 1259 mg/l in the valley bottom of Awash. On the contrary the calcium ion shows a decreasing trend from values of 150-200 in the eastern upland areas to lower values below 10 mg/l in the river valley. Rock weathering, sodium absorption to clay minerals could be the possible sources for high sodium amount.

Fluoride concentration in the lower river valley graben of the study area (Awash Valleys) in Melka werer, Melka sedi, Serkemo) areas ranges from 2-4 mg/l where some maximum values have been observed around Awash Sheleko, around 10 mg/l and relatively higher values in Gewane area 6-8 mg/l.

Fluoride concentration in the Alyadegea plain as well as around Awash towns ranges from 1-2 mg/l the possible source of Fluoride concentration is a chemical weathering on Acid Volcanic rocks and magmatic emission

The situation of some high fluoride values for the hot springs shows the deep thermal sources and high rock water interaction due to the higher temperature , are the major factors for higher fluoride amount in the area.

From graphical presentation of the water types for the analyzed samples different water types have been obtained from the piper plot which shows some spatial variations. From this it has been observed that bore holes from the Alaydegea plain in general shows Na – Ca –HCO3 and boreholes in the Awash river valley are Na –HCO3 type. The hand dug wells are of some mixed types with Na-HCO3 –So4- Cl types. The hot springs are of Na- HCO3 type.

The ground water in general shows an evolution trend from Ca – HCO3 in the eastern upland regions towards Na- HCO3 - So4 –Cl types in the river valley floor.

CHAPTER EIGHT: CONCLUSION AND RECOMMENDATION

CONCLUSION

From the Hydrogeologic point of view the ground water condition in the Alaydegea plain in general is characterized by the existence of deep aquifer system with fractured aquifers of scoracious basalts, trachy basalts and ignimbrite interchanged with old pediment out wash plain gravel. The depth to water level in the plain varies north wards from 60m to more than 80m depth.

On the basis of the prevailing hydrometeorolgic conditions in the study area, A direct recharge from local precipitation for the groundwater in the area is almost negligible where almost all the rain fall is lost by evaporation before joining the water table.

The Aquifer units in the Alaydegea plain relatively shows better transmissivity Values than the Alluvial aquifer of the river valley. Transmissivity values ranges from 200-600 m^2 /d with minimum drawdown of less than three meters for most wells from pumping test data with well yields of 7-10 l/s. this might shows the closer situation of some recharging zone boundary for the aquifer system.

Recent tectonics like the wonji fault lines and associated volcanic units play an important role for the groundwater circulation and storage in the area where potential sites for the groundwater exploitation are situated along this lines close to the river graben margin. Similar potential sites also exists on pediment plains with out wash gravel and sands interbadded with old volcanic units.

Groundwater flow to the plain is from the eastern upland recharging zones which might be considered as the possible way of ground water recharge to the plain. This groundwater flow further passes towards the river valley with some local discharges in the valley bottom as hot springs and artesian wells. The ground water condition in the Awash river valley aquifers is however more dependent on the indirect recharge from the Awash river where percolation from the river channel is the main source of recharge to the ground water.

From the Hydrochemical point of view the groundwater on the Alaydegea plain shows relatively lower values of TDS and Fluoride than the waters from the river valley Aquifers with TDS values ranging between 500 -700 mg/l and Fluoride amount 1-2 mg/l . This condition shows the close situation of this aquifers to the recharge waters in the eastern mountain range.

The relatively lower values of TDS for the hot springs and artesian wells in the local discharge zones also indicates the occurrence of some groundwater recharge to this points where the groundwater discharge at these sites is a part of the groundwater flow from the eastern highlands. Heat from deep thermal source in the area results for high temperature water for these sources. Regarding the hydrochemistry, samples in this part of the study area relatively shows a higher TDS (>1500mg/l) values and higher fluoride values(>2 mg/l). long residence time for rock water interaction for the groundwater, evaporative enrichment and salt dissolution is the principal cause of this higher values.

The general geochemical trend for the groundwater follows the topographic flow path evolving from calcium bicarbonate water in the eastern upland zones towards sodium bicarbonate water type in the river valley aquifers.

