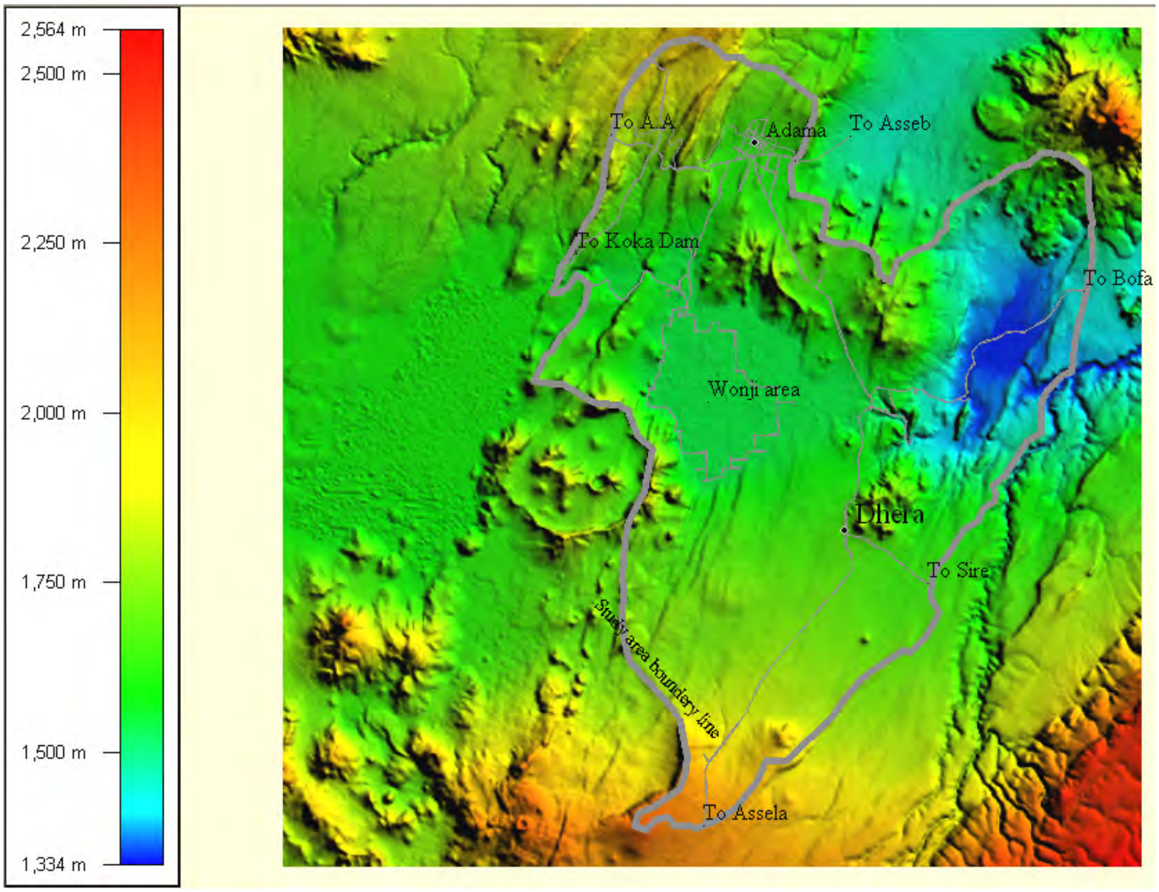
ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

HYDROGEOLOGICAL AND HYDROGEOCHEMICAL ASSESSMENT IN ADAMA (NAZARETH) - DERA AREA, CENTRAL ETHIOPIA



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

IN

HYDROGEOLOGY

BY ABERA TAYE
July, 2007

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ABSTRACT

The investigated area, Nazareth-Dera sub-cachement is located in the central part of the Main Ethiopian Rift within 8^0 09'24.58'' to 8^0 36'28.75''N latitude and 39^0 08'36.70''to 39^0 27'47.23''E longitude and covers about 941 km^2. This research work assesses the hydrogeological and hydrogeochemical nature of the area based on the analysis of hydro metrology, hydrology, hydrogeology and hydrogeochemistry data. The assessment and interpretation of the chemical analysis of the previous works and the current works are made to accomplish this objective.

The area has semi-arid to semi-humid climate with a mean annual temperature and precipitation of 21.47^0C and 807mm respectively. The study area has both flat and rugged topography. The annual potential evapotranspiration and actual evapotranspiration of the area are calculated to be 1979.1mm and 726.55mm respectively.

The total annual estimated runoff value that leaves the cachement area is to be 175.72MCM. In the study area the direct groundwater recharge from precipitation is negligible. Instead, there is huge amount of groundwater recharge from Koka Lake, which is inflow for the study area to be 485.4 MCM/annum. Values of net annual groundwater recharge estimate is determined from water balance calculation and found to be 298.36 MCM.

Concerning the hydro lithological characteristics of the area, there are four hydro lithological units which are grouped as high to very high, Moderate to high, low to moderate and low to very low permeability groups. The main aquifer units in the area are alluvial, volcano- lacustrine deposits, weathered and fractured basalts and ignimbrites, which have generally greater than 2m/day permeability whereas, all fresh basaltic flows and domes, ryholitic and trachytic rock units and pumice and ash fall deposits, densely welded fine-grained and green ignimbrites have poor permeability.

According to major ions hydrogeochemistry analysis result and tri-linear piper diagram plots most of the borehole waters are Na-HCO3 and Na-Ca-HCO3 type, springs and all hand dug wells are Na-HCO3 water type. All Awash River samples in the area are Na-Ca-HCO3 water type. Based on the analysis results of major cations and anions, the general water quality are discussed from public supplies, irrigation and industry point of view. Concerning the water quality, Wonji and Sodere area have groundwater with ionic concentration of Na, TDS and fluoride beyond permissible limit.

Concerning water pollution, the underlying unconfined shallow aquifers groundwater in Wonji area and alluvial aquifers along Awash River may be generally considered as highly vulnerable to any type of pollution.

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Declaration

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

Dr. Tamiru Alemayehu (Advisor)

Signature____________________

Abera Taye

Signature ____________________

Date and place of submission: July 2007, Addis Ababa.

Chapter One

1. Introduction

1.2 Background

Both surface and groundwater are primary requirement for the well-being of society in every country. Water is one of the fundamental natural resources for all living things to exist on the earth and it plays a vital role to bring significant socioeconomic development. This natural resource is used for irrigation, industries, domestic uses (drinking and cleaning) and plant growth. Although fresh water is one of the limited resources, its demand is increasing as a result of an increase in population growth and modern civilization all over the world. At present nearly one fifth of all the water used in the world is obtained from groundwater resources (Raghunath, 1987). In an area where surface water is not available, groundwater is the second alternative for irrigation purpose if the demand for irrigation and groundwater potential is promising without significant negative environmental impact. This implies that detailed research in the sector of water resources, specially in relation to their chemistry and their spatial and temporal variability, proper implementation and protection of water resources from quality degradation is an essential requirement to attain sustainable development.

The investigated area hosts both rural and urban communities with characteristics of densely populated, high rate of population growth, extensive and poorly developed farming practices except Wonji irrigation and the area is mainly characterized by complex volcanic geology. The study area is contained within the Awash Basin, which is one of the seven major basins of the country, placed in the central part of the basin.

The hydrology, hydrochemistry, hydrogeology and water pollution of this study area, Nazareth-Dera sub-cachement, as a whole is not studied separately and in detail except geology of Nazareth–Dera area at a scale of 1: 50,000, by Alula Damte (1992). Therefore, this research will have important role towards the sustainable use of water resources in the area in order to launch development activities using integrated surface and groundwater.

The six chapters are organized in a way that can give clear picture of the study area about its location, physiography, Geology, Volcano-tectonic, climate, Hydrometrology, Hydrogeology and hydrogeochemistry as well as water pollution in relation to domestic, agricultural and industrial water quality uses point of view.

The composition of surface and groundwater is strongly dependent on natural factors such as geological, topographical, meteorological, hydrological and biological in the drainage basin and their seasonal variation.

Nowadays adequate quantity and quality of fresh water supply plays a vital role for sustainable development. However, human intervention to natural system has a significant effect on the natural water quality.

Human activities include improper disposal of untreated toxic chemicals and industrial wastes, contamination of water bodies with inorganic fertilizers, over pumping of aquifers and agro-industries wastes that promote Eutrification (i.e. algal growth) are some of the common causes of water quality degradation in the area. This research work is conducted to make hydrogeological investigation and assess the main pollution sources and causes of water quality degradation of surface and groundwater resources in the study area.

1.3 Previous Works

The most pertinent works related to the present study were done by Kazmin and Seife Michael Berehe,[41], Degefe Shiferaw [18], Gethahun Kebede [28], Skutan B., Kidane A., and Birhanu B.[61], Alula Damte, Boccaletti M.,Getaneh Assefa,Mazzuoli R.,Tortorici L [3], Ashely,R.P.and ,Burely M1J.,[5], Dereje Ayalew [19], Woldu Ameneshoa [87], Darling W.G., Berhanu Gizaw,Arusi M.K., [17], Tamiru Alemayehu and Vernier, [67], Sileshi Mamo [63], Teshome Dechasa [74] , Selome Tibebu [62] and Adama Master plan Revision project (2005) have yielded important clues and information about the area.

Fluoride occurrence in the east African Rift system which is the natural cause of water degradation has been described by Darting et.al., (1996), Berhanu Gizaw (1996) and of the ERV by Ashley and Burely (1994) and Tamiru Alemayehu (2006).

Detailed Geology of the Nazareth-Dera area with a map of scale 1:50 000 presented by Alula Damte(1990); which was used as base map for Hydrogeological mapping of the present work. However, some lithological units of this geological map classified as different units have been regrouped together, taking in to consideration their similar hydrogeologic characteristics.

However, all the above mentioned studies didn’t indicate the detailed reason for groundwater depth variation between Dera basin and the rest of the study area, their flow mechanisms, the role of structures, their interaction with Awash River, the possible recharge and discharge mechanisms, zones and possible sources of water pollution.

This study is therefore proposed to give some picture in these and other related aspects regarding the hydrogeology and hydrogeochemistry of Nazareth-Dera sub-cachement.

1.4 Objectives and scope of the study

1.4.1 General Objective

The general objective of the research is to describe and give detailed picture of the hydrogeologic characteristics of the groundwater systems concerning aquifer type, groundwater recharge estimation and mechanism, the role of tectonics and structures in groundwater flows and hydro chemical nature of water resources in the Nazareth-Dera area.

1.4.2 Specific Objectives

The present research in the area was carried out with the following main objectives in mind:

Description and characterization of the major aquifer systems and units in the area, defining the major structures and litho logic controls on the groundwater flow systems and explaining the origin and mechanism of recharge for groundwater potential in Nazareth-Dera area.

- Zonation of permeability ranges to identify and regroup aquifer types on different aquifer parameters within the cachement and produce hydrogeological map.
- To analyze spatial variation of the hydrochemistry of water samples in the cachement and discussing the hydrogeologic implications behind the hydrochemical variations.
- To determine the regional and local groundwater flow systems in the cachement.
- To delinate potential shallow and deep groundwater sites for immediate development.
- Quantification of the major hydrologic components.
- Delinating recharge, discharge and shadow zones through analyses of the surface contours and water chemistry of the area.
- To assess the type and extent of possible sources of water pollutant and their major sources.
- To study awash and groundwater interaction using groundwater contour map (using pizometric contour line) and hydrochemistery;
- To investigate the possible groundwater depth variation reasons between Dhera basin and the rest of the study area;
- To recommend potable water alternative sources for Dera basin and other similar areas especially for rural areas, where their groundwater level is very deep and there is no nearby surface water sources;
- To suggest the possible measures that can be applied to safeguard water resources of the area from antropogenic pollution sources.
- To suggest possible future sustainable integrated utilization of the surface and groundwater resources.

1.4.3 Scope of the Study

The scope of the study incorporates the analysis of the available data obtained from multiple sources and interpreting them in accordance with the specific purpose of the study and finally gives some picture about the hydrogeology and hhdrogeochemistry of the Nazareth-Dera area supported with different maps.

1.5 Methodology

During the study of this research the following methods and activities have been employed:

- Field observation, assessing and collecting necessary field data with the help of field equipments and different maps and were supported with satellite images of the areas analyzed with different computer soft wares.
- Hydrometerological data were collected from the National Meterological Service Agency and Awash Melkasa Agricultural Research Center.
- The quantification of the hydrometrological components in to actual and potential evapotranspirations by different techniques.
- Discharge data for Awash River at below Koka dam and Wonji gauging stations were collected from Ministry of water Resources.
- An inventory of existing boreholes, dug wells and springs was made in the area. This has led to a map of the distribution of water points, potential of the aquifer and piezometric contour line, allowing a first order reconstruction of the groundwater flow direction.
- Collecting constant pumping test, recovery data and geologic log of some of the wells from different organizations were executed. These have led to make aquifer characterization by estimating hydraulic parameters such as transmissivity and permability values of the aquifers in the study area.
- The above two methods can help to understand how Awash River and groundwater interact in the area.
- Multiple methodology and approaches have been used in the study area. Literature review, secondary data compilation, and historical data analysis is carried out to understand the past trend of hydrologic and hydrogeologic investigations.
- Estimation of annual groundwater recharge is done from computation of the general water balance equation that introduces the main components that are prevailing and omits those that are of less effect in the balance.
- Water samples are collected from wells, springs, and Awash River for the hydrochemical characterization of different water sources in the area and their water quality report is analyzed.
- Assessing and gazering a series of information about point and non point sources of pollution were executed within the study area in order to know their impact on the water quality.
- Data processing: It was done on personal computer with the help of the following soft wares such as Global Mapper-8, Arc view-3.2, Surfer-8, Aquachem-4 and Excel.

Chapter Two

2 General Description of the Study area

2.1 Location, Area extent and Accessibility

The study area is located in the central part of the Main Ethiopian Rift, which is situated in the Upper Valley of the Awash Basin (in the centre- east of Ethiopia) within the East Shoa zone of Oromia National Regional State. The Area lies between 8^0 09'24.58'' to 8^0 36'28.75''N latitude and 39^0 08'36.70''to 39^0 27'47.23''E longitude. It is located about 100km southeast of Addis Ababa, and covers total areal extent and perimeters of 941sq.km and 167 km respectively (Fig.2.1).

Bofa village is the extreme eastern boundary, whereas Koka reservoir marks the western limit of the study area. The south and northwestern part of the region is delineated by Dera basin and Kechema ridges respectively. The northern boundary of the area is delineated by a local water divide roughly 200m south of Mermersa seasonal stream.

The Addis Ababa-Asela main asphalt road passes through Nazareth-Dera, which crosses the study area dividing approximately in to two equal parts. The Awash River, the only major river that drains the plateau and flows towards the rift, rises to the west of Addis Ababa at an elevation of about 3000m in the central high lands passes through the study area.

In general many parts of the study area are very accessible and can be reached by a four wheel drive vehicle because even all weather roads have a good net working that enable to access in every direction almost to all constructed water schemes to monitor all water points in the area.

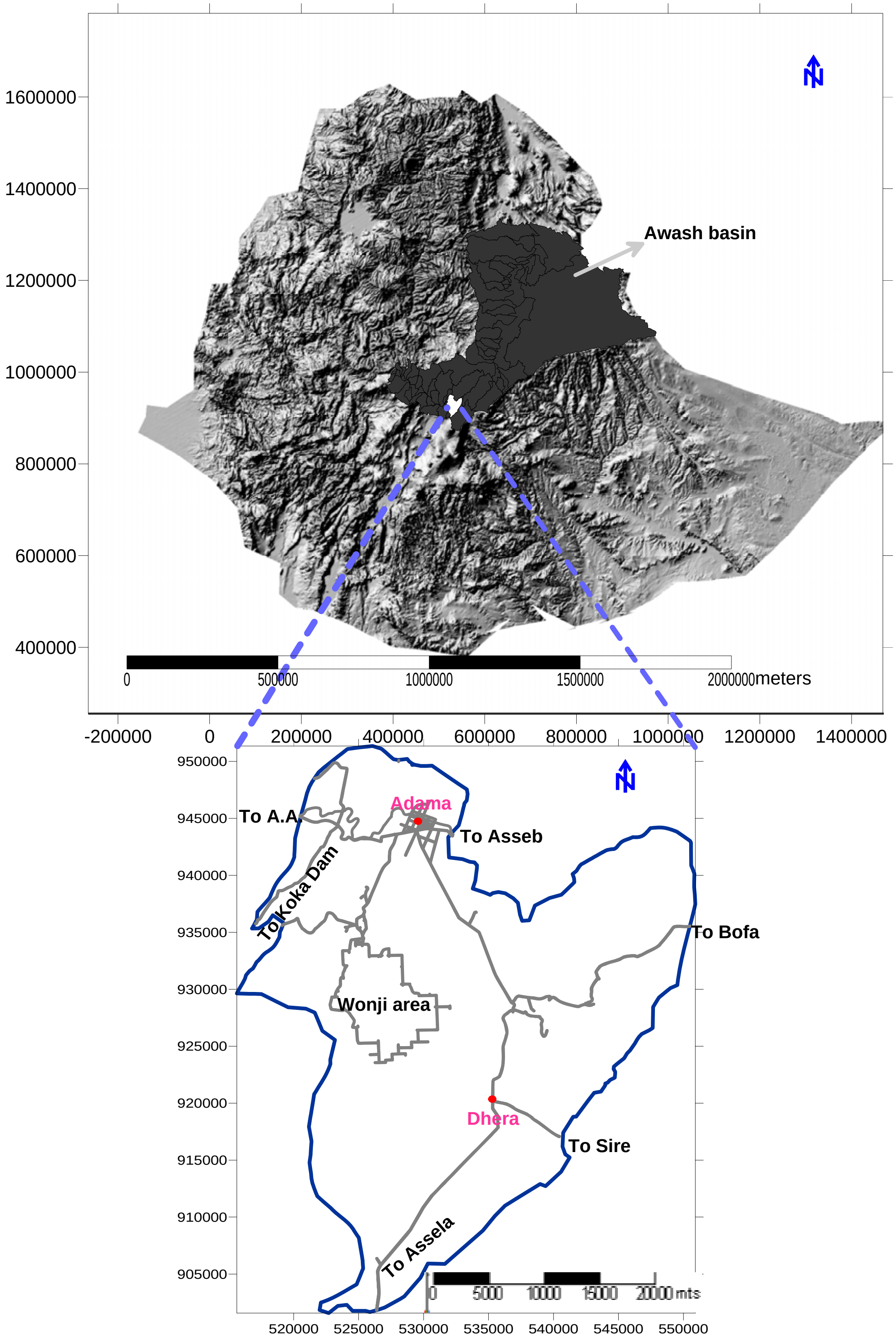


Figure 2.1 Location map of the study area

2.2 Climate

The investigated Area is characterized generally by warm climate with a mean annual temperature of 21.47 ^{0}C and mean annual rainfall of 806.9 mm. Climatic variations are a function of largely land surface altitude.The climate is marked by long dry period and short duration of precipitation from June to September. As a result it can be considered as semi-arid to semi-humid climatic zone which mainly marks the altitude range between 1300 to 1900 m a.s.l. and annual rain fall between 700 to 1000mm (Axumawite, 1984). Semi-arid to Semi-humid classification is made on the bases of the elevation above mean sea level of the areas. Precipitation in the area has strong seasonal and elevation variability. Metrological data are used as a basis for the study of climatological elements, and hence are among the main tools for the investigation of water resources.

In general, mean minimum and maximum temperature of the study area is about 13.99c^o and 28.94c ^{o} respectively. The mean relative humidity of the area is calculated to be 54.4% with an average wind speed at 2m heights above the ground surface of 5.55m/s.

The relative humidity for Nazereth, Wonji & Awash Melkasa is 51.23, 59.2 & 52.71% respectively.

Since the study area is found within the central part of the MER floor, the annual PET and AET exceeds the mean annual rainfall.

2.3 Physiography of the study area

The physiography is an expression of the underlying geology with the Ethiopian plateau underlain by Tertiary volcanics (basalt tuffs, younger rhyolites, trachytes, agglomerates, tuffs and ignimbrites) and the Rift Valley floor comprising basalts and ignimbrites near active volcanic centers in between thick, Quaternery-aged lacustrine, fluvial and beach sediments. The topography of the study area ranges with elevations generally between 1,341m to 2,300 m. Land drops steeply from the plateau to the Rift Valley floor, which slopes in a North- Easterly direction.

The study area has generally rugged terrain with deeply cut and dissected morphology with undulating topography and flat plain with variable slopes. The present physiography of the area is mainly the result of volcano-tectonic activities that occurred in the past and depression of mainly fluvial and lacustrine origin sediments. Therefore, the main morphology of the area are fault scarps, fault controlled grabens which are often covered with sediments, horsts, volcanic domes and cones (which are mostly elongated in the NNE direction).

The Wonji Fault Belt (Mohr, 1960) that has generally NNE-SSW oriented faults also forms minor graben and horsts. Their discontinuity in the study area might be due to the back fill of sediments in the depressions and denudation by the Awash River. Elevation of the study area varies from around 1,341m a.s.l.in Sodere area to more than 2,300m a.s.l on the South-East part of the area around Eteya volcanic masses.There is a significant elevation variation between many other ridges, scarps, domes and cones above the flat plain.. The area is drained by a number of different sized intermittent streams and gullies which usually start from the sides of the elevated scarps, ridges and domes. Their drainage patterns are generally parallel and rectangular due to the

NNE-SSW oriented faulting. They start initially as rills and gullies on elevated areas and gradually join the low lying main streams that finally feed Awash River.