Recommendation

From the water resource development point of view , it is recommendable that groundwater development activities should focus on areas of pediment plains close to the recharge zones like the Alaydegea plain to exploit the deep aquifer system with relatively better hydrochemistry and productivity than the valley aquifer systems.

Within the river valley system, a very shallow groundwater developments activities should be avoided from the hydrochemical point of view where most shallow wells and hand dug wells are dominated by high sodium , salinity , sulphates and chlorides and fluorides. Whereas areas close to the valley margin which is close to the horst structure which most possibly be the line of wonji fault belt, shows better well productivity which might be related to their proximity to the line of groundwater circulation and hence are recommendable for water resource development.

Since the existing well data over the entire plain is few, some test well drilling and detail hydro geophysical investigations could give a better picture for the hydrogeologic pattern of the area.

Groundwater potential evaluation and the possibility of interaction of the deep groundwater system in the plain with the shallow groundwater or the river Awash also needs some detail hydrogeologic investigations.

The hydrogeochemical trends and the most possible geochemical controls along flow paths from the entire escarpment area to the basin floor requires a detail isotope hydrologic analysis which could also give a better answer with respect to recharge mechanisms, tracing recharge source and recharge amount estimation for the groundwater system in the Alaydegea plain.

References

Boonstra J. (1997) Ground water Survey and Balance, Enschede, Netherlands

Barbari F, Varet J. (1975) Recent Volcanic units of Afar and their structural Significance

Bouwer Herman, (1978) Ground water hydrology Mc Graw –Hill series in water resource and Environmental Engineering

Borchers A., James W., Fields L, Galloway Dev, Izbicki John, Kulongoski Justine,Galloway Devin L. Michel Robert L. (2003) Hydrogeology and Geochemistry of Aquifers underlying the san Lorenzo and San Leandro Areas of the east bay plain, Alameda country, California. US. Geological survey, water Resource Investigation Report 02-4259,61P.

Currey D.T. (1973) Additional Geomorphic Geological and ground water studies in the Awash Valley

Currey D.T. (1972) Geomorphic, Geologic and ground water studies in the Awash Valley

Croke. B.F.W, Ivkovic Km, Letcher, R.A. , Ground water – River Interaction in the Namoi Catchment, NSW and their implication for water Allocation. Australian National University, Karen. **ivcovic@ annu . edu-au .**

Fetter C.W. (1994) Applied hydrogeology. third edition, Prentice Hall, New Jersy,695 PP.

Freeze R.Allan and cherry John A. (1979) Groundwater. Prentice Hall, New Jersy 616 pp.

FAO, (1965) Survey of the Awash river basin.

Guler C., Mc Cray John E, Thyne Geoffiy D , Turner A. Keths, (2002) hydrogeology Jounal (2002) 455-474, Evaluation of graphical and multivariate statistical methods for classification of water chemistry data.

Guler C, Thyne ,Geoffrey D. (2003) Hydrologic and geologic factors controlling surface and ground water chemistry in addition in Indian well – Owens valley area , south eastern califrnia, USA .

Gurdak Jason J, Greve Adriennel I , Spahr Norman E. (2002) Water Quality Data Analysis of the upper Gunnison River Watershed, Colorado, 1989-99, US Geological Survey, Water Resource Investigation Report 02-4001, 59 P

Halcrow, (1983) Ground water Resource Assessment, Master plan for Water Resource development in the Awash basin, vol.5.

Industrial Potential Service (IPS) .(1988)Study on natural and physical resources of Afar.

Kazmin V.(1962) Stratiaraphy and correlation of Cenozoic volcanic rocks. Geological survey of Ethiopia, Addis Ababa.

Kazmin V. (1975) Explanation of the geological map of Ethiopia, Bulletin number one, Ministry of mines and Energy.

Ketema Taddesse and Heroic F. (1983) Ground water resources of the Alaydegea plan.

Lee Karl K.and Risley Hohn c. (2002) Estimate of Ground water Recharge, Base flow and stream reach gains and losses in the Willamette River basin, Oregion. US Geological Survey, Water, Resource Investigation Report 01-4215, 47 pp.

Lerener David N. (1990) A guide to Understanding and estimating ground water Recharge

Mezmure H.Meskel, 1981. Hydrogeology of South Western Afar and adjacent Escarpment.

Pola Di. (1970) Geological and geothermal report on the central and part of the Ethiopian rift valley.

Rosler A., Pilger A. (1974) Afar rifting and related rifting, Inter Union commission on geodynamics , Scientific report.

Reimann C, Bioruatn k. and Frengstad B., Reimann C, Reda tekle – Haimanot, Siewaers V , Zenebe Melaku ,Drinking Water Quality in the Ethiopia Section of the East African Refit valley I – data and health aspects. **www. Science direct .com.**

Shaw E.M,(1988) Hydrology in practice. Second edition, Chapman and Hall, Newyork, 53pp

Sumioka S.S. and Bauer H.H. Estimating ground water recharge from precipitation on Whidbey and Camano islands, island country, washing ton, for water years 1998 and 1999, 33P.

Teshome Estifanos, (2001) Indicative land use plan in Afar, Bureau of Agriculture, Afar.

Titus R, Holness S.D and Tonder GJ., Zhang J , A hydrogeomorphological approach to quantification of ground water discharge to streams in south Africa. Department of Earth Science, University of the Western Cape, south Africa.

Thompson Ryan F. (2002) . Evaluation of Recharge to the Skunk Creek Aquifer from a constructed wetland near Lyons, South Dakota. US geological Survey, Water Resource Investigation Report 02-4133, 23P.

Tenalem Ayenew and Tamiru Alemayehu, (2001) Principles of Hydrogeology.

UNDP,(1973) Investigation of geothermal resource for power Development.

UNESCO, (1984)Surface water and ground water Interaction, International Commission on ground water.

UNESCO, (1984) Method of Computation of the water balance

Visetin Justin E, and Piccirillo EM, Zanettin B. (1977). Volcanic Succession, Tectonics and Magmatology in Center Ethiopia.

Annex 1 : Bore hole data in the study Area and around used for Hydrogeologic interpretations

Site name	Code	Location(UTM)		Depth(m)	St. water Level (l/s)	Yield (l/s)	Draw down (m)	Specific cp. l/s/m	Aquifer type	Transmisivivity
		X	Y							
BurkaMisra	BH-35	696722	1018866	123	67	8	0.85			506.29
Tutuftu	BH-36	685854	1009743	196	87	5.6	84.02			3.35
Daga dhaba	BH-37	681409	1009313	151	53	5.6	4.95			790.56
Sabaka	BH-38	676209	1005803	150	67		20.7			
Ufe/Negib farm/	BH-39	681160	1014332	118	81	1.5	14.52			
Kurfa Jarti	BH-40	676671	1014620	267	157		35.23			
Hayo	BH-41	668814	1001716	228	61	3				
Fugnan Ajo	BH-42	668234	1011339	272	162	0.4	93.65			
Awa. Dudub deep	BH-1	626351	999671	139	91.75	1.5			gravel	
Kessem	BH-2	606466	1011563	100	17.9	5.3	1.23		basalt	
Kebena		611283	1022078	100	17.5	5.6	0.77		sand,conglo	
Awash	BH-4	618963	1023518	100	3.76	5			sand, grael	
Kurkura	BH-5	632047	999422	137	91.08	4.6				
Kurkura	BH-6	632412	998041	242	121	4				
arba	BH-7	628900	1008000	80	60.94					
Gonita birka ,,	BH-8	637070	1017019	140	85.72	3.5				
Awa. Arba	BH-9	628683	1008918	126	55	2.1				
Awa Arba	BH-10	629018	1008158	52	23.3					
arba wonz	BH-11	628898	1007914	148	93	2.5	10.03	2260		
lalib.Cons.arba ,,	BH-12	632471	1008252	194	66	5			fractured ignimbrite	
Arba mil. Ca deep	BH-13	628311	1007852	117	39.14	6.2	1.4	0.322	basalt	117.9
Kerensa	BH-14	624548	1017845	81	38.45	2.95	65.39	0.03		
odeelise	BH-15	639503	1028950	117	61	6.7				
Elfora	BH-16	643277	1025555	120	78	2.6	3.97			0.91
Andedo	BH-17	646560	1040111	120	81.37	5.6	1.39			
Andedo	BH-18	647560	1039522	88	78.04	3.8	3.81	1.6	tuff	396