The two main seasonal streams in the western part of the area that mark the high elevated west escarpment of Nazareth are Luma and Jogo. Luma stream joins the main Awash River at Luto (west of Melka Hida) whereas Jogo joins the koka Lake at Adada (NW of the Koka Dam). Both of them have deep gully cut and their water courses are suspected to be a continuation of Wonji faults. On the south eastern side of the area there are also two another main seasonal streams which are called Kobo and Fechiso Streams that join Awash River around sodere and Bedicha areas respectively. Awash River is the only perennial river in the study area. Estuaries and Levees, which are features of floodplain of Awash River, exist up streams of Awash Melkasa reservoir.

The main (relatively wider) and smaller intermittent streams and gullies are characterized by deep v-shaped valleys and sometimes have nearly vertical walls especially in places of soft sediments.
In general, the western, southeastern and northern (Mermersa seasonal stream) parts of the area contain relatively well developed drainage pattern. The main reason of a wide channel of Awash River at the down stream of Koka dam is that the erosional flow velocity of the river highly reduced due to the presence of this dam. As a result Awash River elevation around the Wonji area is higher.
During heavy storms almost total runoff from the North highland part of the Nazareth drain into the western sub-catchment of the town and passes through the only outlet of an artificially developed drainage way that finally feed Awash River.
In the study area there are also areas free from seasonal streams such as around Dera town and its surroundings, North of Sodere Area, Wonji shoa, Awash Melkasa area and soon.

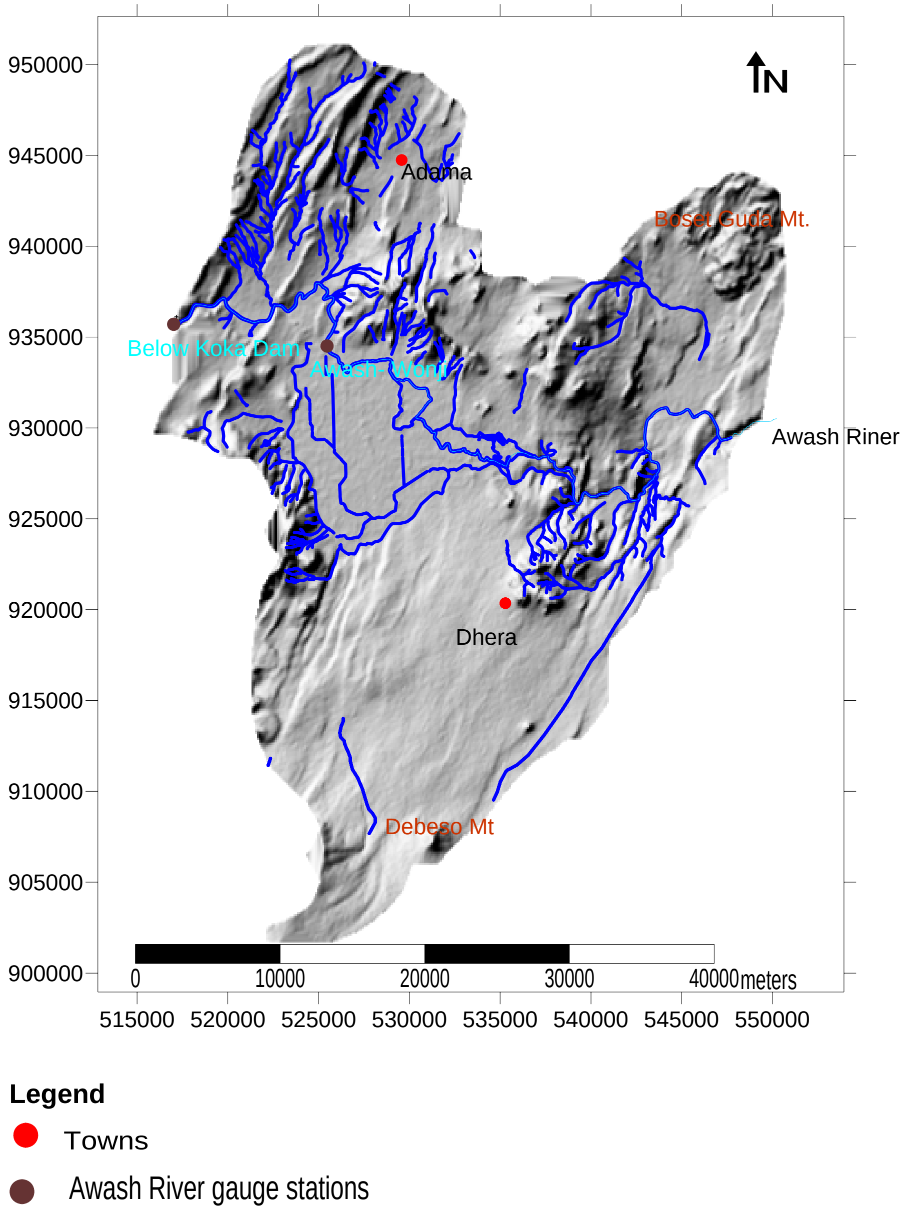


Figure2.2 Drainage pattern of the study area plotted on a shaded relief map.

2.4 Land use and Land cover

Land is basic agricultural resource in which our society depends largely upon for the production of food, clothing and also for energy and housing requirements. In the study area the land use and land covers are controlled by the topography of the area.

2.4.1 Land use

Most of the study area is generally used for agriculture (cultivated with perennial and annual crops), residence, Industrial and grazing land. Wonji shoa irrigated land is under perennial crop cover dominated by sugar cane plantation and uses high amount of water from Awash River during dry season of the year. The Horticultural Development Corporation (HDC) runs several farms along Awash River in the upper valley. Almost all farm use fertilizers with different types vary some what from farm to farm. On many farms the main fertilizer product applied is urea (46%N). Phosphate in the form of triple super phosphate (approximately 18%P) and di ammonium phosphate (approximately 21%N and (23%P) is applied on most crops in the upper valley, excepting sugar cane. Insecticides & fungicides are applied to most crops (Halcrow, 1989).

2.4.2 Land Covers

The main forms of land cover in the study area are bare land and vegetation cover. As a result of uncontrolled deforestation over the past decades and the attendant soil erosion, the land cover of the area has been heavily degraded.

2.4.2.1 Bare Land

The study area is characterized by some bare land (exposed soil/rock) which is mainly un-utilizable land such as very steep escarpments and cliffs.

2.4.2.2 Vegetation Cover

The natural forest resource is very minimum and characterized by scarcely distributed acacia and scattered shrub trees. Eucalyptus and Junipers types of plants occur in very few places and isolated ever green trees (shola) and the riveriane types of vegetation are dominant along the course of the Awash River in the study area.

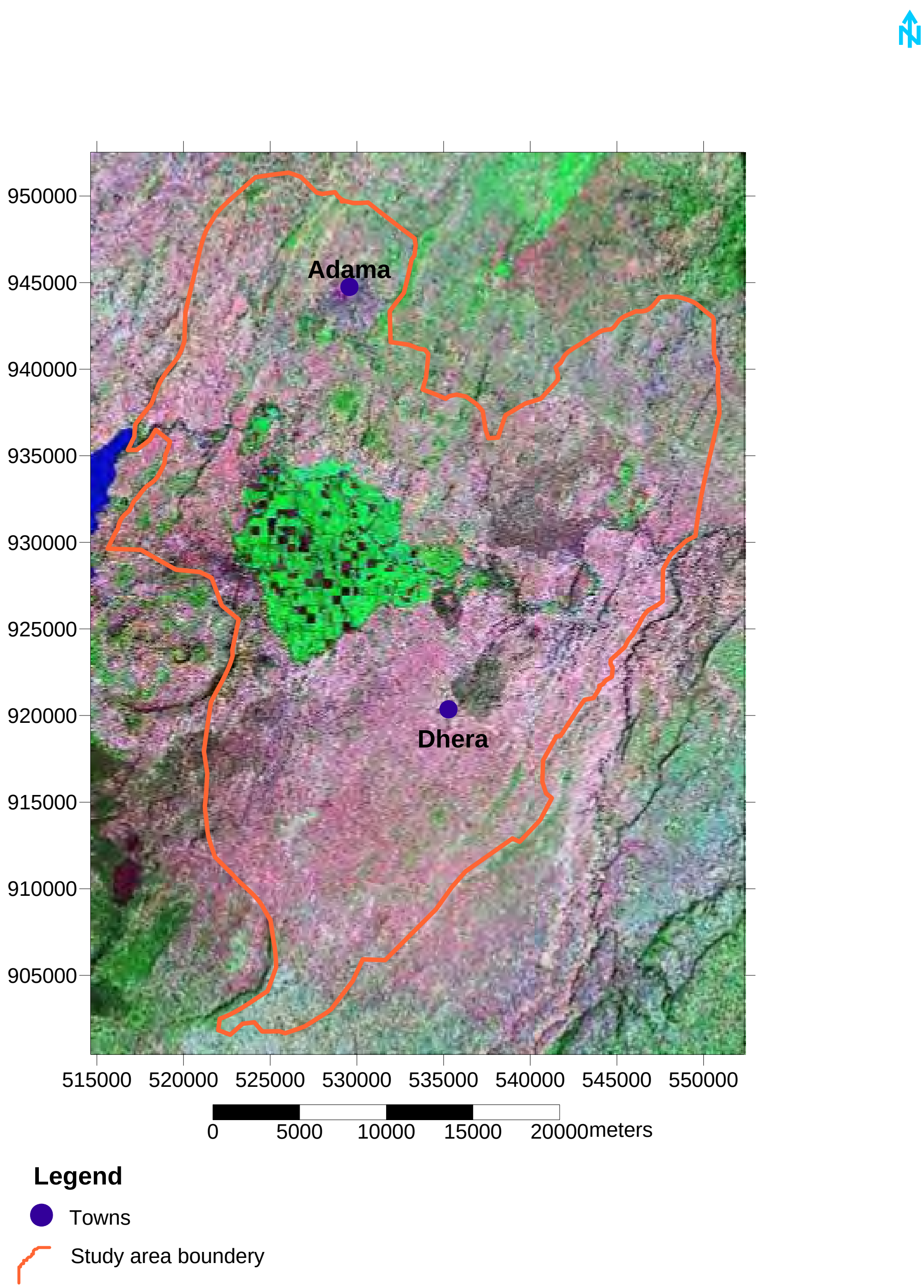


Figure 2.3 Satelite image of the study area (inside the boundery).

2.5 Geomorphology of the study area

Geomorphology is a natural or Earth Science and its focus is on the study of the processes of production, movement and storage of sediment within the landscape and on the characterization of the features these processes produce. Nazareth–Dera area is characterized by different land forms and associated geomorphic units.

The primary processes responsible for driving geomorphological change in the area are rain splash, gullying and wind erosion. According to Halcrow, 1989 erosion resulting from rain splash and overland flow is the primary cause of sheet erosion; also the significance of wind erosion is noted for drier areas of the Awash basin.

In general the study area consist the following landscapes and land forms:

- High plateau volcanic lands,
- High to mountainous relief hills volcanic lands,
- Plains and low plateau with hills, moderately dissected side slopes and plains residual land forms,
- Moderate to high relief hills and severely dissected side slopes and plateau structural land forms,
- Plains occupied by alluvial and lacustrine deposits and undulating side slopes of residual land forms.

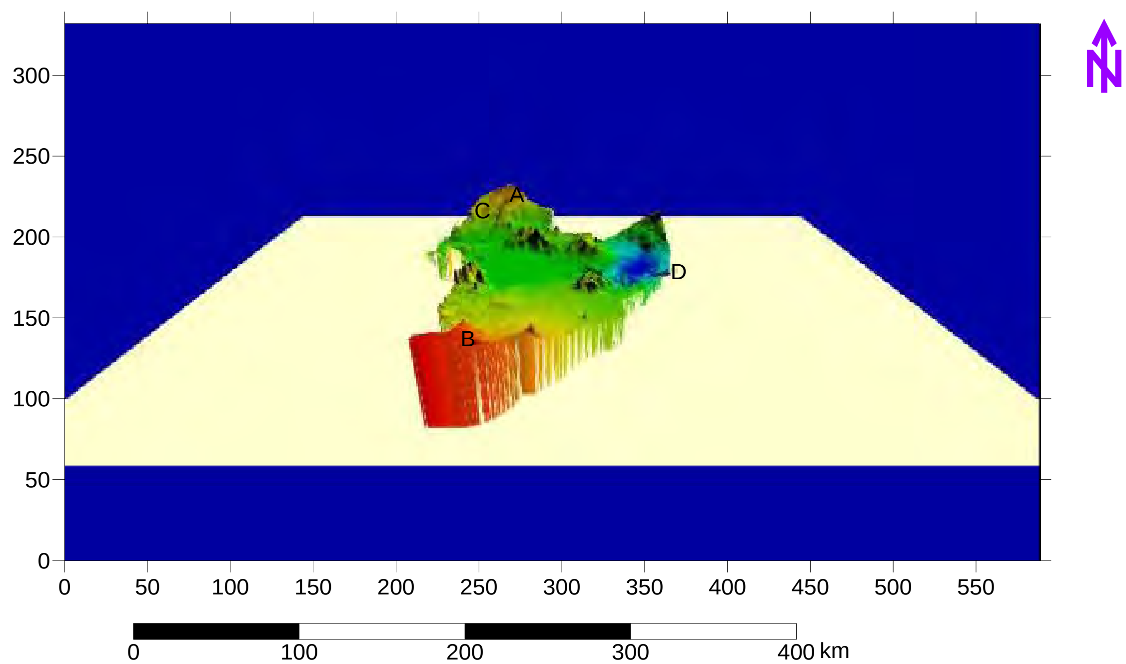
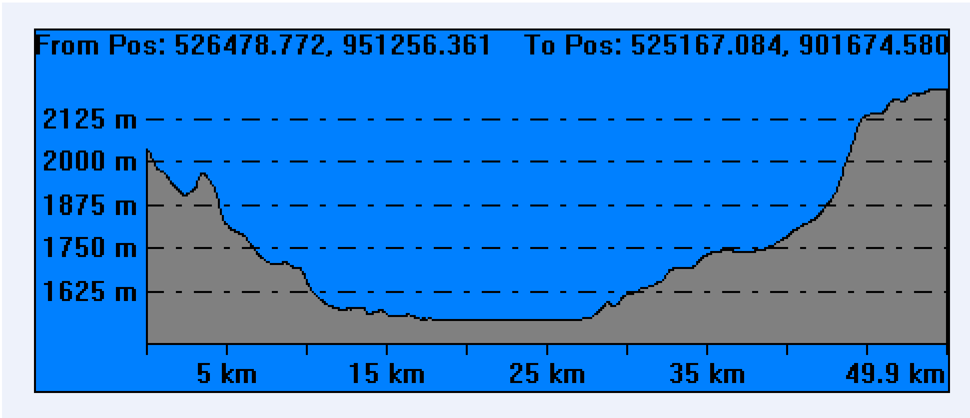
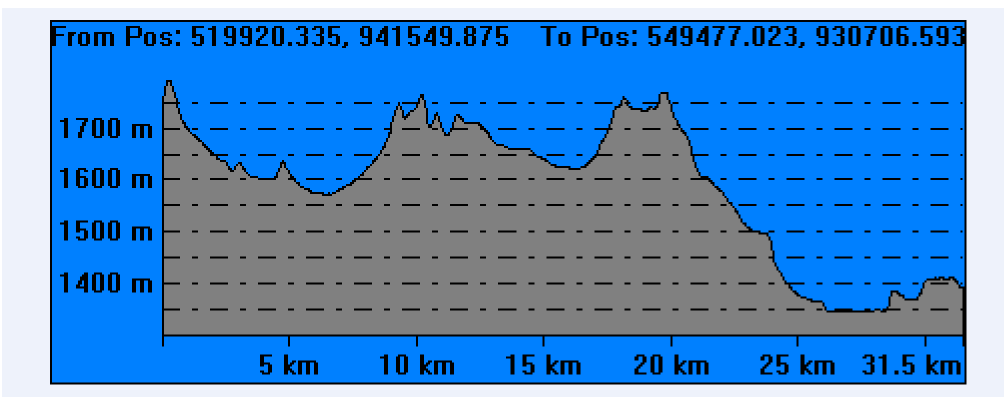


Figure2.4 Digital Elevation Model of the study area



a) Cross sections of the study area along the line A-B on the DEM



b) Cross sections of the study area along the line C-D on the DEM

Figure2.5 (a and b) Cross sections of the study area on the DEM

Chapter Three

3 Geology

3.1 Regional Geology

The Ethiopian plateau and the Rift Valley are the main components of the Awash Basin. The dominant Ethiopian plateau rocks are Tertiary volcanics: basalt tuffs, and agglomerates of Palaeocene and Miocene age and the younger, silca- rich rhyolites, trachytes, tuffs and ignimbrites of Miocene to Pleistocene age. On the floor of the Rift Valley the volcanic rocks are mainly basalts and ignimbrites (Miocene to Pleistocene) with Holocene lavas occurring near active volcanic centers. During the Pleistocene pluvial period, very large lakes were formed on the floor of the Rift Valley and the flat plains of Wonji and Metehara. The lower Awash plains contain thick successions of lacustrine deposits. The flat floor of the Rift Valley is frequently broken by fault scarps and the effect of Pleistocene and Holocene volcanic activity.
The Ethiopian Rift system, which is a segment of the east African Rift system, is a structure of great interest to understand the early stages of ocean-basin evolution. It may be sub-divided in to two main segments. These are: The Main Ethiopian Rift (MER), and the Afar. The Main Ethiopian Rift again sub-divided in to three segments (Southern, Central and Northern).

According to many authors (Di Paola, 1972; Mohr 1986; and others) this Rift is the result of tensional movements which affected the uplifted Ethio-Somalia plateau. A large number of step faults produced a total difference in altitude of more than 1000m between the top of the plateau and the floor of the rift. Almost all of these faults are normal faults (Di Paola, 1972). The MER is a symmetrical graben with uplifted flanks and steep border faults (Gidey WoldGabriel, 1990).This structural depression with an average width of 80km where the study area found is a low-lying region separating two remarkable plateaus namely the north western Ethiopian plateau and the south Eastern Somalian plateau. These plateaus are composed of extremely folded and foliated basement of Precambrian age overlain by sub-horizontal Mesozoic transgressive and regressive sedimentary strata separated by a marked Paleozoic unconformity, and covered by Tertiary volcanics.

The WFB extends from south of Lake Chamo in southern Ethiopia to the Lake Abhe area in Central Afar where it abruptly terminates at Tendaho Graben.

Two main tectonic events have been recognized concerning the tectonic evolution of the Ehiopian Rift System. The first event involved the uplift of the Ethiopian swell which started since Eocene as part of the Afro-Arabian swell (Mohr, 1967). The second major tectonic events took place across the swell to form the Afar and the Ethiopian Rift of large scale faulting to form the eastern and western margins of the rift. The eastern marign is morphologically well expressed as compared to the western one, which at places is so sub-dued that the boundary between the rift floor and the plateau is hard to define. According to Kazmin and Seifemichael, 1978, the initiation of the Ethiopian Rift and the Afar can be traced to 14 MY ago. Other authors suggest an early Miocene for the Rifts (Barberi et al., 1975, and others). The last major episode of Rift Faulting resulted in the formation of the WFB which is characterized by a number of faults which shattered the rift floor in to several relatively small horst and graben structures. The faults are short, normal type and are oriented in NNE, SSW direction.

From magmatic point of view the area is characterized by the occurrence of many volcanotectonic features like calderas, composite volcanoes, spatter cones and fissures which gave rise to huge volumes of ignimbrites and sub-ordinate basaltic lava flows ranging in age from 5 to 0.06my (Morbidelli et al.,1975;Morton et al., 1979; Bigazzi et al., 1981).
Meyer et al., (1975) distinguished two main volcanic units in the northern part of the rift system. These volcanic units include an older Nazareth group with age of 5-2my and a younger Wonji group with Pleistocene-Holocene age. The two units are divided by a Nazareth faulting phase which came in to activity 1.6 to 1.8my ago.

The Nazareth series composed of a thick succession of ignimbrites, rhyolites, trachytes and pumice form the larger part of the rift floor and also outcrop in the rift escarpments and on the adjacent plateau margins. In the region of Nazareth, the succession, according to the authors, consist of light rhyolites and ignimbrites. Light pumice on top of Nazareth series has in some places greater thickness than normal because it accumulated in previously formed basins and grabens. Beds of tuff and yellow loam alternate in the pumice breccias. Eruptions of this phase are considered to be mainly through fissures and vents, but local centers also occur.

From tectonic point of view, in the first phase during the deposition of stratoid Nazareth series a tensional stress caused the tectonic pattern within the MER, with fractures, fissures and dykes running NE-SW and NNE-SSW. The tectonic activity came to an end with the Nazareth faulting phase. The pattern can be referred to as a tentional tectonics perpendicular to the direction of the MER.

In the second and main part of the Nazareth faulting phase a fundamental and completely different evolution began with the wonji fault belt. Mayer, et al 1975, suggested the name the wonji series for the volcanic related to the belt. As pointed out by many authors (Mohr, 1967, and others, Mayer et al 1975, Gibson 1970, Dakin and Gibson 1971) the latest volcanism in the Ethiopian Rift is related to its axial extensional zone, the wonji fault belt. The bulk of the Pleistocene to recent volcanism is undoubtedly controlled by this tectonic feature even though some eruptions of basalts and central volcanoes occur out side the belt.

The wonji group includes all the rift volcanic formed after the last major episode of rift faulting. Groups of fractures, open fissures and dykes show a north-northeast, south-southwest and north-south direction. The north-northeast direction of the WFR is oblique to the direction of the MER and makes an angle of 10-25.

3.2 Stratigraphy

The stratigraphic sequence of the various volcanic products in the northern part of the MER and adjacent plateaus which have been emplaced since Eocene to recent has been reconstructed by Di Paola, 1972, as depicted in Table: 3.3:
Absolute age determinations of some of the rock units outcropping in the vicinity of the study area (Table: 3.4) are reported by Morton et al (1979) and Bigazzi et al (1981).

According to Morton et al (1979) there is an overall southeastern dip of volcanic units at the latitude of Addis Ababa where disconnected older volcanic rocks outcrop and this gentle down warping is not associated with faulting (major escarpment) leaving a gap in the line of western margin. At this latitude absolute age determination of volcanic rock units from different localities show younging trend towards the rift. The age range of the rocks in the vicinity of the study area is from Pliocene to Holocene.

A summery of the youngest phase of volcano tectonic development within the study area is given by Bigazzi et al (1980).He stated that the collapse of Gedemsa caldera is younger than 0.2my and the post caldera perlites and pumice inside Gedemsa were erupted between 0.2 and 0.1my.The ages, he presumed, of the great number of faults which affect these products are younger than 0.1my and the aphyric hawiites and mildly alkali-basaltic flows and spatter cones have age of 0.06my.

The general volcano tectonic history of the northern part of the MER has been reviewed and summarized by Mohr (1986) as follows:

1	0.0 – 0.25 million years	Wonji fault belt
2	0.9 – 1.00 million years	Eastern margin faulting & plateau uplift
3	1.5 – 1.80 million years	Margin and floor faulting
4	3.5 – 5.00 million years	Faulting and massive silicic eruptions especially in the north
5	7.0-10.0 million years	Faulting and fissure basalt extrusion
6	13.5 – 15.0 million years	Warping and initial faulting of northern rift marigin
7	18.0 – 21.0 million years	Broad crustal down warping and fissure basalt in northern part of the rift, local rifting developed in the south.

Table 3.1 The general volcano-tectonic history of the northern part of the MER

According to Giday Woldegabriel (1987) from magmatological point of view: (Table 3.2)

1	1.6 million years	Biomodal volcanism has become virtually rift bound.
2	1.6 – 3 million years	Trachytic shield volcanoes & ranges confined to the rift shoulders.
3	3 – 4.2 million years	Widespread crystal rich ignimbrite
4	8 – 11 million years	Biomodal & confined close to the present day rift & its marigins.
5	12 – 17 million years	Intermediate to felsic rocks.
6	26 – 32 million years	Thick (500m) widespread basalt.

Table3.2 Magmatological episode history

Besides, he states that each volcanic episode was accompanied by faulting and down warping. Fluvial sediments of the first and second episodes imply that embryonic down warping preceded rifting.

Finally the tectonic of the rift system is analyzed by Bocaletti et. al. (1998) and states that strike-slip tectonics has played a major role in the development of the rift and oblique extension along major northeast-southwest trending strike-slip faults is responsible for the upwelling and differentiation of most of the acidic volcanic products known to occur, whereas basaltic lava flows and associated volcano tectonic features are derived from a development of north-south trending extensional features. The authors conclude that strike-slip system play a major role in the development and evolution of the post ignimbritic tectonic history of the MER while it is a possibility that this mode of deformation might have also been important for the earlier tectonic phases.

1	Age	Stratigraphy
2	Recent to Pleistocene	Alluvium, lacustrine deposit
3	Holocene	Recent alkaline and peralkaline ryolites, pumice, Ashes and obsidian lava flow
4	Recent to pleocene	Alkali trachytes lava flows and domes
5	Recent to Pleistocene	Recent basaltic lava flows and spatter cones
6	Recent to Pleistocene	Basaltic hyaloclastites
7	Early Pleistocene to late Pliocene	Old alkaline and peralkaline rhyolites lava flows And domes associated with pumices and ashes.
8	Pliocene	Alkaline and peralkaline ignimbrite associated to Pumice,ashes and lahars.
9	Pliocene to early Eocene	Tertiary basalts and ignimbrites of the plateau trapp Series.

Table 3.3 Summery of age and Stratigraphy of volcanic products outcropping in the northern part of the MER Di Paola (1972).

1	Age	Location
2	3.32-0.06my	Gara Mariam Tedi
3	3.11-0.06my	Gara Mariam Tedi
4	1.74-0.04my	3km south east of Tedi
5	0.51-0.03my	KImbibite horest 4km west of Adama
6	0.61-0.03my	Scarp 2km west of Adama
7	0.85-0.07my	Northern rim of Gedemsa Caldera
8	0.41-0.04my	Nagow cones ,Gedemsa Caldera
9	0.61-0.04my	Northeastern flanks Gara Boku
10	0.44-0.05my	2km south west of Bofa

Table 3.4 Absolute age determination of volcanic rocks outcropping within the area under investigation after Morton et al (1979) unless stated otherwise absolute age determinations are k/Ar.

3.3 Geology of the study area

The Geology of the study area has been mapped by Alula Damte (1992). It is covered with various types of volcanic rocks with different occurrence and ages, and lacustrine and alluvial sediments which are mainly identified between wonji and Awash melkasa Areas (Fig.3.1)
The different rock types of the area are dominantly belonging to the following groups as it has been determined by Alula Damte (1992).

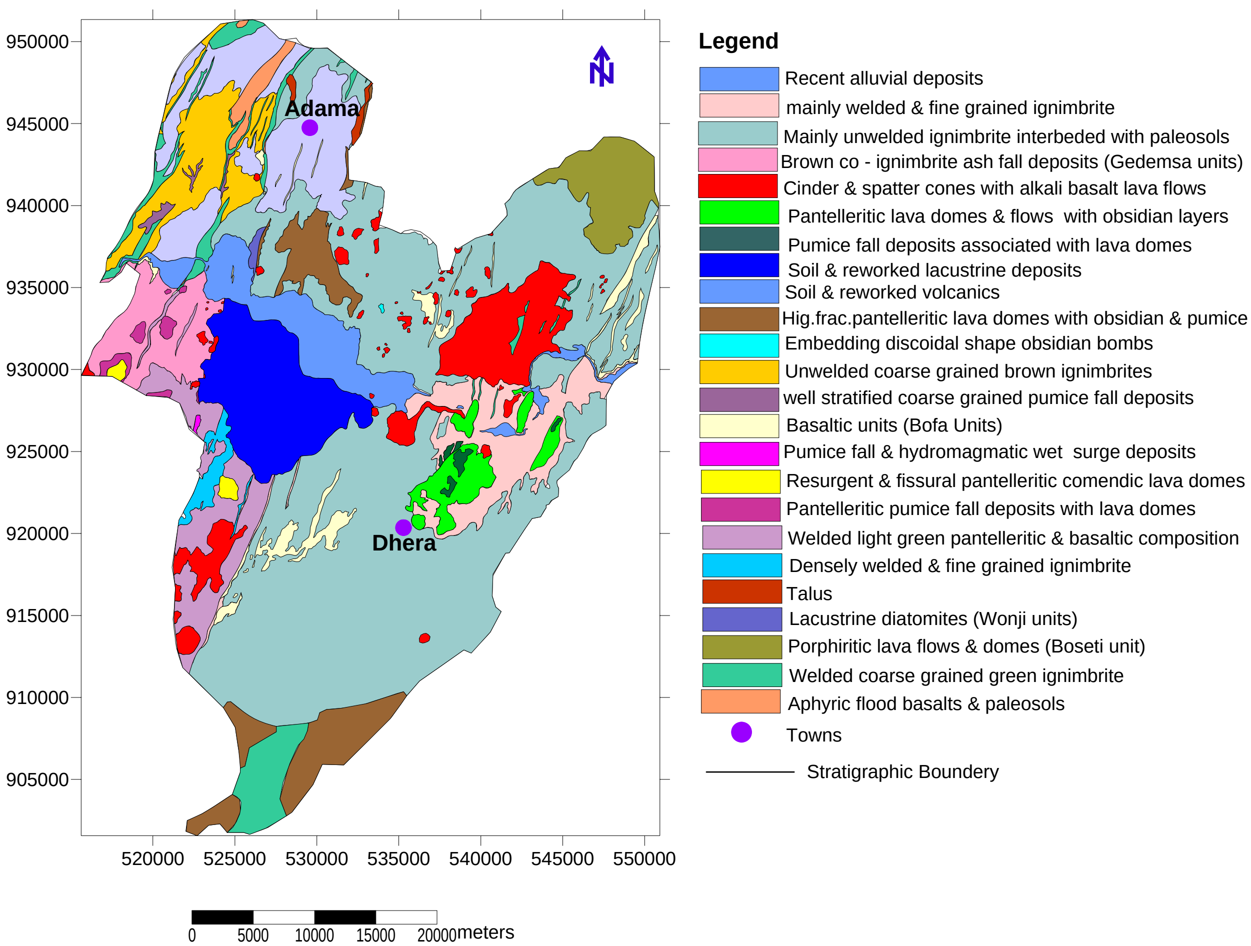


Figure 3.1 Geological map of Nazareth-Dhera area
Modified from: Alula Damte (1992).

3.3.1 Lithlogical Description

3.3.1.1 Dhera-Sodere-Nazareth group

This unit is composed of a thick succession of welded ignimbrites with fiamme pumice ashes and acidic lava flows and domes with two basaltic units one of which is interlayered between lava domes and ignimbrites.

3.3.1.1.1 Acidic lava domes and flows

It is exposed along either northeast enlongated ridges or a typical domal structure at Dera and Bodecha where as at Sodere it forms north-northeast elongated ridge. Its main part is exposed in the Dera-Sodere area. In the vicinity of Nazareth town at Dibibisa there is also a ridge that has similar orientation.
These rock units are composed of rhyolites, trachyte light in colour interlayered with dark obsidian levels. They show clear flow structures and at places are characterized by columnar joints. These rocks are generally porphritic with felsic to glassy groundmass including phenocrysts of plagioclase, quartez, pyroxene and alkli feldspar.

3.3.1.1.2 Ignimbrite

This unit mostly outcrops along north-northeast oriented fault escarpments exposed west of Nazareth (scarp west of Nazareth, Jogo and Didimitu, Germama areas). It is represented by pale green, well welded ignimbrite characterized by the occurrence of several lenses of dark glass (fiamme) ranging in size from 3 to 20cm.The thickness of the unit varies from 2 to 40m, where towards the top ,the ignimbrite becomes less welded and includes larger amount of lithic fragments.
Similar ignimbrite unit has also been found along the road to Sodere having an exposure thickness ranging from 20-25m.It is characterized by a base of gray well welded ignimbrite with “fiamme” of dark glass, while the top 1.5m is formed by an ignimbrite containing peches of glass, pumice clasts, and abundant lithics. From petrographic point of view, these rocks exhibit eutaxitic with collapsed partially crystallized pumice, crystals of quartz, pliageocase, amphibole and pyroxene and lithic fragments of basalts and trachytes.

3.3.1.1.3 Basaltic unit

This basaltic unit were also called Bofa unit by the EIGS (Kazimin et al.1980) to all the Pliocene rift floor basalts. They are flood basalts mostly subaphyric, locally vesicular and fresh with several flows separated by scoracious horizons. This unit is exposed along the scarp west of Nazareth under the ignimbrite previously described, separated by a 30cm thick red brown paleosol and one meter thick fine grained brown ash flow deposit. It is also exposed along Nazareth-Awash-Melkasa main road side around golba area. This rock is 2.5m thick, mostly fine grained, dark in colour and show flow lamination. Under thin section it presents a fine grained texture containing micro- phenocryst of plagioclase and olivine. The groundmass is formed by microcrystals of olivines, plagioclase pyroxenes and abundant opaques. The volcanic eruption and flow of this unit took place 0.4my ago (Alula Damte, 1992).

3.3.1.1.4 Aphyric flood Basalt

This type of basalt is exposed along the ridge of Kimbibit, at the base of Tedecha cone and along the ridge on the road to Sodore near the junction of Melka Woba.
These rocks are represented by vesicular dark generally fine grained basalts carrying few phenocrysts of pliageoclase.
Petrographically it presents sparsely porphyritic texture set on micro granular groundmass formed by olivine plagioclase and pyroxene. The phenocrysts are of zoned plagioclase and pyroxene only.

3.3.1.2 Keleta Group

Keleta Group is an extensive pyroclastic flow deposit which can be considered as the oldest true rift floor deposit outcropping in the study area. The type locality is located in the south east direction of study area. In the area, it is possible to subdivide the whole pyroclastic section in to a lower unit of proximal facies and an upper unit of distant facies.
The lower pyroclastic flow deposit starts with grey ash flow covered by glassy ignimbrite and a thick ignimbrite. Separating the yellow tuff unit from the underlying ignimbrite there is a 20cm thick coarse grained sandy paleosol containing chips of glass, fragments of pumice and underlying rocks. The upper pyroclastic deposit exposed on the top part of the Keleta River. It is composed of loose unconsolidated units of brown and grey ash flow deposit with intercalation of several levels of paleosols. The total thickness is approximately 10m. The ash units are fine grained and carried small pumice fragments especially in the grey ash unit; silicified fossil plants and gas escape routs characterized by fine depleted coarse lenses of pumices are present. The upper most unit of this group is represented by a fine grained brown ash flow deposit which is seen to cover large areas, including Dera domes, Awash Melkasa area and east-south of Gedemsa Caldera.
The products of the Keleta group are also well exposed at Feyiso intermitent river .Here the section starts with a yellow ignimbrite unit carrying large pumice clasts and lithic fragments followed by 8m thick brown ash flow deposit which show weak stratification and in turn overlain by 10m thick reworked volcanoclastic deposits showing a crude stratification marked by stone lines of rounded pebbles. At the top 2-3m thick well welded ignimbrite carrying large lenses of dark glass is found. The base of this unit is glassy and is separated from the underlying reworked volcanoclastic unit by a thin layer (20cm) of fine grained ash flow deposit. Petrographically the ignimbrite shows an eutaxitic texture with glass shards and collapsed pumice containing crystals of plagioclase, quartz, pyroxene and lithics of trachyitic nature. Even though the unit of this section are similar to the ones exposed at Keleta river liner correlation between them is not impossible.

3.3.1.3 Boku Group

The rocks of this group are associated with large central volcanoes and are characterized by collapsed calderas, among which the Boku Caldera occupies the southern part of Nazareth city in the MER. The volcanic eruption and emplacement of the products took place 0.8my ago (Alula Damte, 1992).The volcanic products from the Boku volcano can be grouped as alkaline and per alkaline rhyolite lava domes, flows, and pyroclastic falls, which cover the floor complex ignimbrite deposits. After the emission of these products and collapse of the Caldera, intra-Caldera products such as scoria cones with associated basaltic lava flows cover the central Caldera. The elevation of Boku ridge in the area rises from 1600m to 1875m above sea level.

The rocks of this group also outcrop near Wegillo intermittent river and the volcanic products are observed to extend as far as Jogo ridge and fill all the depressions found in the western part of the study area. These rocks are constituted by a base of acidic lava flow unit covered by a pyroclastic flow unit characterized by pumice fall deposits, ignimbrites and ash flow.

Acidic lava flows of these groups are constituted by light rhyolites having thickness which vary from 100m at Boku to 20m at Wagillo and show clear flow structures with interlayers of obsidian lava. Petrographically the rhyolites show porphyritc texture with felsic groundmass containing phenocrysts of quartz and amphibole; needle like plagioclase are also present.

Pyroclastic flow and fall of this group are exposed at Wagillo, Boku, near Nazareth city dump, at Kimbibit intermittent River and in a quarry located along the Koka-Nazareth road and Tede Mariam.

According to Tamiru Alemayehu and Vernier (1997) and Tigistu Haile, et al (2003): The elevation of Boku ridge in the area rises from 1600m to 1875m above sea level and the main lithological units identified in Boku area from older to younger are the following:

- -Rift floor Ignimbrites;
- -Slightly welded tuffs;
- -Unwelded tuffs;
- -Rhyolitic lavaflows;
- -Pumice fall deposits;
- -Obsidian flows and
- -Basaltic lava flows and scoria.

These lithologic units are not laterally continuous and show variations in thickness.

3.3.1.3.1 Rift floor Ignimbrites

The rift floor ignimbrites are the oldest outcropping unit in the area. The main outcrops are found just west of Nazareth town having elongated outcrops and bounded by faults. The ignimbrites are strongly welded and massive. The total observed thickness is about 100m with the K/Ar age of 1.7my (Alula Damte, 1992). According to the regional stratigraphy, rift floor ignimbrites are believed to be the basal rocks below the boku volcanic products.

3.3.1.3.2 Slightly welded tuffs

This unit is rich in pumice clasts and lithic fragments. The tuff has brown colour and outcrops along the eastern rim of the Boku Caldera. The unit has a thickness of about 80m.

3.3.1.3.3 Rhyolitic lava flows

The rhyolitic lava flows occur as a basal layer on the western rim of the Caldrea .This flow is grey in colour and porphyritic in texture. The outcrop is limited around the vent. This unit confines the pumice fall and the obsidian flows and forms steep slops around the rim.

3.3.1.3.4 Pumice fall deposits

Stratigraphically, the deposit covers the lower rhyolitic lava flow is areally very expensive. In the hydrothermally active areas, it is completely altered. This unit forms gentler slope even far away from the caldera with the exposed thickness of about 4.5m.

3.3.1..3.5 Obsidian flows

These flows are limited around the Caldera rim and have characterstic black colour. The flows are intensively fractured and at some places weathered to the state of perlite.

3.3.1.3.6 Unwelded tuffs

The unwelded tuffs cover the entire plain areas of the region. The unit has small amount of pumice fragments, some dark coloured rock fragments as much as 4cm in diameter and is generally dominated by ash. Since the unit is very loose, the surface runoff has formed deep gullies all over the farmlands.

3.3.1.3.7 Basalitc lava flows and Scoria

These units are the result of post caldera eruption and are localized within the Caldera. The basaltic lava flows are vesicular in texture and some of them are filled with secondary minerals. In some outcrops basaltic lava flows underlie the scoria deposits.

3.3.1.4 Gedemsa Group

These groups are related to the youngest intrarift acidic event occurring in the study area, connected with a large central volcano which later collapsed to give rise to a 7km wide caldera bounded by vertical wall of 150-200m height. The floor of Gedemsa is characterized by an E-W elongated ridge formed by several domes connected with post Caldera activity. Pumice and surge deposits are also found as products of later activity.

The stratigraphy of this group along the northern boarder starts with a base of very thick pyroclastic flow and ignimbrites followed by rhyolites and obsidian lava flows of post caldera activity capped finally by a pumice fall deposit.

Pumice fall deposit is exposed within Gedemsa, and along the Wonji road near the bridge on the Awash River. It is characterized by 20m thick grayish, very coarse grained in Gedemsa. The clasts are usually angular and contain fragments of obsidian red and green lava and levels of 2.5cm thick grey fine ash deposit.

At the bridge Awash River the fall deposit is three meter thick and show intercalation of fine grained grey ash flow deposit. The pumice clasts have smaller size as compared to the outcrop within Gedemsa.

3.3.1.5 Melkasa Group

These rocks are results of basaltic volcanic activity represented by numerous N-NE aligned spatter cones and associated lava flows. It has been established in the field that spatter cone activity began earlier than the pumiceous phase of the Boku cycle and continues up to later times. Fissural type phase of volcanism is the youngest and closely associated with the spatter cones and gave rise to the scoracious basaltic ‘aa’ type of flow. This unit is exposed along Tedecha area where it flows down the fault scarps and at places in to river channels.
Petrographically the basalt shows porphyritic texture with a microgranular groundmass with olivine and zoned Plagioclase are as phenocrysts.

3.3.1.6 Boseti Unit

This lithological unit is related to the central volcanic complex event occurring in northeast of Awash Melkasa around Tatesa area in a form of a typical domal structure. These rocks are generally porpyritic lava flows and domes of pantelleritic composition. Its glass groundmass is texturally perlitic and marked by flow structures.
The total observed thickness is up to 180m with the K/Ar age of 0.8my (Alula Damte, 1992).The origin of these flows is believed to be fissural eruptions.

3.3.1.7 Wonji Unit /Cinder cones and spatter cones with associated basaltic flows

These are the youngest units in the area which are associated with basaltic lavas erupted through a number of emission centers. These cones mainly occurs SE and SW (around Wonji) of Nazareth town. There are only two cones west of Nazareth (At Aroge Adama and Tede). Starting from north of Gedemsa rim and Dhera, these cones show north-northeast alignment along young fissures commonly known as the Wonji Fault Belt (Mohr, 1960).The main component of these volcanic centers are rhyolites, trachytes, obsidian, and recent fissural basalts (Teshome Dechasa, 1999).

The basaltic lavas contain small quantity of phenocryst composed of olivine and plagioclase. As it has been noted by Bigazzi et al (1981) the age of these spatter and Cinder cones could be younger than 0.06my.
The age of the lacustrine rift sediments is contemporaneous with the Wonji volcanics.They are mainly of volcano clastic sediments and tuffs with silts, clays and diatomites, Silts and clays are the dominant once.