Site name	code	Location(UTM)		Depth(m)	St. water Level (l/s)	Yield (l/s)	Draw down (m)	Specific cp. l/s/m	Aquifer type	Transmisivity
melkasedi	BH-19	623270	1023044	105	25		1	6.6	Alluv, Basalt	864.6
melkas.agr	BH-20	624705	1021649	70	26.6				Alluv, Basalt	
serkemo	BH-21	632337	1031448	84	12	2			Alluv, Basalt	
serkemo	BH-22	632988	1031094	76	13	6.5	17.7	0.28	Alluv, Basalt	86.4
berta well	BH-23	633107	1027266	82	34.16	5	0.98	6.73	Alluv, Basalt	2108
Worer	BH-24	629485	1031634	41	9.12	0.6	14.64	0.14		
Worer	BH-25	629045	1030474	72	11.6	6.2	1.66	3.02	sco.baslt	
Ambash	BH-26	630511	1043228	48	7.67	7.9			Alluv volc	31.37
Sheleko	BH-27	628562	1038760	50	5.85	5.6			Alluvium	134.69
gelsa	BH-28	638732	1072353	140	108	4.2	8.31		basalt	790.56
Halidebi	BH-29	641074	1068549	66	19.64	3.5	20.07		basalt	
Belen	HSP-1	644235	1046853						sand, peble,coble	
Hassoba	BH-30	638824	1043036	100	17.95	4.8			basalt	
Hassoba	HD-1	635843	1045364	5.9	5		1.61		gravel	
Hassoba	HD-2	635941	1045568	15	5					3.32
Angelele	HD-3	643808	1050476	6						
Angelele	HD-4	643193	1060626	6.3						736
Angelele	HD-5	642580	1060857	7.4			14.9	0.322	sand clay	
gelealo	BH-55	663997	1092189							31.88
buremedaitu shalow	BH-31	663409	1102863	97	Artesian	4.5				
Ouref	BH-32	673286	1119646	120	25	6.7				
gewan town	BH-33	681441	1126215	88	56.4	2.4				
gewa.town	BH-34	680061	1120521	113	9	4.2			welded tuff	

Annex 2 : Piezometer water elevation data on the Awash river bank (1976-1989)

year	Piezo.No.	Surf.elev. (m)	Water elevation in piezometers (meter)											
			Jan	Feb	Mar	Apr	may	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1976	3	743.6	742.99	742.02	742	742.97	743.21	742.72	742.3	742.64	742.71	741.85	741.92	741.81
	10	741.22	739.07	739.02	738.463	739.09	739.1	739.17	739.05	739.12	739.07	739.05	739.00	739.02
	20	738.75	733.5	733.45	733.43	733.42	733.4	733.37	733.75	734.15	734.97	734.98	734.66	733.95
1978	3	743.6	742.04	742.13	741.90	742.11	742.20	741.46	741.45	741.74	741.60	741.46	741.43	741.46
	10	741.22	738.83	738.72	738.77	738.87	738.88	738.86	738.32	739.03	738.92	738.90	738.90	738.83
	20	738.75	735.00	734.58	734.54	734.75	735.15	736.30	735.25	735.73	736.13	735.75	735.85	735.47
1979	3	743.6	741.31	741.42	742.00	742.04	741.96	742.09	742.22	742.33	742.33	741.97	741.97	742.13
	10	741.22	738.83	738.82	738.87	738.88	738.87	738.91	738.92	739.17	739.12	739.67	738.67	738.62
	20	738.75	735.38	735.18	735.27	735.22	735.34	735.96	736.06	736.30	736.40	736.46	736.39	736.15
1980	3	743.6	743.47	742.03	741.91	741.82	741.71	741.88	741.60	742.07	742.42	741.46O	741.6	742.02
	10	741.22	739.52	739.40	739.36	739.31	739.21	739.15	739.12	739.14	739.13	739.04	738.98	738.97
	20	738.75	734.75	735.03	735.12	735.05	735.25	735.78	736.07	736.35	736.45	736.49	736.25	736.08
1981	3	743.6	742.06	742.18	741.45	742.16	741.93	741.43	741.45	741.54	741.43	741.46	741.43	741.41
	10	741.22	738.88	738.88	738.82	738.92	738.90	738.88	738.88	738.89	738.86	738.82	738.80	738.86
	20	738.75	735.58	735.36	735.30	735.67	736.75	736.57	737.03	737.18	737.16	737.06	736.36	736.17
1982	3	743.6	741.48	741.82	741.55	741.45	741.45	742.41	742.66	742.13	741.43	741.46	741.60	741.75
	10	741.22	738.90	738.96	739.08	739.08	738.89	738.97	738.99	738.96	739.05	739.00	739.00	739.02
	20	738.75	736.00	735.92	736.07	735.97	736.13	736.08	736.70	737.06	737.57	737.41	736.47	736.25