3.3.1.8 Lacustrine Deposit

Extensive and thick lacustrine sediments occupy the Area between Wonji and Awash Melkasa .These lacutrine deposits are consists of clay, silt, fairly welded travertine, ashes, diatomite with intercalation of pumice and are compact.

From obtained data of shallow boreholes these surfacial sedimentary deposits has a maximum thickness of 90m at Wonji. They cover mainly the central main Wonji floodplain, and some low-lying flat land in the north. As it has been explained from drilling data these deposits lay directly on ignimbrite and scoria. Away from Wonji plain this unit has variable thickness of 6-25m. At Melka Hida it has a maximum thickness of 25m overlying tuffs, ignimbrite and volcanic ash.

Lacustrine deposit is mainly fine to medium grained. Lenses of fine sands are common within the thick layer of lacustrine deposit. This unit of Wonji area is lake deposits in small graben within Wonji faults. According to Di Paola (1972) lacustrine deposit is believed to be deposited in the lake during Holocene time. These formations are not disturbed by tectonic and as they have not been subjected to long periods of sub aerial denudation and show a vast and relatively flat land surface.

3.3.1..9 Soil and Reworked Volcanics

These units occupy the whole central part of Nazareth and west of Nazareth. Coarse grains are contained as reworked volcanic material of different size. They excludes recent lacustrine, alluvial, and colluvial sediments which represent the only volcanic deposits in the study area.
These units developed from the weathering of the volcanic rocks. The type and development of soil within the study area is a function of the nature of volcanic rocks, the climate to which it is subjected, and the time of sub aerial exposure, determine the degree of weathering and the rainfall intensity.

3.3.110 Talus

Talus is the term that used for rock fragments which are usually coarse and angular and lying at the base of a cliff or steep slope from which they are derived ; also the mass of such broken rock which is considered as a unit.
Talus occupies the area at the flanks of Dibibisa ridge which is east of Nazareth and at the escarp of northwest of Nazareth.

3.3.1.11 Recent Alluvial Deposits

These lithological units occupy both nearby sides along the course of Awash River. At Melka Hida it has a maximum thickness of 25m overlying tuffs, ignimbrite and volcanic ash. Away from Wonji plain thickness of this unit shows variation from 6-25m.The grain size ranges from clay to silt to gravel, sometimes to cobble, where gravel dominates at the bottom of river channels. They are mainly medium grained in the floodplain of Awash.
The alluvial deposits in the central awash plain of the study area were accumulated as a result of the erosion of the surrounding uplifted areas. They are unconsolidated material consisting of sand, silt and clay beds with brown color. Fine ash material is interbeded with the alluvium at places in the central Awash River plain. The thickness of this deposit varies considerably from place to place.

3.3.2 Structures and Volcano-tectonic History

Tectonic activity is mainly restricted to Afar and its southern Rift Valley extension. In fact, about 95% of the Awash Basin is congruent with the Afar triangle (the Afar is situated where three important tectonic structures, the Red Sea, the Gulf of Aden and the East African Rift system come together in a triple junction) and its extension in to the Main Ethiopian Rift.

The study area is located in the northern part of the MER and the main geological structures that have been observed in the area include faults, joints, fissures, fractures and other mesostructures like flow layering and folding associated with silicic lavas. In the region a clear feature of lineaments are demonstrated by pantelleritic volcanic cones and domes. Mostly joints in the study area are of columnar type particularly associated with welded ignimbrites. Few of these joints are filled by secondary materials such as clay, calcite and fragmented rocks at places.

The Wonji Fault Belt which makes the axial portion of MER has a significance implication in the study area. It is characterized by a number of minor and major normal types of faults running almost parallel to each other in a NNE-SSW direction and is usually arranged in the form of an "en echelon" feature, commonly in a right stepping manner. These faults are commonly associated with volcanic activities and in general younger in the central part and get older towards the rift margins. They form steps and local graben-horst structures and dissect almost all litho logic units outcropping in the area and recent volcanism has been observed to be associated with these faults. Some faults are reported to be presently buried under the lacustrine sediments (Skutan et.al., 1992).

The faults of the floor which are part of the Wonji Fault Belt (Mohr,1960), form several tectonic depressions like the ones found in the area of Boku, Wagillo, Dera, Eastern side of Koka and at Gedemsa. They show throws ranging from 5 to 60m and are characterized by a nicely developed escarpment. In general the area under investigation is affected by several tectonic and volcano-tectonic features such as partly destructed (Boku, Wagillo area) and completely preserved Calderas (Gedemsa), other volcano-tectonic collapse structures like Jogo, elongated rhyolitic domes include Sodere, Dibibisa, Tede mariam, and aligned spatter cones.

Well developed fault system is present along the eastern rim of Gedemsa Caldera, just south of Wonji Sugar Plantation. The floor of the Gedemsa Caldera is dominated by several approximately east-west aligned rhyolitic domes of post caldera activity.

The basaltic spatter cones are concentrated along a north-northeast aligned belt which starts from the eastern side of Gedemsa and continues with a right "an echelon" displacement at Boku area. Some of the spatter cones have later been disrupted to give rise to fresh 'AA' type of lava flow as observed near Melkasa area.

From the volcano-tectonic history point of view of the study area, the eruption of the fiamme ignimbrite and the aphanitic basalt units almost contemporaneously occurred in the beginning. This event is probably followed by a major faulting event which mainly affected the western and southwestern parts of the area. This was likely followed by the eruption of younger acidic volcanics which most probably occurred along previously formed faults.(Dibibisa and Migira domes).The formation of the precalderal volcanics, the formation of the calderal itself and the deposition of the post calderal volcanics at Gedemsa took place at this stage. The eruption of younger scoriaceous basalts and scorias and associated flows forming spatter and cinder cones occurred earlier and contemporaneously with the deposition of lacustrine ,alluvial and colluvial sediments in the study area. The alluvial sediments represent the youngest deposition unit in the study area.

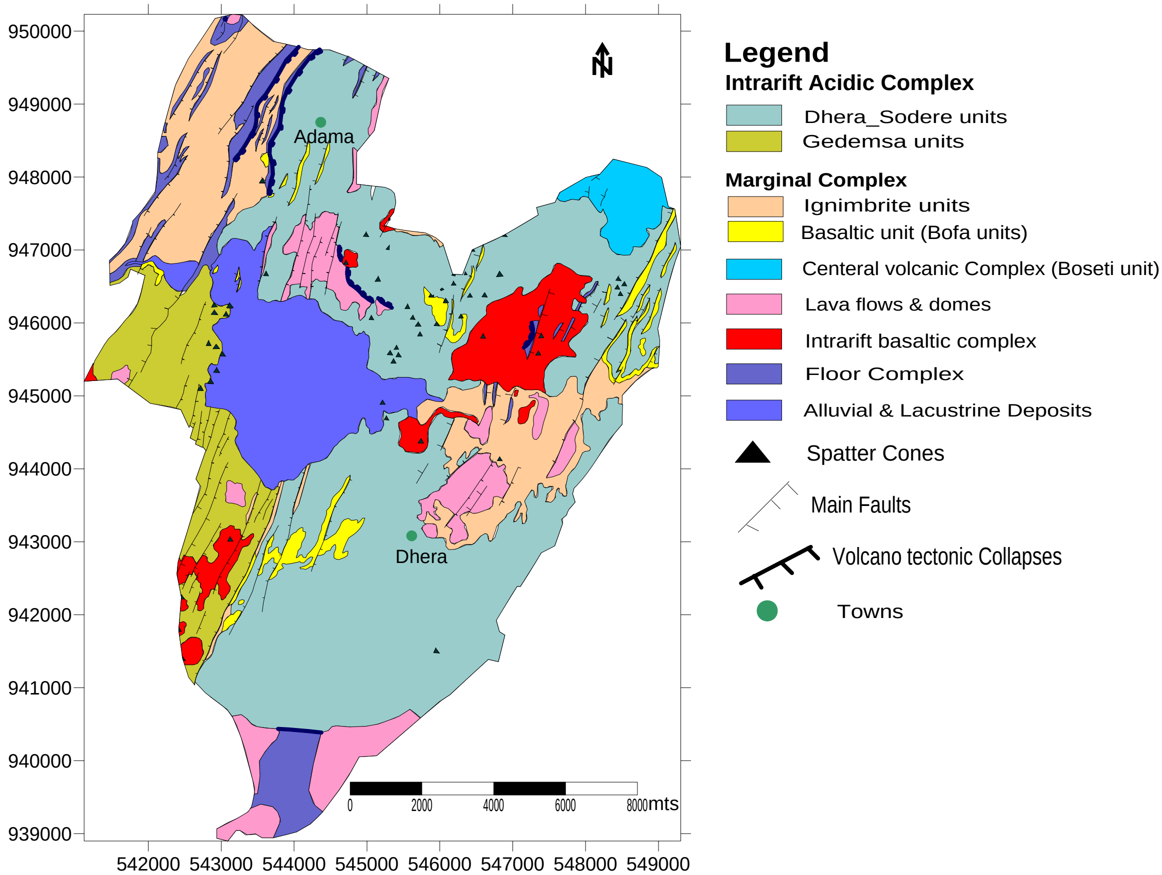


Figure 3.2 Structural map of the study area
Modified from Alula Damte (1992)

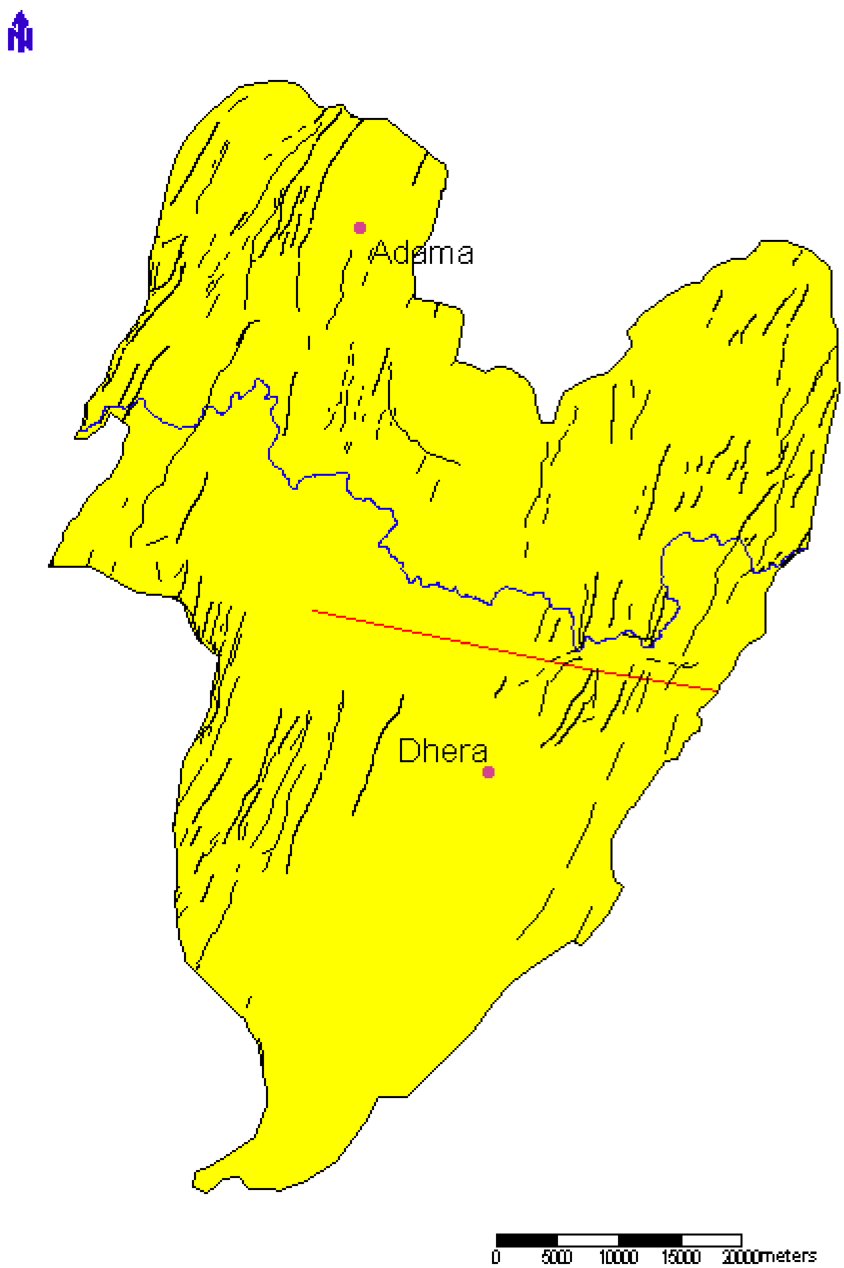


Figure3.3 A map that shows all faults within the study area

According to Bekele Abebe et al (2007) the (the red line) represents transverse fault that dip towards north and can block the flow of water from Awash River to Dera basin through sub-surface.

Chapter Four

4 Hydrometrology

4.1 General

Hydrometrology is the study of the two fundamental phases in the processes of hydrological cycle (precipitation and evaporation) within the atmosphere and at the earth's surface or atmosphere interface (Shaw, 1988). Hydrometrological data play an important role to solve different problems, such as forecasting of precipitation for reservoir operation and in the spill way design, for the design of dams and other structures, determination of temperature for evaluating water resource potential etc (Jayarami, 1992).
Hydrometrological data such as precipitation, temperature, wind speed, relative humidity, sunshine hours, evaporation, atmospheric pressure and radiation are the main parameters to understand the atmospheric phenomena. To analyze various hydrologic cycle components, long-term metrological data have been taken from NMSA and Awash Melkasa Agricultural Research Center for the stations distributed in & in the vicinity of the study area (Table 4.1).

No	Stations	UTME	UTMN	Altitude(m asl)	Av.annual total ppt (mm)	Recording year
1	Nazareth	531182	945047	1648	883.3	1996_2005
2	Melkasa	538582	928520	1564	828	1997_2006
3	Sodere	542528	928849	1361	688.3	1998_2005
4	Koka Dam	517144	935982	1605	853.4	1995_2005
5	Wonji	523576	933844	1564	846.1	1981_1994
6	Tibila	562936	939444	1262	864.9	1965_1991
7	Alem Tena	493167	916923	1720	792.5	1987_2004
8	Modjo	513766	949621	1784	935.2	1986_2005
9	Ejere	528440	970221	2225	851.9	1985_2004
10	Welenchiti	547650	958122	1461	984.4	1985_2005
11	Sire	554108	914992	2000	867	1987_2004
12	Huruta	539070	900708	2026	900.2	1984_2001
13	Eteya	525555	898697	2196	1056.2	1987_2003
14	Dhera	535235	920625	1674	705.7	1977_1992

Table 4.1 Metrological stations in and around the study area.

Metrological stations are located in such a way that, in the vicinity of the study area there ar eight stations a within the cachement there are six stations. Of these stations, class-A metrological station which can measure all parameters currently are those of Nazareth, Koka Dam, Modjo, Huruta, and Wonji stations. The rest (class-3 and class-4) stations measure only temperature andrainfall. The rainfall data obtained from all these stations are used to estimate rainfall of the study area in thiessen and isoheytal methods. Six stations within the study area are used to analyze the rest hydrologic cycle components.

4.1.1 Temperature

Temperature records in the study area are available for all metrology stations. It is measured at six stations and the mean monthly temperature is computed as the arithmetic average of the mean daily temperature of all the days in the month. The maximum temperature of all the six stations is recorded in the month of February where as the minimum temperature recorded is during the month of December.

The temperature of water surface governs the rate at which water molecules leave from the water surface and enter to the overlying air as water vapor. Therefore it has short term effect up on the rate of evaporation.

Based on the records of the mean monthly maximum and mean minimum temperature data the monthly average maximum, average minimum and average temperatures of the study area are about 29, 14, and 21.5 C^o respectively.

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

Stations	Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Agu.	Sep.	Oct.	Nov.	Dec
Nazareth	Maximum	26.85	29	29.4	29.9	30.9	29.7	26.2	25.8	27.3	27.6	26.9	26
	Minimum	13.07	14.1	15.1	15.7	16.4	17.4	16.1	16.1	15.1	13.8	13.1	12.1
	mean	19.96	21.55	22.25	22.8	23.65	23.55	21.15	20.95	21.2	20.7	20	19.05
Koka Dam	Maximum	28.2	29	31.2	30.9	32.3	30.7	29.8	30.2	30.6	28.7	28.9	29
	Minimum	12.8	13.9	15.4	15.7	15.7	15.3	14.7	15	15.2	13.3	13	13.3
	mean	20.5	21.5	23.3	23.3	24	23	22.3	22.6	22.9	21	21	21.2
Wonji	Maximum	27	28.3	29.8	29.2	30.2	29.6	26.5	25.8	27.2	27.7	27.4	26.6
	Minimum	9.5	12.1	13.5	13.7	13.7	15.1	14.9	14.5	13.2	10	8.6	9.2
	mean	18.25	20.2	21.7	21.5	22	22.4	20.7	20.2	20.2	18.9	18	17.9
Melkasa	Maximum	27.9	30.1	30.2	30.6	31.9	30.4	26.7	26.2	27.8	28.5	28.2	27.6
	Minimum	11.5	12.1	14.6	14.7	15.1	16.10	15.4	15	11.9	12	10.1	9.8
	mean	19.7	21.1	22.4	22.7	23.5	23.3	21.1	20.6	19.9	20.3	19.2	18.7
Sodere	Maximum	30.03	30.6	31.5	32.5	33.3	32.7	31.6	30.5	30.9	32.1	30.5	29.8
	Minimum	13.5	14	15.2	16	16.9	16.9	16.9	16.5	16.4	15.5	12.2	11.8
	mean	21.8	22.3	23.4	24.3	25.1	24.8	24.3	23.5	23.7	23.8	21.4	20.8
Dhera	Maximum	26.3	27.2	28.5	28.8	29.2	29.3	26.5	16.2	26.8	27.9	26.9	26.6
	Minimum	12.3	14.2	15.2	15.3	15.1	15	14.3	14.1	14.4	13.3	11.9	12
	mean	19.3	20.7	21.9	22.1	22.2	22.2	20.4	20.2	20.6	20.6	19.4	19.3

Table 4.2 Monthly mean maximum and mean minimum temperature variability of the six stations.

station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Nazareth	19.96	21.55	22.25	22.8	23.65	23.55	21.15	21	21.2	20.7	20	19.05
Koka Dam	20.5	21.45	23.3	23.3	24	23	22.25	22.6	21.95	21	20.55	22.15
Wonji	18.25	20.2	21.7	21.5	22	22.4	20.7	20.2	20.2	18.9	18	17.9
Melkasa	19.1	21.1	22.4	22.7	23.5	23.3	21.1	20.6	19.9	20.3	19.2	18.7
Sodere	21.8	22.3	21.4	24.3	25.1	24.8	24.3	23.5	23.7	23.8	21.4	20.8
Dhera	19.3	20.7	21.9	22.1	22.2	22.2	20.4	20.2	20.6	20.6	19.4	19.3
Average	19.8	21.2	22.5	22.8	24.2	23.2	21.7	21.4	21.3	20.8	19.8	19.7

Table 4.3 Monthly mean of maximum & minimum temperature (C^o) of the six stations.

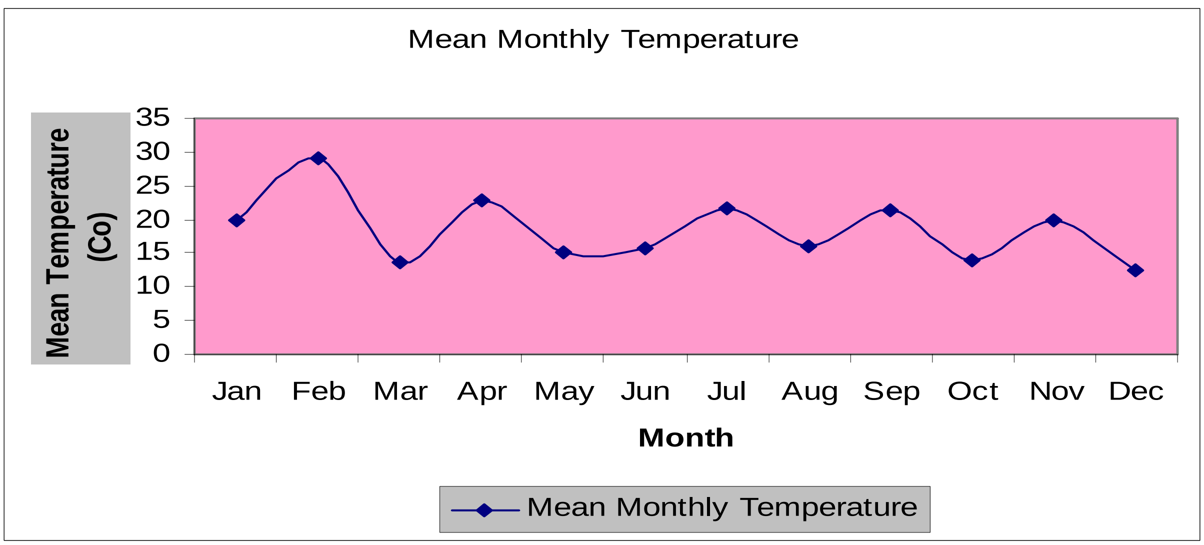


Figure 4.1 Monthly mean temperature variability of the Nazareth-Dhera area

In general, from the assessment of the available data, it can be concluded that the temperature of the study area is supposed to show the same trend except with the possibility of insignificant variation during the month of February.