1983	3	743.6	741.81	742.09	741.98	742.09	742.00	741.90	741.67	741.96	741.88	741.73	741.80	741.33
	10	741.22	738.94	738.89	738.96	739.00	738.13	738.23	739.00	738.84	738.73	738.89	738.87	738.72
	20	738.75	735.83	735.58	735.50	735.52	735.84	736.08	736.27	736.03	736.84	736.03	735.68	735.39
1984	3	743.6	742.09	741.42	741.81	742.15	742.10	741.89	741.82	741.45	741.45	741.46	741.37	741.48
	10	741.22	738.77	738.87	738.11	739.14	739.19	739.08	738.92	738.83	738.58	738.57	738.54	738.57
	20	738.75	735.14	735.11	734.82	735.21	735.32	735.90	736.93	736.70	736.65	736.39	735.96	735.85
1985	3	743.6	741.56	741.5	741.47	741.48	741.78	742.4	741.5	741.65	741.67	741.5	741.5	741.49
	10	741.22	738.63	737.46	738.55	738.60	738.59	738.69	738.74	738.71	738.21	738.78	738.40	738.25
	20	738.75	735.63	735.53	735.52	735.35	736.56	735.92	735.92	736.24	736.84	736.31	736.12	735.94
1986	3	743.6	741.50	741.49	741.3	742.4	741.5	741.49	741.48	741.4	741.54	741.5	741.56	741.68
	10	741.22	738.17	738.10	738.02	738.01	737.89	737.82	737.83	737.86	738.21	737.99	737.93	737.86
	20	738.75	735.77	735.59	735.29	735.24	735.51	736.41	736.39	736.60	736.84	736.59	736.17	735.97
1987	3	743.6	741.6	741.5	741.9	741.72	741.65	741.5	741.49	741.49	741.44	741.48	741.48	741.48
	10	741.22	737.82	737.75	737.83	737.81	737.56	737.47	737.40	737.45	738.22	737.28	737.22	737.22
1988	3	743.6	741.48	741.48	741.51	741.5	741.71	741.4	741.53	741.75	741.58	741.48	741.48	741.48
	10	741.22	737.36	737.35	737.24	737.22	737.16	736.87	737.08	738.46	737.04	736.59	736.77	736.87
1989	3	743.6	741.60	741.50	741.50	741.43	741.44	741.44	741.50	741.50	741.20	741.55	741.50	741.60
	10	741.22	736.72	737.47	737.95	736.44	736.32	736.48	736.53	736.52	736.56	738.49	736.52	736.52