4.1.2 Relative Humidity

Relative humidity is the relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature (Shaw, 1988). It varies from time to time, depending on variation in rainfall and air temperature. As Relative Humidity rises, proportionately fewer of the water vapor molecules leaving the evaporating surface can be

retained in the air, and so the total number of molecules leaving minus the total number of molecules returning is gradually reduced.
Available relative humidity data is from Nazareth, Wonji and Melkasa stations which has 13, 12, and 10 years data respectively and the average is used for the calculation. In the area the relative humidity attains its maximum and minimum values in the months of August and November respectively (Table4.4).

Location	Month											
	Jan	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep	Oct.	Nov.	Dec.
Nazareth	53.7	47.43	53.43	53.13	50.67	53.07	66.87	68.37	63.33	57.37	49.67	50.77
Wonji	54	56.63	55.9	58.1	56.6	56.2	65.52	71.8	70.53	57.77	52.5	54.83
Melkasa	51	44.4	49	48.3	47.3	51.1	64.4	68.4	64.5	51.1	45	48
Average	52.9	49.49	52.78	53.18	51.52	53.46	65.6	69.52	66.12	54.41	49.1	51.2

Table 4.4 Monthly mean relative humidity at the study area

The relative humidity of almost all the stations is more than 50% except that of Nazareth during the months of February and November, and Melkasa which is a bit less in the months of February to May and November to December. This could be due to change in wind pattern.

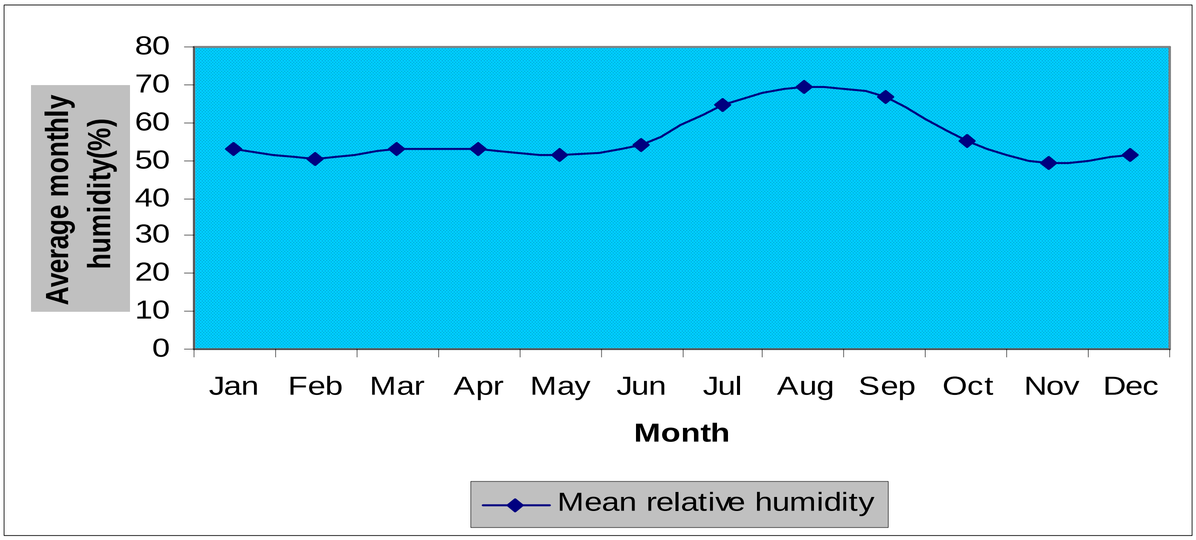


Figure 4.2 Monthly mean relative humidity of the study area

4.1.3 Wind Speed

According to the assessment of wind speed data collected by NMSA and Melkasa Agricultural Research Center at Nazareth and melkasa stations respectively, the monthly mean wind speed at Nazerth area lies in the range of 1.85 m/s to 3.17 m/s whereas at Melkasa area lies in the range of 1.8 m/s to 3.38 m/s (measured at 2m above ground level). Some sort of air movement is necessary to stir up the air and to remove the lowest moist layers in contact with the water surface and to mix them with the upper drier layers. Data on wind velocity is required in the

evaporation studies. Because most of the time the rate of evaporation is influenced to some extent by air movement. The higher the wind speed takes away the moisture in the air which facilitate evaporation if its movement is turbulent than laminar.
Wind speed varies with the height above the ground. In the study area wind speed is measured at 2 mts above the surface of the ground level. Nazareth and Melkasa are the two data source stations which are averaged and used for the calculation of potential evapotranspiration. Even though there is no wind speed data in the Year 2003 at Nazareth station, it has been considered 15 years (1990-2005) data and ten years (1997-2006) data at melkasa station.

Location	Month											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Nazareth	3.12	3.02	2.79	2.49	2.49	3.06	3.17	2.62	1.85	2.23	2.84	3.1
Melkasa	2.94	3.25	2.83	2.74	2.61	3.15	3.38	2.56	1.8	2.45	2.95	3.14
Average	3.03	3.14	2.81	2.62	2.55	3.11	3.3	2.59	1.83	2.34	2.9	3.12

Table: 4.5 Mean monthly wind speed at the study area above 2m from ground level.

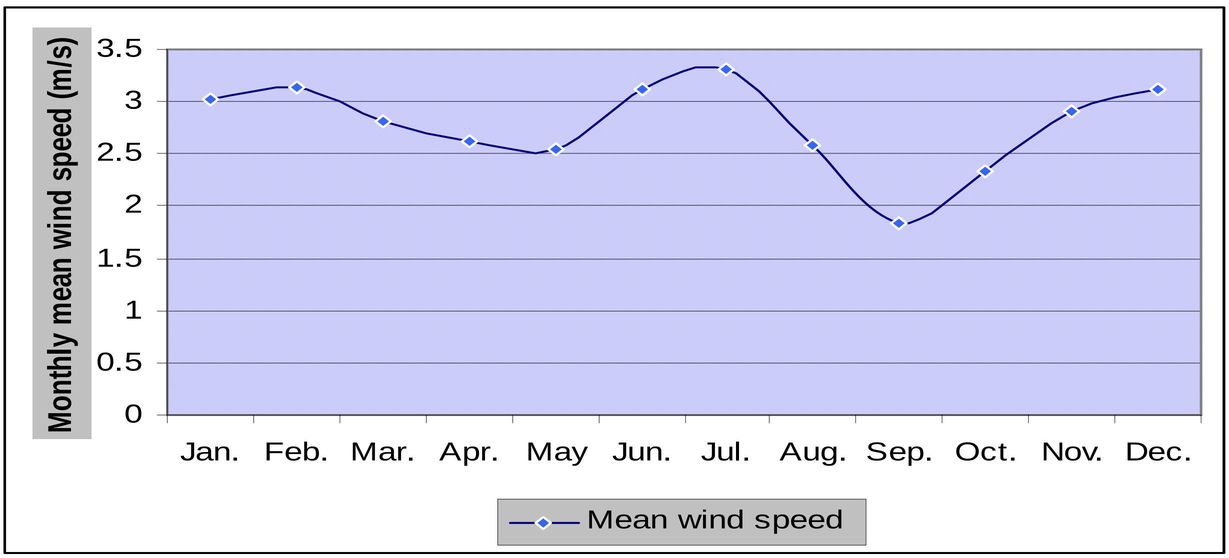


Figure4.3 Average mean wind speed (m/s) of the study area

For the sack of fast understanding the above figure shows about the distribution of the wind speed in the study area. Wind speed in the area gets its maximum and minimum value in the months of July and September respectively.

4.1.4 Sunshine hours

Sunshine hour is one of the variable characteristics among the metrological elements. It plays an important role for evaporation and has a direct relationship with it. According to the assessment and analysis result of sunshine hour data collected at Nazareth,Wonji and melkasa by NMSA and Melkasa Agricultural Research Center for the last 13,22 and 11 years respectively, the study area experiences the mean annual total sunshine hours ranging from 101.82 hours at Nazareth to 103.61 hours at Melkasa station.At Nazareth station there is no data in 1997, 2001 and 2003 years all in all (i.e. There are missing data) with in the range of 1990-2005 years sunshine data. There is no data for melkasa station in 1991 and 1992 years with in the range of 1985-2003 data. For quick visual understanding, graphs for the three stations drawn using mean monthly sunshine (hours) versus months.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
Nazreth	9.12	8.82	8.28	8.28	9.06	8.61	6.6	7.29	7.48	8.83	9.82	9.63	101.82
Melkasa	9.27	9.07	8.38	8.18	9.16	8.6	7.31	7.29	7.94	8.78	9.99	9.78	103.61
Wonji	8.85	8.49	8.43	8.41	8.89	8.58	7.16	7.05	7.55	8.80	9.64	9.31	101.16
Average	9.08	8.79	8.36	8.29	9.04	8.55	7.02	7.21	7.66	8.80	9.82	9.57	102.19

Table 4.4 Average monthly mean sunshine duration (in hour) at the study area

The area attains its minimum and maximum sunshine hours during July and November respectively.This is due to the result of cloud cover during winter and summer.

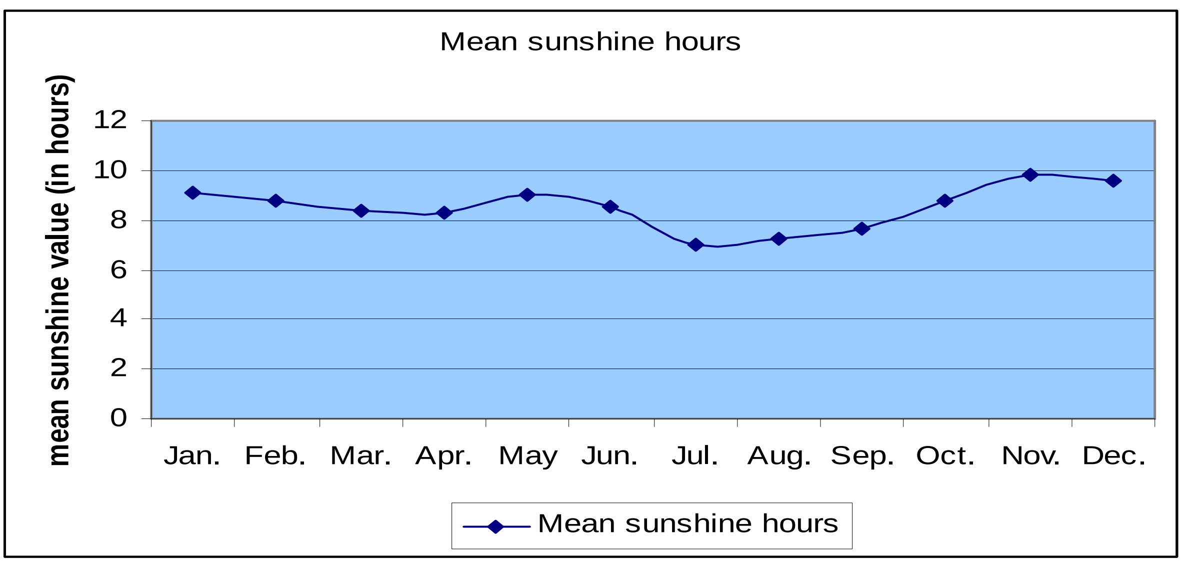


Figure 4.4 Mean sunshine hrs of the study area

In general, the monthly mean daily sunshine hours over the area for the last 13, 22 and 11 years varies in the range of 6.6 to 9.82, 7.05 to 9.64 and 7.29 to 9.99 at Nazareth, Wonji and melkasa respectively.

4.2 Hydrology

Hydrology deals with the origin, distribution & circulation of water bodies in land phases and atmosphere (K. C. Patra 2001). The hydrology of an area depends on climate, topography and its geology. Hydrometrological study is an important description of the hydrology of an area.

The major water bodies in and around the area are Awash River, Melekasa Reservoir and Koka lake, which present hydrological feature of the area. Besides, during rainy season there are numerous minor tributary rivers in the area even though all of them are intermittent streams and their contributions to Awash River discharge seems insignificant. There are a number of streams that drain at times directly in to the Awash River (Berhane Melaku, 1982). Hot and cold springs are also other water bodies present at different places in the study area.

The study area is situated on the upper part of the middle Awash River basin & Awash River (AR) travels within the study area a distance of 54km from koka dam up to the lower part of the study area.

Throughout this reach, it is gauged at two stations (Koka Dam and Wonji gauging station). Staff gauge at Wonji station is located about 10km down steam of Koka station and reading of Wonji station represents the total value of upper Wonji basin where as records at Koka station are discharge value of upper Awash basin. The data indicated that high flow occur in the rainy months of July, August and September (fig-4.2).

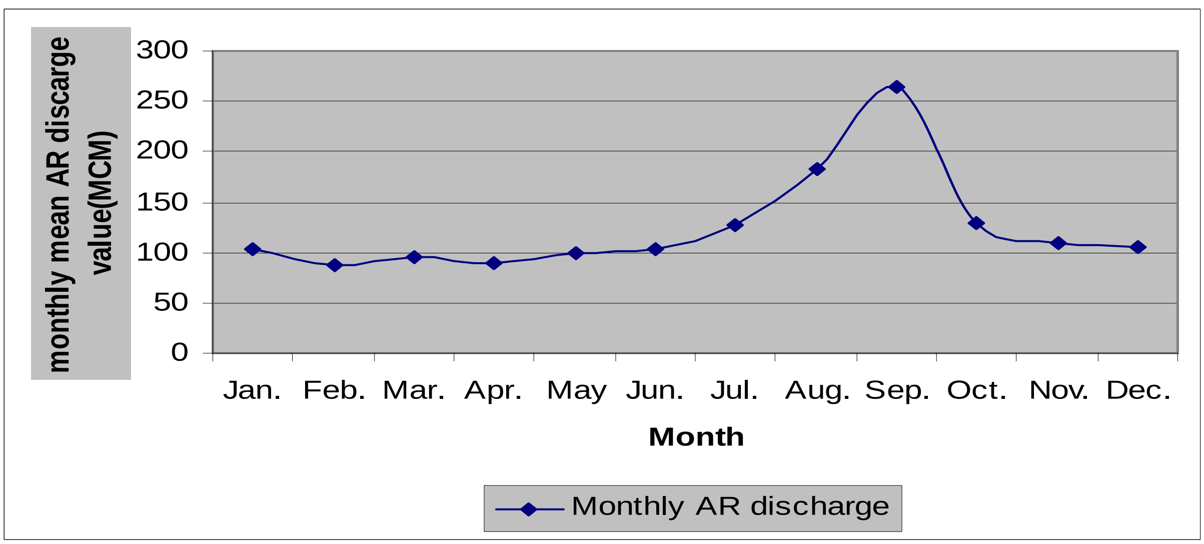


Figure 4.5 Total monthly flows (Mm^3) of Awash River at Awash-Wonji station (1983-2002)

4.2.1 Rainfall

Rainfall is the most important part of the atmospheric precipitation in the hydrologic cycle that falls on the earth surface in the form of water droplets and its amount is one of the most important factors to determine the density and distribution of vegetation. The rainfall in Ethiopia varies from less than 200mm in arid zones to 2000mm in the southwest part of the country. This is due to altitude variations over the country from about 120m below sea level in dallol depression to peaks of more than 1000m sea level. The explanation of the seasonal rainfall distribution with in the Awash River basin lies in the annual migration of the Inter Tropical convergence tone (ITCZ) across the basin. The ITCZ starts its advance across the Awash basin from the south in March, bringing the spring rains. In the month of June and July the ITCZ reaches its most northerly location beyond the basin which then experiences the heavy or summer rains thought. During September and October the ITCZ returns South wards, restoring a drier, easterly air stream which prevail until the ITCZ resumes its northward migration in March **(**HALCROW, 1988/1989). Rain fall records in the study area available from fourteen (14) stations. The study area is being part of the south eastern area of the country characterized by bi-modal rainfall pattern. According to (Tenalem and Tamiru, 2001), it is expected to receive rainfall during summer and spring with maximum rainfall is evidently experienced in summer.

To show this rainfall data were analyzed and the graphs of the total mean monthly rainfalls for the study area have been drawn .From these graphs we can see that the area has two-rainfall seasons and dry seasons. The rainy seasons include months June to September (summer), March and April (Belg). Where as, the rest months belong to dry season with small rainfall. According to the assessment of rainfall meteorology data from all stations, the study area also receives the maximum values of rainfall in July and August months. In general it can be concluded that the rainfall in the area varies from a mean annual rainfall of 699.31 mm at Sodere to a mean annual rainfall of 1056mm at Eteya station.
Therefore the distribution and amount of rainfall in the area is largely dependent on geographical position with respect to the climatologic elements and orographic factor.

4.2.2 Rainfall coefficient for Monthly Distribution of rainfall

The distribution of rain fall in year can be analyzed by rainfall coefficient method. This is explained by Daniel G. from publication on Awash River basin (UNFAO 1965) on his book entitled Aspects of climate and water Balance in Ethiopia.
- In order to have a complete understand of months of rainfall distribution, rainfall coefficient has been calculated for rainfall stations, which is a ratio between mean monthly rainfall depth and one twelfth of the mean yearly rainfall.
- It is given by the formula,

$$Rc = p_{m}/(p_{y}/12) \qquad \text{Equation 4.1}$$

Where , **Rc**= rainfall coefficient,
p_m = mean monthly rainfall depth
Py = mean yearly rainfall depth.

A month is considered to be "rainy" when the corresponding monthly rainfall coefficient reaches 0.6 and distinctly rainy when it exceeds 0.8. Extremely rainy months may have a coefficient of more than 1 (Daniel 1977).
In the area the rainfall coefficient has a variable value falling with in a range of 0.13 to 3.05.
The following table shows the rainfall coefficients for the weighted mean of precipitation of the study area. Py = 800.8 mm, Py/12 = 66.73

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
P_m(mm)	16	22.1	59	45.6	53.8	62.9	190	203.6	82.9	44.2	12.2	8.70
Rc	0.24	0.33	0.88	0.68	0.81	0.94	2.85	3.05	1.24	0.66	0.18	0.13

Table 4.5 Monthly Rainfall coefficients for the study Area

Calculated rainfall coefficient indicates that months in the water year can be classified in the area as follows.

i) **Dry months**: November, December, January and February.

ii) **Rainy months**: March, April, May, June, July, August, September and October

The following table gives a broad classification of months of a water year (after Daniel, 1977). The dry months contribute only about 7.34 % of the total mean annul rainfall to the area where as the remaining 92.66 % of the total mean annual rainfall is contributed by the rainy months .

	Dry months	Rainy months			
		Small rains	Big rains		
			Moderate concentration	Higher concentration	Very high concentration
	Rc<0.6	0.6<Rc<0.9	1<Rc<1.9	2<Rc<2.9	Rc $\geq$3
months	November	April, May	September	July	Auguest
	December	October, March			
	January	June			
	February				

Table 4.6 Classification schemes of monthly rainfall values.

4.2.3 Annual Effective aerial depth of Precipitation

In water budget studies, it is necessary to know the average depth of precipitation over a drainage basin. Based on the available rainfall data taken from 14 stations analysis should be done to obtain the effective uniform depth of precipitation for the cachement to get a more reliable & representative result. The average depth of rainfall is also known as effective uniform depth of rainfall (Jayarami, 1996).The three methods are the following to obtain the effective uniform depth of rainfall over the drainage basin:

Arithmetic mean method

Thiessen polygon method

Isoheytal method

4.2.3.1 Arithmetic mean method

If the rain gauge network is of uniform density, flat area, and the variation of individual gauge records from the mean is not too large then a simple arithmetic average of the point – rainfall data for each station is sufficient to determine the average depth of rainfall over an area (Shaw, 1988 and Jayerami, 1996). But these conditions are not fulfilled in the study area and the result obtained using arithmetic could not represent the average aerial depth of the whole study area.
It is the simplest of the three methods and the result is obtained by dividing the sum of the rainfall amounts recorded at all the rain gauge stations which are located within the area under consideration by the number of stations (Wilson 1983).

i.e:

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

Where,
P is the average depth of rainfall & P1, P2, --- Pn are the rainfalls recorded at stations 1, 2, ---etc. and n is the number of rain gauge stations within the area. Based on this method the average depth of rainfall of the area, P = 800.8 mm (Table 4.7).

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual (mm)
Nazareth	23.1	12.2	78.2	39.6	55.0	68.8	212.3	220.0	96.0	59.5	13.1	9.8	
Wonji	5.1	46.8	52	52.1	73.7	53	207	229.1	93.7	22.3	8.6	2.7	
Sodere	11.8	3.4	62	39.8	33	47.3	169.3	188.8	65.9	42.0	7.8	12.7	
Melkasa	17.3	14.4	64.1	52.5	43.7	71.2	201.2	191.6	91.4	39.6	10	11	
Koka Dam	19.6	18.3	47.5	40.1	45.8	87.6	214.5	253	71.4	55.3	8.8	5.1	
Dhera	19	37.5	50.2	49.2	71.7	49.5	135.5	139.1	78.8	46.5	24.8	10.7	
Arithm.mean	16.0	22.1	59.0	45.6	53.8	62.9	190.0	203.6	82.9	44.2	12.2	8.7	**800.8**

Table 4.7 Long terms arithmetic mean monthly depth of rainfall (mm) of the six stations in the study area.

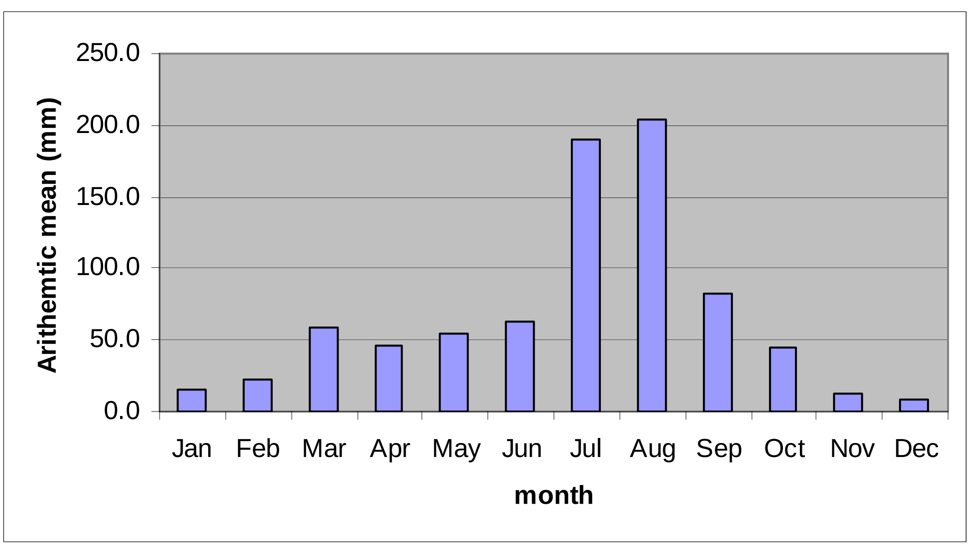


Figure 4.6 Monthly arithmetic mean depth of rainfall in the study area

4.2.3.2 Thiessen polygon method

This method attempts to adjust for nonuniform gauge distribution by weighing the record of each gauge in proportion to the area which is closer to that gauge than to any other gauge (Figure 4.2). It calculates the weighted average of each precipitation station in and near by the cachement based on the following relationship.

That is:

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

Where,

P = Average aerial depth of rainfall

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

A1, A2, --- An = polygonal areas around each stations.

i refers to the i^{th} precipitation gauge and n is the number of the Thiessen polygons.

The result obtained by using this method is 796.72 mm (Table 4.8).

Station	Mean Annual PPT(mm)	Area of influence (km2)	Weighted area (%)	Weighted rainfall (mm)
Nazareth	883.300	122.93437	0.130507	115.332481
Melkasa	828.000	108.29525	0.114966	95.191848
Sodere	688.300	163.54066	0.173614	119.4985162
Koka Dam	853.400	38.05064	0.040394	34.4722396
Wonji	846.100	159.39619	0.169214	143.1719654
Tibila	864.900	7.48769	0.007949	6.8750901
Modjo	935.200	7.16529	0.007607	7.1140664
Welenchiti	984.400	2.08578	0.002214	2.1794616
Huruta	900.200	10.16037	0.010786	9.7095572
Eteya	1056.200	57.24390	0.060770	64.185274
Dhera	705.700	265.61802	0.281979	198.9925803
Total		941.97816	1.000000	**796.72**

Table 4.8 Theissen polygon method to calculate annual rainfall in Nazareth-Dhera area.

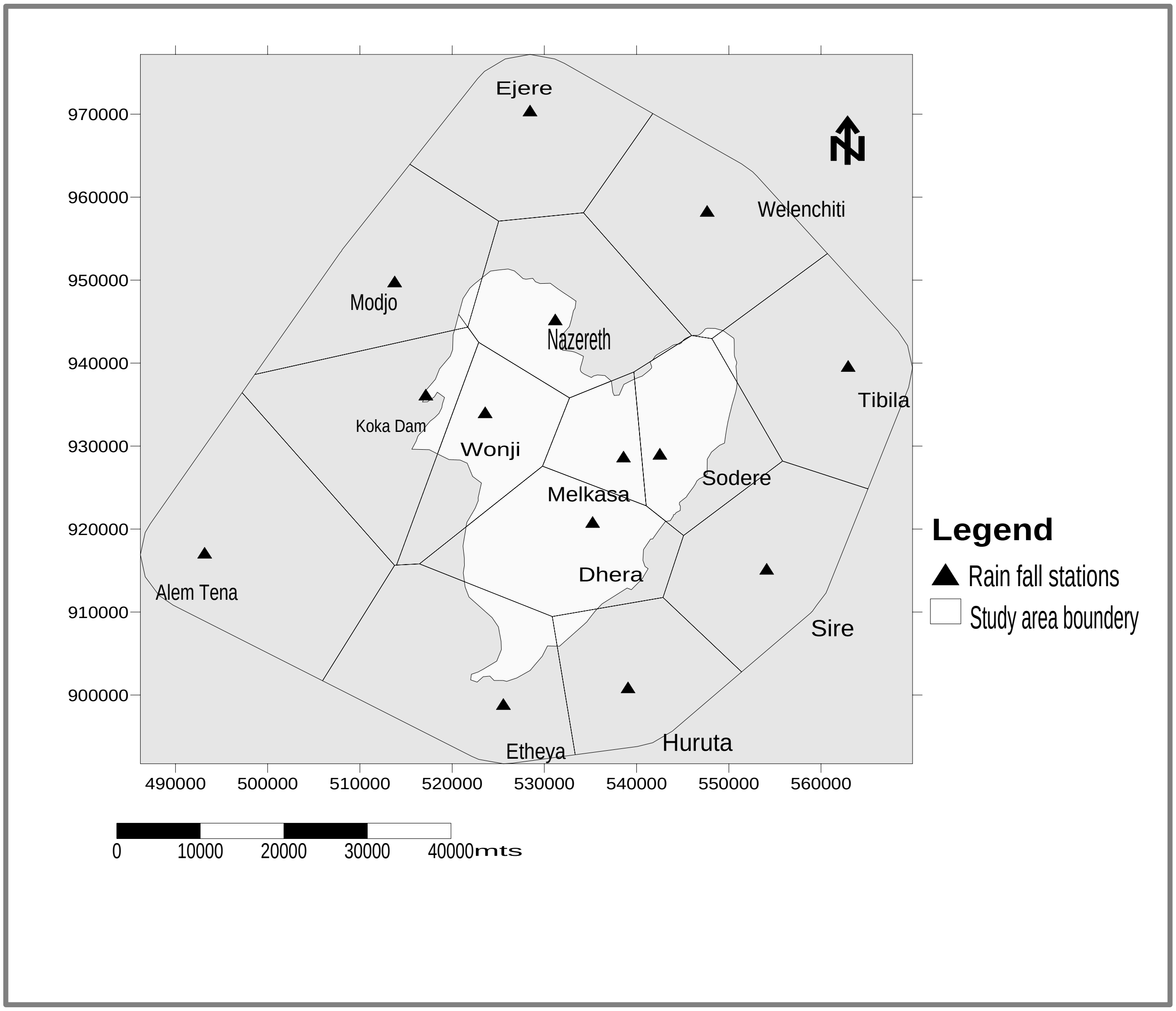


Figure 4.7 Thiessen Polygon Method

4.2.3.3 The Isohyetal method

This method allows the influence of physiographic parameters such as elevation, distance from the coast, slop, and exposure to rain bearing winds (Shaw, 1988) to be taken in to account and is the most accurate method of computing the average depth of rainfall. It is employed by plotting isohyetal map on a suitable chart by drawing contours of equal rainfall. That means isohyets are lines joining points of equal precipitation. According to this method the mean annual precipitation of the study area is equal to 823.18mm (Figure4.8).

Isoyetal range (mm)	Av.Isoyetal value (mm)	Enclosed area (km2)	Weighted area (%)	Weighted rainfall (mm)
< 700	688.3	81.8	8.692879	59.83
700-750	725.0	140.9	14.973433	108.56
750-800	775.0	187.3	19.904357	154.26
800-850	825.0	213.9	22.731137	187.53
850-900	875.0	266.3	28.299681	247.62
900-950	925.0	40.2	4.272051	39.52
950-1000	975.0	8.99	0.955366	9.32
>1000	1025.00	1.6	0.170031	1.74
Total		**941**	1	**823.18**

Table 4.9 Isoheytal method of calculating annual rainfall in the study area.

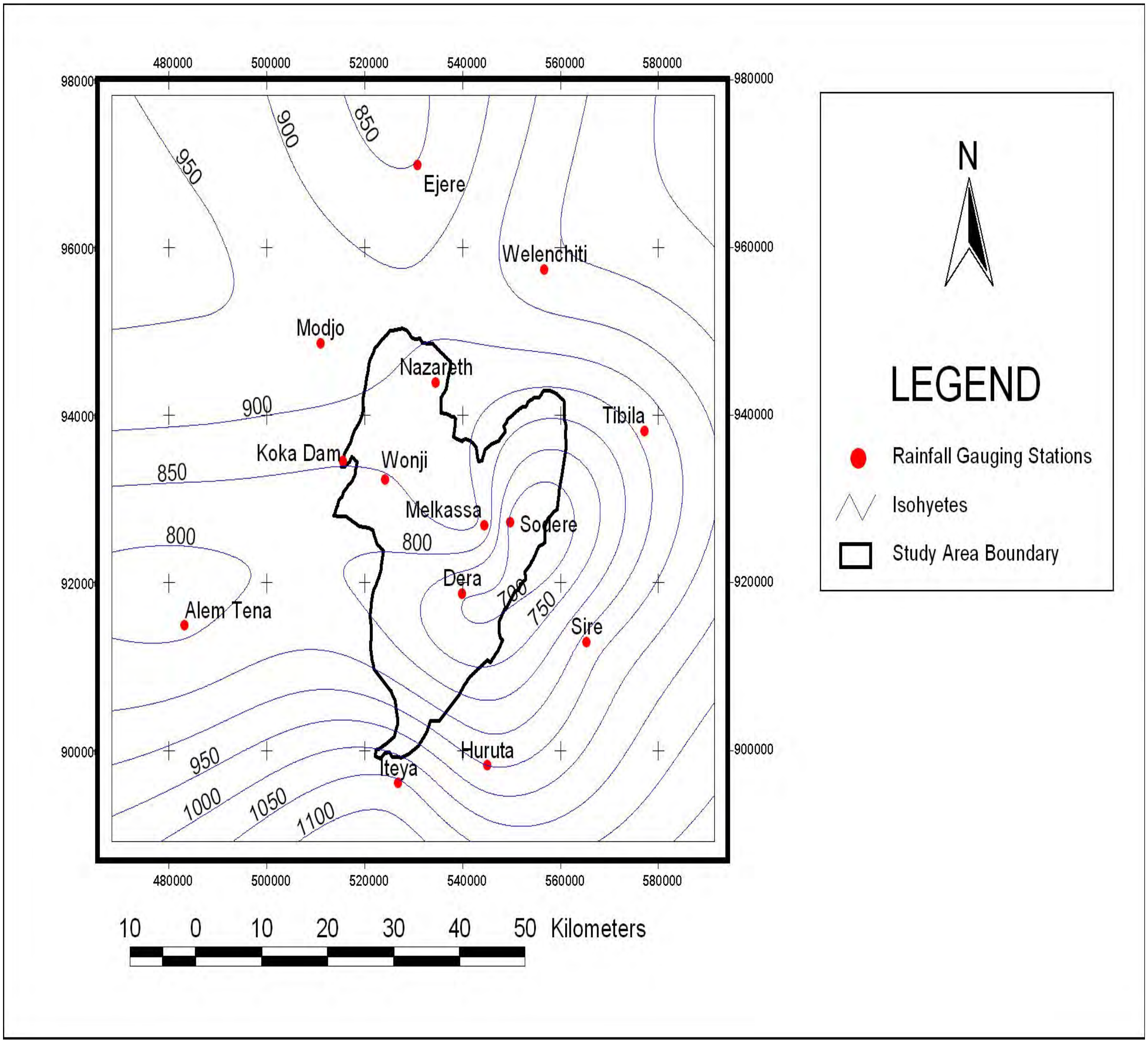


Figure 4.8 Isoheytal map of the study area

The above three methods result is more or less similar. Therefore the arithmetic, Theissen, and Isoheytal methods are averaged to fit best for the study areaand hence the mean annual precipitation of the cachement is equal to 806.9 mm.

In general the analysis of the rainfall data obtained over a long period in the past would help to make reasonable estimates of rainfall to be used in various development activities. The rainfall distribution in the study area is not uniform which ranges from 688.3mm to 1056.2mm. The highest rainfall is recorded in Eteya which is located southeast part of the study area and the lowest rainfall record is in Sodere. From precipitation bar graph (Figure 4.9) it is possible to see that the maximum rain fall is recorded in the month of August and the minimum rainfall is recorded in the month of December. Majority of the rainfall in the study area is obtained during the summer time (Kiremt) during July, August and September which covers about 58.2% of the total annual rainfall (Table 4.10). The minimum records are in the months of November, December, January and February. The monthly rainfall intensity of the area is clearly seen in the graph shown below (Figure 4.9).

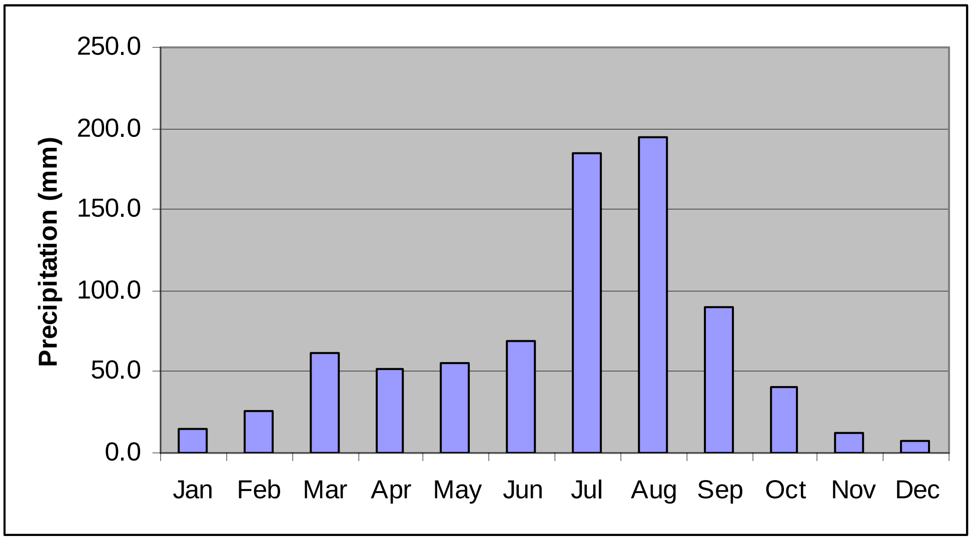


Figure 4.9 monthly average mean rainfall distributions in Nazareth- Dhera area.

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Nazareth	23.1	12.2	78.2	39.6	55.0	68.8	212.3	220.0	96.0	55.3	13.1	9.8	883.3
Wonji	5.1	46.8	52	52.1	73.7	53	207	229.1	93.7	22.3	8.6	2.7	846.1
Sodere	11.8	3.4	62	39.8	33	47.3	169.3	188.8	65.9	46.5	7.8	12.7	688.3
Melkasa	17.3	14.4	64.1	52.5	43.7	71.2	201.2	191.6	91.4	59.5	10	11	828
Koka Dam	19.6	18.3	47.5	40.1	45.8	87.6	214.5	253	71.4	42	8.8	5.1	853.4
Dhera	19	37.5	50.2	49.2	71.7	49.5	135.5	139.1	78.8	39.6	24.8	10.7	705.7
Etheya	22.7	29.6	65.4	71	89.2	97.8	217.8	225.9	168.8	55.8	8.8	3.5	1056.2
Huruta	11.2	28.2	60.6	74.6	90.4	107.3	150.3	165.6	132.2	48.8	27.7	3.2	900.2
Sire	9.2	10.1	70.4	82.1	64.5	85.7	166.4	186.5	137.3	40.9	6.8	7.1	867
Tibila	12.6	62.5	97.4	73	63.7	92.6	144.5	162.7	84.3	39.9	23.4	8.3	864.9
Welenchiti	16.8	56.2	92.7	81.8	49.6	58.4	220.7	249.6	102.6	40	6.9	9.1	984.4
Ejere	12.51	35.4	44.6	50	46.4	71.8	218.9	228.5	99.7	29.3	7.3	7.7	851.9
Modjo	12	23.2	72.4	53.5	53.3	101.8	257.6	221.5	103.1	27.7	7.2	2	935.2
Alem Tena	14.7	36.9	57.9	76.9	39.5	73.8	202.3	157.7	97.2	27.2	5.1	3.3	792.5
A. mean	16	22.1	59	45.6	53.8	62.9	190	203.6	82.9	44.2	12.2	8.7	800.8
Thiessen polyg.	14.3	27.73	61.97	52.33	55.82	69.68	177.83	187.57	90.8	39.84	12.3	6.52	796.7
Isoheytal Mean	14.15	28.29	62.52	57.06	55.93	72.86	185.68	192.6	97.15	39.28	11.1	6.6	823.2
Average	14.8	26.0	61.2	51.7	55.2	68.5	184.5	194.6	90.3	41.1	11.9	7.3	806.9

Table 4.10 Long terms mean monthly rainfall (mm) of all stations in & around the study area.

4.2.4. Estimation of Evapotranspiration

Evapotranspiration is the conversation water to vapor by evaporation and transpiration and enter from the water shed surface to the atmosphere (Axon, 1982). Quantitative assessments of water resources and the effects of climate and land use change on those resources need a quantitative understanding of evaporation.

Direct measurement of evaporation from open water body in the study area is of no interest for the reason that channel evaporation of Awash River including Melkasa reservoir is negligible and the role of evaporation will not be treated separately instead, it will be dealt in combined effect of evapotranspiration.

Estimation of evapotranspiration by direct methods is much more difficult, very expensive and not practical .Instead there are several methods to estimate it based on measurement of more readily measured quantities such as using pan evaporimeter up to Empirical formulas. Evapotranspiration refers to evaporation and transpiration. Evaporation is the process where by solar energy frees water molecules directly from water bodies like lakes, rivers etc. The process happens when the water molecules have absorbed enough energy to escape from the surface tension that holds them in the liquid or solid state. It can occur at land surface in water logged soils consisting of sand, silt or clay. Transpiration is the process where by the transformation of water in to water vapor is taken place through the vegetation at land surface. Water is taken up by the roots of plants and trees and transported to their leaves.

As a result of the physical properties of the vegetation itself and the supply of solar energy, the water at the leaves can be freed in to the atmosphere as water Vapor.

Evapotranspiration is controlled by Metrological conditions, the type of vegetation, and the supply of water. For a given set of metrological conditions, evapotranspiration rates reach maximum values if the supply of water is unlimited. We call this maximum rate of potential evapotranspiration. This is nearly always true for open water bodies like lakes, rivers, etc. For the upper part of the soil the amount of water available for evapotranspiration depends on the soil moisture content. The supply available through capillary action depends on the depth of the groundwater table below land surface or the root zone, and the type of soil. The actual evapotranspiration refers to a real evapotranspiration at land surface usually do not reach the potential rates.

The evaporation over the study area shows an increasing trend from the upstream (Koka Dam) and Eteya to the down stream sides of the study area, which seems to have direct relationship with the temperature and inverse relation with the altitude of the area.

4.2.4.1. Potential Evapotranspiration (PET)

According to Thornthwaite (1948), PET refers to the rate at which evapotranspiration would occur from an area completely and uniformly covered with growing vegetation which has access to an unlimited supply of soil water and without heat storage effects.

Potential evapotranspirations to be used for hydrogeological assessments can be determined by various methods: These methods can be classified on the basis of their data requirements (Jensen et.al., 1990).

4.2.4.1.1. Pan Evaporation Method

This method is one of the oldest and most common methods of estimating potential evapotranspiration from a shallow pan of water. The method relates PET from a vegetated land surface to the evaporation from open water, (Penman, 1950).

Data from pans are an observation of effects of radiation, wind, temperature and humidity related to evaporation, all integrated together, from an open surface. All these factors are included in the

pan coefficients from many observational researches on the effect of climate on crop evaporation (UNESCO, 1987).
Now adays around the world the most common types of evaporation pans are: Colorado Class A Pan, Sunken Screen Pan, floating pan etc. Researchers have developed estimation of PET, from Pan Evaporation using pan coefficient. This is given by:

PET = C_p *Ep Where, **PET**=potential evapotranspiration
Ep=Pan evaporation
Cp=Pan Coefficient

The value of **Cp** is selected based on the ground cover of the pan station and its surroundings and general wind and humidity conditions (FAO, 1977). Accordingly, for the mean relative humidity range of 40-70 % (medium) mean wind speed of 24hr ranging from 175-425 km/day (moderate), pan station surrounded to a distance of 10-100m by green crop in the wind ward side, the pan coefficient ,**Cp**, is determined to be 0.75 (FAO, 1977).

In the study area monthly mean pan evaporation data of each 10 years for (1963-1972) and (1997-2006) at Wonji and Melkasa Stations respectively have been obtained for this research work (Table: 4.11 and 4.12). The calculated weighted mean annual pan evaporation gave 2471 and 2575 mm for Wonji and Melkasa respectively. Therefore, annual mean of PET of the area to be 2523mm. According to (Jenson, 1973) the pan coefficient varies from 0.70 to 0.83 and averaged 0.77.
Accordingly the PET of the study area is calculated and yields the following mean monthly values of PET.