Annex 3 : Laboratory Water chemical Analysis Results

No.	Site	Woreda	Code	Location X	Location Y	TDS mg/l	Ec (µs/cm)	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	F mg/l	Cl mg/l	NO3 mg/l	HCO3 mg/l	SO4 mg/l	PO4 mg/l
1	Trinity Monastery	Meisso	BH-47	674163	1025893	54	80	1.3	1	15.5	1.1	0	1	4.8	48.7	1.1	0.2
2	Butiji	Meisso	BH-46	692622	1057124	324	519	33	4.4	55.5	20.9	0	19.2	10	282	12.1	0.4
3	Arba Wonz	Amibara		628925	1007946	424	649	43	5.5	82.8	17.6	1.4	23	7.5	361	18.2	0.4
4	Hayo	Meisso	BH-41	668814	1001716	486	765	43	8.4	105	20.9	0.5	37.4	17.5	407	17.3	0.6
5	Huse Sodoma	Meisso	BH-43	695877	1015842	424	662	44	5.6	84.6	19.2	1	20.2	10.5	400	6.6	0.7
6	Gende Aliware	Meisso	BH-44	694136	1019853	404	576	50	8.2	57.3	16	0.8	15.4	16.3	333	7.43	0.4
7	Daga dhaba	Meisso	BH-45	681409	1009313	505	775	53	3.6	112	18.7	0	25	13.5	487	12.1	0.5
8	Nearby the town's reservoir.	Meisso	BH-48	693001	1021056	362	572	54	8.2	57.3	16	1.1	10.6	17.5	328	4.4	0.5
9	Awash Arba Town	Amibara	BH-9	628683	1008918	440	683	56	8.5	72.8	16.5	0.8	41.3	10	338	37.1	0.4
10	Kora	Meisso	BH-49	669172	1006483	958	1451	60	4.6	209	45.1	0.2	188	29	492	68.8	0.7
11	Tutuftu	Meisso	BH-36	685854	1009743	468	748	69	21	63.7	17.6	0	31.7	10	397	50.9	0.5
12	Fayo	Meisso	BH-50	691053	1020494	446	726	70	9.1	80.1	14.8	0.8	16.3	7	469	14.3	0.9
13	Afasse	Gdamaitu	HD-6	693627	1072312	820	1250	71	1.4	151	24.2	0	49.9	29	241	330	0.5
14	Halidebi	Amibara	BH-51	641074	1068549	386	640	72	6.6	47.3	17	1.6	29.8	19.5	320	26.4	0.2
15	Defence	Amibara	BH-13	628311	1007852	478	689	74	9.1	61.9	13.2	1	38.4	8	354	33	0.4
16	Kurkura	Amibara	BH-6	632047	999422	458	666	81	8.8	49.1	11.6	0.9	29.8	7.5	351	21.8	0.6
17	Bordede town	Meisso	BH-52	652583	996169	588	893	82	21	82	24.2	0.5	55.7	11.5	423	56.4	0.8
18	Andido -1	Amibara	BH-17	646837	1039522	508	734	116	12	30.3	15.7	1.8	39.4	5	366	46.2	0.1

19	Udileisi-2	Amibara	BH-15	639503	1028955	592	846	135	14	24.6	12.6	2.2	52.8	8	410	44	0.2
20	Elfora	Amibara	BH-16	642486	1025611	516	797	144	13	20.9	7.7	2.5	49.9	8	381	49.5	0.3
21	Bilen	Amibara	HSP-1	644235	1046853	586	915	172	17	19.6	17.3	3.3	55.7	3.2	430	46.2	0.1
22	Bilen	Amibara	BH-53	644586	1047321	608	906	174	12	22.3	8.1	2.2	57.6	1.5	441	35.6	0.3
23	Kurfa Jarti	Meisso	BH-40	676671	1014620	546	889	184	5.5	18.2	4.4	0	105	8.5	366	1.68	0.6
24	Berta	Amibara	BH-23	633107	1027266	630	1004	186	16	18.2	11	4.4	65.3	8	464	57.8	0.4
25	Hasoba Bilen	Amibara	BH-30	638824	1043036	600	949	190	3.9	15.5	4.4	1.2	77.8	10	400	68.8	0.7
26	Kilaito	Amibara	BH-54	633683	1033917	584	894	190	4.1	9.1	2.75	3.2	57.6	7	415	49.5	0.2
27	Gelealo	Gewane	BH-55	663997	1092189	626	1030	196	12	15.1	3.8	1.8	114	10	267	89.8	0.1
28	Kerensa	Amibara	BH-14	624546	1017845	672	1095	204	11	20.5	17.3	2.7	92.2	7	500	47.5	0.3
39	Eigile	Amibara	HD-7	674028	1119302	956	1577	206	9.7	121	37.8	1.8	303	20	447	211	0.4
30	Middle Awash	Amibara	BH-20	624705	1021649	626	1008	208	13	13.4	7	2.7	71	4.8	456	60.7	0.1
31	Dudu	Amibara	BH-1	626351	999671	960	1523	220	25	86.5	24.8	0.9	236	20	269	176	0.5
32	Meteka	Gewan	HSP-3	668821	1102656	682	1164	248	12	6.2	1.6	2	111	7	398	87.1	0.2
33	Badulale	Amibara	BH-56	629784	1027212	686	1060	248	2.3	4.5	2.2	3.7	82.6	7	503	73.9	0.2
34	Adgura	Gewan	HSP-2	669108	1103908	730	1201	266	8.3	2.7	1.1	1.9	109	5	374	83.2	0.2
35	Banana/muz/Camp	Amibara	BH-19	623270	1023044	800	1302	276	10	12.5	3.2	2.3	119	1.25	517	76.6	0.5
36	Gelealey	Gdamaitu	BH-57	660074	1077852	1058	1792	290	11	45.5	9.4	0.9	313	22.5	167	168	0.5
37	Middle Awash	Amibara	BH-58	624305	1021359	952	1588	325	17	19.6	10.8	2.7	158	8	548	132	0.2
38	Store/Megazen	Amibara	BH-59	623396	1027152	926	1464	335	4.5	4.5	2.2	4	121	5	573	75.2	0.5
49	Ufe/Negib farm/	Meisso	BH-39	681160	1014332	1304	2040	340	5.5	57.3	2.8	0	572	8.5	30.7	117	0.2
40	Afasse	Gdamaitu	HD-8	693732	1072401	1126	1724	345	1	20.9	6.1	1.7	112	25	359	400	0.5

41	Eiei-2	Gewan	BH-60	632988	1031094	1212	1888	355	20	31.9	15.4	3.7	239	10	602	41.3	0.4
42	Walgeli	Gewan	BH-33	681441	1126215	1304	2060	425	19	28.5	7	1.8	303	20	447	211	0.4
43	Melka Worer	Amibara	BH-25	629045	1030474	1840	3010	585	6.9	37.3	23.7	4	358	17.5	940	80	0.6
44	Melka Worer Town	Amibara	BH-24	629485	1031634	1936	2970	660	7.6	40.1	18.9	3.3	365	10	922	304	0.3
45	Ouriesi-1	Gewan	HD-9	677693	1114533	2004	3240	790	21	7.1	1.6	6.2	438	4.8	998	235	0.4
46	Ouriesi-2	Gewan	HD-10	677533	1114397	1990	3280	810	21	4.45	1.6	8	474	5	800	209	0.5
47	Keleat	Gewan	HD-11	639409	1048416	2956	4410	1020	6.1	30	14.8	18	425	8.5	1686	143	1.4
48	Gidboso Ela	Gewan	HD-12	675748	1109515	4004	6110	1180	32	16	2.2	6.2	831	5	1181	950	1.5
49	Hasoba	Amibara	HD-1	635843	1045364	14066	17090	1250	77	2093	616	1.7	3836	800	743	2780	0.6

Annex 4 : Mean Monthly discharges of Awash River and its Tributaries averaged for long years (1973 -1998)

Location	Jan	Feb	Mar	App	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Awash R. at at Awash Sebat	**46.5**	**42.3**	**55.0**	**62.2**	**60.4**	**44.8**	**93.7**	**160.8**	**150.6**	**85.0**	**42.0**	**40.0**
At Melka - Worer	**39**	**43**	**59.0**	**54.6**	**48.9**	**33.5**	**92.6**	**160.9**	**132.6**	**72.9**	**402**	**31.7**
At Hertale	**49.25**	**50.69**	**65.56**	**70.98**	**63.65**	**57.48**	**142.36**	**229.9**	**173.2**	**71.37**	**41.66**	**45.13**
Kessem Stream	**5.383**	**5.280**	**10.60**	**7.654**	**4.882**	**11.768**	**93.580**	**129.934**	**67.12**	**16.29**	**8.52**	**7.76**
Kebena Stream	**2.47**	**2.87**	**2.73**	**6.33**	**3.82**	**2.87**	**13.25**	**44.36**	**18.7**	**6.11**	**4.77**	**2.15**