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1963	251.1	249.2	313.1	171	198.4	213	179.8	155	162	223.2	192	195.3	2504
1964	226.3	249.2	300.7	252	241.8	192	164.3	158.1	150	204.6	231	176.1	2547
1965	181.1	268.8	297.6	243	303.8	273	232.5	204.6	165	223.2	216	232.5	2842
1966	235.6	162.4	220.1	213	279	204	189.1	145.7	165	195.3	228	-	
1967	248	232.4	254.2	210	226.3	240	164.3	164.3	138	204.6	192	182.9	2458
1968	217	131.6	238.7	207	224.9	-	195.3	161.2	150	-	192	186	
1969	176.7	145.6	244.9	210	217	207	165	171	181.1	235.6	216	232.5	2403
1970	192.2	201.6	189.1	234	232.5	243	201.5	173.6	141	-	207	-	
1971	210.8	218.4	241.8	207	186	195	179.8	161.2	159	198.4	204	170.5	2332
1972	213.6	165.2	254.2	189	260.4	216	192.2	170.5	172	213.9	-	189.1	
Monthly Mean	215.27	202.44	255.44	213.6	237.01	220.3	186.38	166.52	158.21	212.35	208.67.	195.61	2471.19

Table 4.11 Monthly Values of Pan evaporation at Wonji (mm)
Source: From Water Balance and Effect of Irrigated Agriculture on Groundwater Quality in the Wonji Area, by Teshoma Dechasa, June, 1999.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Anu PE
1997	202.5	213.1	287	222.1	292.4	196	151.8	155.1	199.5	200.9	195	203.7	251
1998	205.6	222	291	255.9	267.1	252.8	200.8	182.1	187.9	202.8	271.6	248.6	278
1999	238.8	299.2	228.8	313.8	284.2	158.6	128.3	138.1	160.9	163.8	218.2	227.6	256
2000	243	279.3	347.1	239	248.6	232	171.1	140.2	117.3	161.7	187	208.7	257
2001	211	242.7	212.3	244.4	216.6	182.5	156.2	135.2	229.5	251.8	255.7	239.2	257
2002	200.6	227.4	239.3	247.9	279.3	255.9	217.1	206.2	203.6	261.7	233.4	197.7	277
2003	185.5	230.2	259.7	257.7	311.5	215	121.4	98.9	113.1	252.8	239.2	204.5	248
2004	180.1	242.2	294.8	191.7	278.9	210.4	145.2	123.3	136	203	231.1	212.6	244
2005	204.1	275.6	242	261.3	166.3	204.6	141.1	149.3	134.9	245.7	245.1	247.4	251
2006	245.4	246.2	248.2	187.1	261.1	201.8	159	176.5	133.2	193	x	X	205
Monthly Mean PE	211.66	247.79	265.02	242.09	260.60	210.96	159.10	150.49	161.59	213.72	230.7	221.11	257

Table: 4.12. Monthly total class A pan evaporation (PE) at Melkasa (mm).

4.2.4.1.2. Thornthwaite (1948)

An empirical formula of Thornthwaite, which is used to calculate potential evapotranspiration, PEm, is based mainly on temperature with an adjustment being made for the number of day light hours. In this approach an estimate of the PEm, calculated on a monthly basis, is given by a formula:

$PEm=16N_m\,(10T_{m/}\,I)^{a}$ mm

Where m is the months 1, 2, 3…12,

N_m is the monthly adjustment factor related to hours of day light (Day light factor),

PEm=potential evapotranspiration (mm)

T_m =the monthly mean temperature ^oC

$a=6.7x10^{-7}I^3-7.7x10^{-5}I^2+1.8\ x10^{-2}I+0.49$ (to 2 significant figures)

The Heat index of the year is given by:

$I=\sum i_m=\sum(T_m/5)^{1.5}$, for m=1….12

Where, I=Heat index of the year

I=Heat index of the Month

Thornthwaite computation has a dominant effect in the summer months with the high temperatures. Based on this empirical formula, the weighted mean annual PET over the study area is 1094.09mm.

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Element	**Months**												**Total**
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
T_m ^oC	19.95	21.21	22.46	22.70	23.39	27.o2	21.63	21.36	21.47	20.88	19.8	21.47	
N	11.7	11.85	12	12.25	12.45	12.55	12.45	12.35	12.1	11.90	11.75	11.65	
N_m	0.975	0.988	1	1.02	1.04	1.05	1.04	1.03	1.01	0.992	0.979	0.971	
i_m	7.97	8.74	9.52	9.67	10.12	12.56	8.99	8.83	8.89	8.53	7.88	8.89	
I	=110.59												
A	=2.5												

PE_m	68.17	80.54	96.39	98.56	108.24	156.74	89.04	85.5	84.82	77.58	67.15	81.36	1094.09

Table: 4.13 mean annual PET obtained from Thornthwaite Approach

4.2.4.1.3. Penman (combination method)

This approach has a theoretical foundation and gives representative results (Van Bavel, 1966).The Penman Formula requires average Meteorological data to quantify the PET of the study area.

The physical principles combine the two previous approaches to evaporation calculation, the mass transfer (or aerodynamic) method and the energy budget method.

H = Eo = Q -- (Simplified energy balance equation)

Eo = f(u) (es – ed) --- (Mass transfer method)

Where, H = the available heat

Eo = Energy for evaporation

Q = energy for heating the air

F(u) = a function of wind speed

es-ed = saturation deficit

es = saturated vapor pressure of air at water surface

ed = saturated vapor pressure of air above the water surface

The basic equations are modified and rearranged to use meteorological constants and measurements of variables which are made regularly at climatological stations.

The Penman Formula is given by:

$$PET = \frac{(\Delta/\gamma) H_T + Eat}{\Delta+\gamma}$$

$H_T = R_I (1-r) - R_o$

$R_I (1-r) = 0.75\, Ra*fa\, (n/N)$

$F (n/N) = 0.16+0.62n/N$

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

$Eat=0.35(0.5+u_2/100)(ea-e_d) = f(u)(ea-ed)$
r =albedo
Where,
PET=potential Evapo transpiration
H_T= the available heat
Δ = the slope of the curve of saturated vapour pressure plotted against temperature,T_a
γ = hygrometric constant ($0.27mmHg/^0F$),
R_I = In coming radation,
R_O = out going radation
Ra = the solar radiation (fixed by season and latitude)
Eat = energy for evaporation based on the air humidity and air temperature
Ta = average air temperature for a month, ^oc
σTa^4 = the theoretical black body radiation at Ta
σ = the Stephan Bolatzman constant = $5.67x10^{-8}wm^2/k^4$
U_2 = mean wind speed at 2m above the surface, miles /day.
n = bright sunshine over the same period, h /day
N= average daily duration of maximum possible sunshine hours.
F(u)= a function of wind speed
Ea = the saturated vapour pressure at air temperature, Ta
Ed = the saturated vapour pressure at the dew point, Td; Ea –Ed =the saturation deficit

Elements	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T(0c)	19.95	21.21	22.5	22.7	23.39	27.02	21.63	21.4	21.47	20.88	19.8	21.47
N(hrs)	11.7	11.85	12	12.2	12.45	12.55	12.45	12.4	12.1	11.9	11.75	11.65
n/N	0.778	0.743	0.7	0.68	0.726	0.685	0.564	0.58	0.636	0.739	0.834	0.824
H(%/100)	0.53	0.495	0.53	0.53	0.515	0.535	0.66	0.7	0.66	0.55	0.49	0.51
U_1 (m/s)	6.06	6.27	5062	5.23	5.1	6.21	6.55	5.18	3.65	4.68	5.79	6.24
U2 (miles/h)	13.56	14.03	12.6	11.7	11.41	13.89	14.65	22	8.17	10.47	12.95	13.96
U_2 (miles/day)	325.4	336.7	302	280.8	273.8	333.4	351.6	278	196.1	251.3	310.8	335.04
Ra(mm/day)	13.25	14.2	14.9	15.08	14.7	14.45	14.58	14.8	14.83	14.4	13.48	12.95
fa(n/N)	0.642	0.621	0.59	0.582	0.61	0.585	0.509	0.59	0.554	0.458	0.517	0.67
σT_a^4(mm/day)	14.36	14.61	14.9	14.91	15.05	15.8	14.69	14.6	14.66	14.54	14.33	14.66
e_a (mm/day)	17.53	18.47	17	19.17	19.5	21.22	18.17	18.5	18.59	18.31	17.11	18.59
e_d(mm/day)	9.29	9.14	8.99	10.16	10.04	11.35	12.32	12.9	12.27	10.07	8.38	9.48
R_l((1-r)	6.379	6.614	6.5	6.582	6.725	6.339	5.566	6.57	6.162	4.946	5.227	6.52
R_o	2.835	2.807	2.73	2.529	2.709	2.532	1.94	1.92	2.118	2.643	3.125	2.99
HT mm/day	3.568	3.852	3.99	4.161	4.116	4	3.671	4.69	4.214	2.33	2.148	3.53
Eat mm/day	11	12.95	11.6	10.73	11.45	15.06	9.238	6.68	5.616	8.855	11.39	12.3
Δ/v	2.213	2.359	2.44	2.449	2.49	2.71	2.385	2.37	2.375	2.339	2.274	2.4
PET(mm/day)	5.81	6.435	5.53	5.903	5.937	6.35	5.191	5.2	4.458	4.215	4.827	6.12
PET(mm/month)	174.3	193.1	166	177.1	178.1	190.5	155.7	156	133.7	126.5	144.8	184.5

Table: 4.14 mean Monthly PET calculated using Penman Method (Combination Approach).
Hence, PET Annual, Penmam = 1979.1mm

Using the above formula monthly average meteorological data of PET of the study area has been calculated and the results are indicated in table: 4.15.
From the above three estimates, the thornthwaite values tend to under estimate the potential Evaporation where as the Pan Evaporation Method tend to over estimate the result. Therefore, the PET obtained from penman combination method seems to be more representative and for further water balance calculation the annual PET in the analyzed area assumed to be 1979.1mm.

4.2.4.2 Actual Evapotranspiration (AET)

Evapotranspiration rates at the land surface usually do not reach the potential rates and we refer to these real rates as actual evapotranspiration rates. AET over a drainage basin is mostly obtained by first calculating the PET. The relation ship between AET and PET depends up on the soil moisture content. When the soil is saturated, PET = AET (Shaw, 1984). When the vegetation is unable to abstract water from the soil, then the actual evaporation becomes less than potential evapotranspiration.

The value of AET obtained from measurements of PET is about 994mm / year and procedures and results are presented in soil–water balance (Thornthwaite and Mather, 1957) section.

Water loss from a study area does not alones proceed at the potential rate, since this is dependent on a continuous water supply. AET is used to describe the amount of evapo transpiration that occurs under field conditions (Thornthwaite, 1944).

4.2.4.2.1 Empirical formulae

4.2.4.2.1.2 Turc (1954, 1955)

A widely used formula to estimate annual values of AET for the catchments area was published by Turc. The formula is given by:

$$AET = \frac{P}{[0.9 + (P/L)^2]^{½}} \text{ mm per annum}$$

Where, P= mean annual precipitation (mm),

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

T = mean air temperature (^{0}c)

AET = 726.55mm

In this method precipitation and temperature could be the dominant factors in Evaporation.

4.2.4.2.1.3 Thornthwaite (1948)

In this method a rough estimate of AET was expressed in terms of the ratio of precipitation and temperature data. Its formula is as follows:

$$AET = [11.5(P/_{(T-10)})1/9]^{-1} \times P$$

Or

$$\frac{p}{AET} = \left(\frac{p}{(T-10)}\right)^{10/9}$$

Where, p and AET are in inches (Table: 4.15)

T = temperature in ^{o}F

AET annual, Thornthwaite = 221.41 mm = 8.717inches

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
P mm	18.71	12.6	62.88	42.21	47.74	67.86	194.61	216.86	87.22	51.06	9.88	10.82	
P inch	0.74	0.49	2.48	1.66	1.88	2.67	7.66	8.54	3.43	2.01	0.39	0.43	
T ^{0}c	19.29	21.21	22.46	22.70	23.38	27.02	21.62	21.36	21.47	20.87	19.79	19.52	21.47
T ^{0}F	66.72	70.18	72.43	72.86	74.08	80.64	70.92	70.45	70.65	69.57	67.62	71.12	

Table: 4.15 Monthly Mean Precipitation and Temperature of the study area to find AET annual, Thornthwaite.

4.2.4.2.1.4 Crowe –Thornthwaite formulae

From this method, the AET is given by:

$$AET= (T-10)/9$$

AET Annual, Crowe = 171.17 mm = 6.739 inch

It is useful for a rough estimate of AET when only temperature data is available and applied in a specific area. Since it is not only temperature factor that control the AET in the study area, this approach is not satisfactory .

4.2.6 Runoff Analysis

Runoff is the movement of a component of stream water under the force of gravity through well defined channels or over the land in undefined channels which generates from precipitation in a catchment basin. The runoff process is strongly influenced by the rate of precipitation and the rate of infiltration.

The main controlling factors of runoff over an area are climate, geology, vegetation, topography, soils, Drainage network, size and average height of catchments, land use and human factors such as urbanization that decreases infiltration, Agricultural techniques (method of ploughing, deforestation, irrigation, etc) and construction of dams.

In general the relationship between Runoff, stream flow and precipitation can be expressed in terms of continues circulation of water through the hydrologic cycle.

In the study area the evaluation and analysis of the Awash River discharge data obtained from the data Bank of Ministry of Water Recourses Development, for wonji and Koka Dam gauging stations (period, 1983-2002) for each of them (Look at table: 4.18).

The out flow of Awash River during the dry season is limited to the base flow. Although the base flow component of a stream is more or less constant, the total discharge of the stream may fluctuate greatly through the year. The difference is due to the episodic nature of precipitation events that contribute over land flow (Runoff), inter flow and direct precipitation.

Table: 4.16 Rainfall –Discharge (1983-2002)

Parameter	JAN	FEB	MAY	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Rain fall (mm)	14.8	26.0	61.2	51.7	55.2	68.5	184.5	194.6	90.3	41.1	11.9	7.3
Discharge m^3/s	19.9	18.6	16.7	17.3	17	18.2	26.9	20.6	43.7	24.7	22.7	20.9

The above table was used to compare the monthly mean Rainfall of the area and runoff relation in the upper part of sub-basin. The discharge is a record of monthly mean discharge of the upper wonji basin that was calculated from Awash River discharge data of Koka dam and Awash-Wonji stations and its highest value is recorded in the Month September. As a result of Koka Dam, downstream flood conditions in some agricultural land and settlement areas around wonji town and along the Awash River are controlled.

4.2.6.1 Runoff estimation

In order to analyze and evaluate runoff conditions from a catchments area, existing discharge records of Koka Dam and Wonji stations where obtained from MOWR (period 1983-2002). The distance between these two Awash River discharge stations is about 10 km.The maximum peak discharge that occurred over the past 20 years (1983 – 2002) reaches 43.7 m^3/s in September for the upper part of the area.

The study area is considered as upper and lower part for the convenience of understanding of the study area and their boundary is Awash–Wonji River gauge station. The lower part of the study area has no discharge measuring staff gage and very difficult to calculate runoff value.

In the study area there is no recorded study of flooding, however there were flooding in the area some times during the biggest discharge period at time of large storms in the months of September, July and August. Hurton overland flow (Kirkbay, 1978) is the dominant producer of the storm runoff in the study area. In general, the amount of runoff in the area is generally small and can only be contributed by intense rain events. The computed high evapotranspiration rate of the area also indicates that it contributes to the small amount of runoff. Besides, in some parts of the study area there is low drainage density and this is an indication of the presence of a corresponding low runoff volume. From the value reported for Modjo basin (Tamiru Alemayehu, 1992) and from annex 20 Sharman (1983), a weighted runoff coefficient of 0.3 to 0.4 is assumed for the land type of the study area. By taking this in to consideration the runoff coefficient of 0.3 suggested for runoff calculation of the study area.

The rainfall of the entire study area is 806.9mm and to estimate the runoff of the lower part of the study area is as follows:

Total area of the cachement = 941 km2
Area of the bounded part = 33.75 km2
Area of the remaining part = 907.25 km2

The 33.75 km2 bounded area in the eastern part of the study area (i.e. Eastern cachment of Adama town) which is believed to contribute more to evapotranspiration and infiltration than runoff. This eastern catchment has a serious storm water drainage problem, since there is no natural outlet for storm water runoff. All the storm water runoff will accumulate in the depression within the town boundary and ultimately inundate vast built up areas. It is impossible to drain the sewage by gravity towards a lower site as this site will regularly be flooded entirely. Since it has no contribution to runoff for lower part of the area, its area should be subtracted from total part of the study area for runoff estimation.

Accordingly the runoff is given by

Ro = (A*P) K = 907.25 x 10^6 m^2 x 0.807m x 0.3

Where, Ro: Runoff

A: Area

K: Runoff coefficient

P: Mean precipitation for the study area

The value of estimated runoff for the study area excluding the bounded area is about 219.64 x10^6 m^3 (Table 4.17). However, the losses to the subsurface mainly along the channels, fractured zones, and soil layers in plain parts of the area are very difficult to quantify.

	Jan.	Feb.	Mar.	Apri.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
PPn mm	14.8	26	61.2	51.7	55.2	68.5	184.5	194.6	90.3	41.1	11.9	7.3	807
RO coeffi.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
Area	907.25	907.25	907.25	907.25	907.25	907.25	907.25	907.25	907.25	907.25	907.25	907.25	
Monthly RO (MCM)	4.03	7.07	16.66	14.07	15.02	18.64	50.22	52.96	24.57	11.18	3.24	1.98	219.64

Table 4.17 Calculated runoff for the study area

According to Teshome Dechasa (1999) in the area the losses along stream channels can be roughly estimated to be about 20% of the total available water for surface flow. Based on this approach the total losses through the stream channels were about 43.93 x 10^6 m3. Therefore, the total water volume of surface runoff that leaves the study area is estimated to be 175.72 x 10^6 m3. This will be used as annual runoff value for further study in the analyzed area.

4.3 Water Balance

The water balance represents the hydrological gains and losses of a given system (reservoir, column of soil, aquifer, river basin, etc) over a specific period (Tenalem and Tamiru, 2001). Water balance is extremely important for studies of the hydrologic cycle. On the basis of the water balance approach it is possible to make a quantitative evaluation of water resources and their change under the influence of man's activities. Besides, water balance studies help to make an indirect investigation of an unknown water balance component from the difference between the known components. For natural drainage basin, measurement of the precipitation, transported water, reservoir evaporation and river discharge may be made satisfactorily with some degree of precision. However, groundwater inflow, outflow, and change in storage are computed from the hydraulic aquifer characteristics and measured potentiometeric data. The measurement of groundwater movements into or out of the drainage area cannot be made easily.

The water balance for any water body and at any time interval in its general form may be represented by the general equation as follows:

Inflow = Out flow + Change in storage

Here, inflow includes precipitation and groundwater inflow whereas out flow includes surface runoff, groundwater out flow, evaporation, evapotranspiration, withdrawal and change in storage.

4.3.1 Soil water balance, Thornthwaite and Mather, 1957

The soil-water balance model uses a simple accounting scheme to predict soil- water storage, evaporation and water surplus.

This method helps to quantify the annual AET of the area on the basis of the potential evapotranspiration already computed by penman combination method and then modifying the answer by accounting for the actual moisture content using the method outlined by Thorthwaite and Mather (1957).
The following table shows values of the major components of the soil water balance.
Table 4.18 Long-term average monthly Soil-water balance Method of estimating AET (Thorenthwaite and Mather, 1957), for a soil with available soil water storage capacity of the root zone is 250 mm. The soil is assuming a uniform land cover of silty clay loam under 60% moderately deep rooted and 40% deep rooted vegetations with rooting depth 0.8 and 1m respectively.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
P (mm)	14.8	26	61.2	51.7	55.2	68.5	184.5	194.6	90.3	41.1	11.9	7.3	806.9
PET(mm)	174.3	193.1	166	177.1	178.1	190.5	155.7	156	133.7	126.5	144.8	184.5	1979.1
P - PET	-159.5	-167.1	-104.8	-125.4	-122.9	-122	28.8	38.6	-43.4	-85.4	-132.9	-177.2	
Ac PWL	-598.4	-765.5	-870.3	-995.7	-1118.6	-1240.6	0	0	-43.4	-128.8	-261.7	-438.9	
Sm	23	12	7	4	2.6	1.7	250	250	200	150	85	42	
ΔSm	-19	-13	-5	-3	-1.4	-0.9	248.3	0	-50	-50	-65	-43	
AET(mm)	37.8	39	66.2	54.7	56.6	69.4	155.7	156	140.3	91.1	76.9	50.3	994
D	136.5	154.1	99.8	122.4	121.5	121.1	0	0	-6.6	35.4	67.9	134.2	
S	0	0	0	0	0	0	0	38.6	0	0	0	0	

Table 4.18 Long-term average monthly Soil-water balance method of estimating AET.

Where,

P = Mean monthly precipitation, mm
PET = Potential evapotranspiration, mm
AET = Actual evapotranspiration, mm
Ac. PWL = Accumulated potential water loss, mm
Sm = Soil Moisture, mm
ΔSm = change in soil moisture, mm
D = soil moisture deficit, mm
S = Soil moisture surplus, mm.

Estimation and description approaches of each of the main components that basically influence the Soil - water balance is presented precisely in the following way.