Annex 5: Total Annual flow and Discharge of Awash and the tributary Kessem From 1973-1998

year	Annual total flow of Awash at Melka worer Mm^3	Annual discharge		Awash at Awash Sebat Annual total Mm^3	Kessem river at kessem ,Annual total flow Mm^3
		Max Q (m^3/s)	Min Q m^3/s		
1973	1285.160	264.8	9.3	1013.080	617.8
1974	1723.270	247.9	2.3	1477.270	719.713
1975	2243.990	259	1.96	1986.640	518.68
1976	1693.500	256.6	8.27	1337.490	292.42
1977	2344.810	286	6.7	1984.840	414.596
1978	1873.380	187.67	11.9	1846.250	407.813
1979	1624.198	180.64	13.7	1508.540	249.167
1980	1156.390	180.64	6.18	896.700	465.538
1981	2121.200	213.9	10	2152.600	469.18
1982	1551.870	267	9.5	1358.820	254.2
1983	2230.050	214.25	8.6	2435.370	247.162
1984	1175.060	125.6	4	1050.730	245.402
1985	1175.060	260	4.4	1604.680	402.224
1986	1528.953	172.5	11.16	1361.140	306.437
1987	1191.130	178.4	7.46	1004.980	108.816
1989	2259.800	287.3	13.9	1599.640	203.18
1990	2264.420	245.1	9.1	1917.266	317.617
1991	2088.883	259.2	14.7	1602.460	999.271
1992	1796.740	224	5.8	1686.780	276.11
1993	2483.558	263.6	14.3	2479.080	474.027
1994	1877.590	261.4	10.26	2080.080	463.365
1995	1469.950	199.6	8.5	1405.680	368.565
1996	2465.290	345.700	20.240	2573.661	522.763
1997	2088.883	261.35	10.8	1827.509	358.923
1998	2658.423	359.200	6.000	2935.433	592.926

Annex 6 : Hydromeorologic Data For The Awash Area

Parameters	Locat..	Jan	Feb	Marc.	App.	May	Jun	Jul	Aug.	Sep	Oct.	Nov	Dec	Average
Temp(0C) mean monthly	Awash Town	23.4	24.8	26.5	27.4	28.5	29.7	28	26.6	27.2	26.3	24	23.3	26.3
	Melka Worer	22.2	22.8	24.5	26.4	27.9	29.8	28	25.8	26.5	25.3	24	22	25.8
Wind speed(m/s)	Awash	1.15	1	1.25	1.2	1.4	2.3	2.4	1.4	1.2	1	1.2	0.85	1.36
Relat.Hum(%)	Awash	60.6	60.4	60.4	60.5	60.2	60	61	70	60.8	60.7	61	60.7	61.31
Sunshine hours hours/day	Awash	8.9	8	7.9	7.3	8	7.7	7	7.5	7.3	8.1	9.2	9.3	8.01

Annex 7: Mean Monthly Rainfall at Gauging Stations in Awash Area

Area/ Station	Jan	Feb	Mar.	Apr.	May	Jun	Jul	Aug.	Sep	Oct.	Nov.	Dec.	Total
Awash Sebat	20.11	41.4	56.1	58.3	40	31	118	134	56.82	24.3	14.8	8.91	604.1
Melka Sedi	32.13	30.5	57.4	59.1	28.1	20	114	132	43.16	9.356	30.46	14.9	571.1
Melka worer	6.98	42.8	87.6	63.3	42.8	21	122	127	55.03	25.52	9.22	12.2	615.2
Average	19.74	38.2	67	60.2	36.9	24	118	131	51.67	19.72	18.16	12	596.8