The mean monthly precipitation (p) values obtained from the average of Thiessen, Isoheytal and Arithmetic Methods is presented in row 1 of the table.
The mean potential evapotranspiration calculated by the penman method is listed in row 2.
The difference between mean monthly precipitation and potential evapotranspiration is presented in row 3. The accumulated potential water loss which is obtained by adding the negative values of P – PET of a consecutive months are listed in row 4. The amount of water retained by the soil, the soil moisture is listed in row 5. The change in soil moisture, which can be obtained by deducing the soil moisture of the month under consideration from the soil moisture of the preceding month, is listed in row 6. The AET is listed in row 7. The AET = PET during the months when mean monthly precipitation exceeds PET. When PET exceeds P, the AET will be equal to the sum of mean monthly precipitation and the amount of soil moisture withdrawn from the storage.
The soil moisture deficit is calculated easily by deducting the AET from values of PET and is listed in row 8. Moisture surplus which is available for infiltration and runoff has been computed to be zero and is listed in row 9. Once a moisture deficit developed, it can be reduced when

excess precipitation is stored in the soil at the beginning of wet season. When soil moisture attains its field capacity, further precipitation must leave the soil as runoff. The amount of water that can’t be stored in the soil is known as moisture surplus. Surplus is precipitation which doesn’t evaporate or remain in soil storage and includes both surface and subsurface runoff. If the drainage basin is large, about 50% of the moisture surplus is estimated as runoff.
According to Soil-water balance result, in the study area the moisture surplus is zero. This implies there is no runoff from precipitation that fall in the area. Since the area has semi-arid climate, the PET value of penman combination method & its AET tend to be mostly greater than precipitation in the region.

The soil–water balance doesn’t include storm runoff which usually is a source of runoff in arid and semi arid zones. This approach generally under estimates recharge in arid and semi arid zone and often gives zero value.
According to David N. (1990) soil moisture budgeting is developed for humid climates and has less validity in arid and semi arid zones. This model works best for the seasonal patterns of recharge, well developed soil that don’t dry completely and in conditions when PET and AET are similar and precipitation is also relatively uniform.

4.3.2 Groundwater recharge estimation

A quantitative estimation of a groundwater that will recharge the drainage basin can be evaluated from the components of the hydrological cycle. The main objectives of balancing hydrologic components that prevail in the study area lie in identifying the annual groundwater recharge and the AET of the area. Before making a balance among the components, defining the water balance equation to be applied in the study area followed by estimating and computing each of the components is crucial. Determining annual groundwater recharge follows the general water balance equation that introduces the main components that are prevailinganf omits those that are of less effect in the balance. Allowing for changes of storage within the system input must be equal to out put under study estate. However, for most natural conditions this is not true due to certain topographic situation and geological structures. The natural recharge to an undeveloped aquifer may be determined by a water- budget analysis of the recharge area:

Groundwater recharge = (Precipitation + surface-water inflow + imported water + groundwater inflow) – (Actual evapotranspiration + reservoir evaporation + surface water outflow + exported water + groundwater out flow) $\pm$ changes in surface water storage.

This equation can account for groundwater recharge not only from precipitation, but also from losing streams, irrigation water, unlined canals, and so forth. Water used for many purposes may be recharged to the groundwater reservoir such as excess irrigation water, water used for domestic and industrial purposes. The determination of such additional groundwater recharge is often more complicated than an analysis of the basic amount of recharge. This is because an accurate accounting of this type of recharge involves long and tedious inventory analysis.
In the study area the area boundary is based on surface water divide but it may not coincide all in all with groundwater divide. There is also groundwater inflow from Koka Lake through big fractures. The long term water balance calculation based on different approaches shows that the groundwater recharge from precipitation is almost zero or very minimum.Therefore, in the study area changes in the groundwater storage is mainly groundwater inflows from external cachement.

Considering there is no change in ground and surface water storage (i.e. there are no groundwater abstraction and no contribution to the groundwater from surface water except for Adama town water supply and Wonji irrigation water withdrawal from Awash River) in annual basis and closed water shed boundary, the water balance of the study area is:

$$P + Gi = AET + Ro + W \pm \Delta G$$

Where, p = Mean precipitation = 807 mm
AET = Actual evapotranspiration = 726.55 mm
Gi = Groundwater inflow from Koka Dam = 485.4 x 10^6 m^3
Ro = a runoff from over the study area = 193.7 mm
Wa = Adama town water supply Withdrawal from Awash River = 4.24 mm
Ww = Wonji irrigation water Withdrawal from Awash River = 87.77 mm
W = Wa + Ww = (Withdrawal) = 92.01 mm
ΔG = Groundwater recharge.

Assumptions for this water budget calculation:-

-There is no groundwater abstraction
-Abstraction of Awash River water is for Wonji irrigation & Adama water supply
-No import & export water from the cachement.

Sileshi Mamo (1999), calculated the groundwater out flow from Koka Dam in NE of the Dam, which is inflow for the study area to be 485.4 x 10^6 m^3 / yr.

Then applying the general water balance equation set for the cachement, the annual groundwater recharge is estimated as follows:

$\Delta G = (P + Gi) – AET - SRO - W$
$= (759.39 \times 10^6 + 485.4 \times 10^6) – 684.11 \times 10^6 – 175.72 \times 10^6 - 3.99 \times 10^6 - 82.59 \times 10^6\ m^3$
$= 298.38 \times 10^6\ m^3$ / yr or 317.1mm/annum. (N.B.: This big value is due to additional 485.4 mcm leakage or groundwater inflow from Koka Dam).

Chapter Five

5.0 Hydrogeology

5.1 General

Hydrogeology is the study of the occurrence, distribution and movement of water in addition to physical as well as chemical relationships with the surrounding geological environments (Sen., 1995). In the study area both volcanic rocks and unconsolidated sediments are found. The disruption of lithologies by cross cutting faults; and the variability in volcanic structures make the hydrogeology of the region very complex.
Volcanic rocks are igneous rocks originating from magma that has erupted at earth surface. Magma flowing over and crystallizing at land surface is called lava. In many places within the study area lava flows and domes are manifested as a surface of horizontal or sub-horizontal layers and have variable thickness. The upper part of them is weathered and even old soil profiles are visible. Also, the individual flows are in many places separated by obsidian layers and pumice fall deposits. Unlike many sedimentary basin of Aquifers of the region, which are characterised by groundwater flow continuity over vast regions; the volcanic terrain at different places remains a challenging system to conceptualise its groundwater dynamics. This may need tracing techniques such as noble gases and groundwater age indicators in addition to the widely used conventional tracing techniques such as stable isotopes and major ion geochemistry.

Porosity and permeability are the main criteria for groundwater occurrence and movement both in non-indurated sediments and in hard rocks in general. They are the principal hydro geologic properties of rocks and control the entrance of water in the aquifers. The porosities of volcanic formations in the area vary considerable. Rock porosity refers to the open space in the various rock types.

With one or more lava flows the rock can be porous at horizontals with gas holes or vesicles, lava tubes, and at sections with pronounced joining or fracturing. At the contact between individual layers, buried soils, weathered zones, or deposited sand and gravel may also be porous. Openings do not have an even distribution, but that they are rather localized phenomena. This uneven distribution may be due to the processes acting on the rock mass in the course of time during and after crystallization of the rock, cooling, compaction, & tectonic activity. This type of open space is commonly referred to as secondary porosity.

Structural features of rocks such as secondary porosities, the geometrical properties of the geological system produced by deformation or crystallization (Freeze, 1979), may provide secondary hydro geological properties to the various rock types. There fore the occurrence of water in the rocks of any region is determined by the structure, distribution and the character of the rocks that contain.
In volcanic rocks the porosity depends on the size of the individual fractures, joints and other openings. Besides, the density of these openings in the rock mass is a determining factor. For

instance the porosity of highly fractured basalt may be as high as 0.5. In particular in dense unfractured and un jointed volcanic rock the porosities will be very low.

The capacity of a rock to transmit groundwater is known as permeability. The permeability of volcanic rocks is determined by the size of the fractures and joints, vesicles, and other openings. The inter connection between the openings also play an important role. Due to the uneven distribution of the openings the permeability may vary significantly within the lava flows themselves. For a sequence of lava flows, the permeability in the vertical direction is much smaller than in the horizontal direction.

Volcanic bombs, ash and pyroclastic deposits (such as the tuffs, pumice fall and vollonic ash beds) are also parts of volcanic eruption in the area which are subsequently deposited on the slopes of the volcanoes and the area beyond them. Un welded tuffs usually consist of loose angular and unsorted fragments and their porosities may be moderate and even high, but permabilities are usually low due to poor sorting.. In welded tuffs the fragments are molten together and the porosities and permeabilities are usually lower than in the un welded tuffs.

Pumice fall deposit and volcanic ash deposits usually have porosities and permeabilities which are higher than in tuff. In rocks like un welded tuffs and volcanic ash the porosity is mainly primary porosity, i.e. the openings are around the individual fragments.

The older the volcanic formation, the less permeable is the rock. This may be due to the weight of the overburden or chemical processes.

On the other hand, in unconsolidated sediments openings are mainly present in between individual grains and mineral. The distribution of these pore spaces is far more even than in volcanic rocks of the study area. It is called primary porosity or inter granular porosity which is formed during their deposition. In the course of time, when the unconsolidated deposits turn to a consolidated rock, the primary porosity decreases. In unconsolidated sediments the porosity relates to the packing, the sorting and the shape of the grains.

High permeabilities are mostly found in un consolidated deposits composed of large rounded grains which are well sorted.

As mentioned in previous sections, the study area is dominantly covered by volcanic rocks, which shows greater variations in their hydro geological properties. Volcanic rocks in the area include material having a wide range of hydrologic properties such as basic, acidic and pyroclastic rocks. Basic volcanic rocks such as vesicular basalt are generally rich in cavities due to rapid cooling and escape of gases, cooling joints and bubble like pore space. As a result they are highly permeable. Where as acidic volcanic rocks may or may not contain groundwater even though they generally posses pore spaces. Pyroclastic rocks associated with lava flows are generally porous but their permeability varies depending on the degree of inter connection of the interstices (Davis et al, 1966).

Large fractures in volcanic rocks are usually few in number and are produced by sub-surface earth stresses and may extend to great depth; and small near surface fractures may occur in great numbers (Nockolds, Knox, Chinner, 1979).

Although porosity can be very high, the permeability of volcanic rocks is a function of the degree of its inter connection. Besides to the secondary, fracture induced permeability features, the porosity may be increased locally in the rocks by the various erosions and weathering processes (Davis, 1969).

Generally volcanic rocks are basic, with low silica content (basalt and basalt like rocks), some are rich in plagioclase (tholeiites) and other may be rich in olivine (alkaline basalts). High silica content is found in acidic rocks, such as rhyolites.

From hydro geological point of view, the most important volcanic formations in the study area are cinder, spatter cones, scoraceous basalt, lava flows, ignimbrites, pyroclostic deposits such as tuff, pumice, volcanic ash and so on. Specific yield (drainable porosity) is small for fine grained pyroclastic formations, ash and weathered rocks.

In any hard rocks the ground water movement is restricted to fractures, fissures and cracks by mechanical stresses and the groundwater flow velocities range from less than 1m/day and may be high but the velocity is generally decreasing with depth. Most ground water is stored in the bulk of the volcanic formulations as slowly flowing water.

The more the pore spaces occurring in the rocks, the more is the ground water storage. The other factors that control the amount of ground water in the volcanic rocks and unconsolidated deposits are precipitation, topographic features, runoff distribution, irrigation, hydraulic properties of litholgic units and boundaries of aquifers.

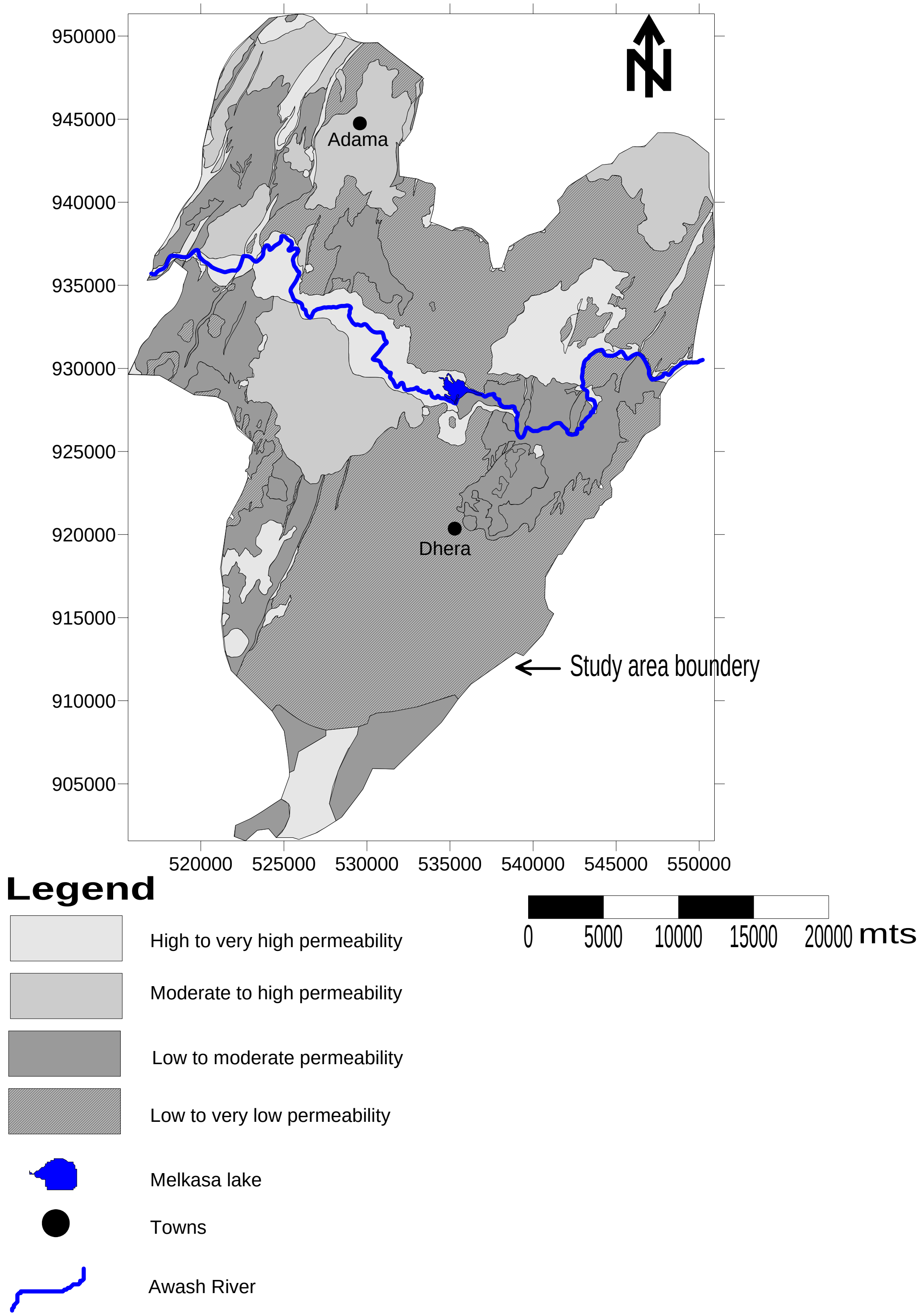


Figure 5.1 Hydrogeological map of the study area

5.2 Aquifer characteristics of different rock units

All geological litho logic units of the study area have been grouped in to four permeability classes based on local geology, lithologic logs, hydraulic parameters such as transmissivity, permeability, specific yield and specific capacity values estimated by pumping test analysis of some of the wells using Jacobs straight line method(Fig:5.2) and field observations of porosity condition.
The four permeability groups, K (m/day) estimated of litho logic units of the study area are the following:

- High to very high: permeability value > 4.5m/day
- Moderate to high: permeability value 2 - 4.5m/ day.
- Low to moderate: Permeability Value 0.1 - 2 m/day.
- Low to very low: Permeability Value < 0.1 m/day.

5.2.1 High to very high permeability group.

These formations are able to transmit water in appreciable quantities. Under this group the following units are found.

-Cinders, Spatters Cones and Scoraceous Basaltic Lava Flows
-Recent Alluvial Deposits
-Apheric flood basalt
- Bofa units (Weathered and fractured basalts)

5.2.1.1 Cinders, spatters cones and scoraceous basaltic lava flows

As it is shown in the Geological map they outcrop mainly in between Nazareth and Sodere area along Nazareth- Dhera main asphalted road, North of sodere and around wonji localities. They have generally high to very high permeability and usually form volcanic cones around vents. Scoria is also the most important unit in the area from its hydrologic point of view.
The scoraceous basalt in this area is highly pervious due to its vesicular nature. Vesicular Scoracious basalts are very good aquifers in the investigated area. How ever their abundant vesicles vary considerably in site and some of them are filled with secondary minerals. Vesicular volcanic rocks have porosity value ranging from 10 to 50 percent (Davis et al, 1966). The porosity and permeability of the rock tend to decrease with depth. This phenomenon can be explained by the decrease in weathering with increasing depth, and the tendency of joints and faults to close as a result of the weight of the over burden.
Not only the high porosity nature of these rocks, but also their pore spaces interconnections play an important role to make them good aquifers.
Besides they contain secondary features like fractures joints and faults at different localities that make them a good recharge zone. They have been observed to be good aquifers. This justified by data of well hydraulics in some wells that gave permeability value of Greater than 5m/day.
For groundwater exploitation, water wells in general can only be successfully drilled around low topographic position (i.e. around the foot slopes) in Volcanic Terrain because they are recharge zones in their out crop area. The secondary features of these geological formations are both

vertical and horizontal. As a result it expected to have good secondary pervious nature for groundwater flow.

Boreholes drilled for water supply in the study area are from this formation. This implies that these units are good recharge zones as well as water-bearing formations. This might indicate that most of the time Vesicular, scoraceous basalt and fractured basalt are localized water-bearing formations where as fractured ignimbrites are regional aquifer system in the region.

5.2.1.2 Apheric flood basalt

This water bearing formation is belongs to Nazareth Group. From hydro geological point of view since these units are heavily weathered and/or fractured, apheric flood basalt are considered to have high porosities.They are outcropped on top of Keshena ridge west of Nazerth.When inter layered between relatively impervious layers aphyric flood basalts form aquifers at depths that may have good ground water potential.

These aquifers can store and transmit appreciable quantity of ground water and have generally high to very high perm abilities. This is because they are products of fissural eruption and are highly vesicular with inter connected pore spaces.

5.2.1.3 Bofa units

These units have very well developed columnar joints. In the study area of Bofa locality the static water level of ground water is about 26 meters (See Groundwater level of Bofa Borehole #2). This is due to the presence of these vertical joints where most of the precipitation infiltrates through it.

5.2.1.4 Recent alluvial deposits

These unconsolidated deposits in the study area are due to mainly Awash River deposits consisting of gravels and sands. The saturated and non-cemented parts of these deposits can be considered as the major aquifers in the area. Alluvial deposits are deposited along Awash River courses and flood plain loose sediments of silts, clay, sand, gravel, cobbles and pebbles of different sizes and shapes.

The alluvial deposits have characteristic textural variability that causes much heterogeneity in the distribution of hydraulic properties. Porosity and Permeability are dependent on the shape, sorting, packing and size of grains distribution. In alluvial deposit the porosity ranges from a minimum of about 20% in coarse poorly sorted alluvium to about 90% in soft mud (Davis, 1966).

The upward changing trend in grain size of the recent alluvial deposits is complicated by intercalations of various pyroclastic materials such as volcanic sand, tuff, ashes and pumice. Near to these recent alluvial deposits (Melka Hida Well Field) there are some productive wells. Among them Sand layers with interbeded basalt are the main aquifers of Melka Hida Well #1, 2 & 3. On the other hand, Aphanatic fractured basalt, pumice with tuff intercalation and highly weathered pyroclastic rocks are main aquifers of Melka Hida well fields.

According to the well logs by manhasbot and yirga (1989) have a thickness reaching up to 18m near the river bank and decreases moving away from the river. Delineation of the recent alluvial deposits is made on the Nazareth-Dera Geological sheet.

The present of clay and silt on the surface of recent alluvial deposits especially on the flood plains gives rise to a limited direct recharge from rain.

The grain size of these recent alluvial deposits is getting coarser towards up stream of the Awash River. Coarse grained sedimentary deposits have high primary permeability. This has been justified from pumping test data of Melkasa Hida and Wonji plantation well fields. Melka Hida is situated down slope of high land recharge zone and it can receive much water from large joints of these high lands. Productivity of Melka Hida wells is getting less away from the Awash River. This implies that the near by river aquifers have high to very high permeability.

5.2.2 Moderate to high permeability group

They only permit the transport of ground water in small quantities which may be significant when the flow in a ground water basin is considered.

5.2.2.1 Highly weathered & fractured Ignimbrites (Nazareth Units)

These hydrogeological units are belonging to the so called Nazareth group volcanics (the oldest volcanic rocks underlying the rift). They form the deepest aquifers in the area. These ignimbritic layers in between basaltic flows, overlying the older Nazareth group volcanics, also form locally important aquifers and their direct out crop in some part of the area is visible. Although direct out crop is not visible, the presence of Mesozoic marine sediments underneath the volcanic cover can’t be ruled out. Qualitative observation shows that the ignimbritc aquifers have relatively lower permeability as compared to the shallow volcano-lacustrine sediments.

5.2.2.2 Porphyritic vesicular basalts (Boseti unit).

These units are outcropped north east of Awash Melkasa of the study area. In general vesicular basalts have high vesicles and if these vesicles are inter connected by fractures, Joints, cracks and/or are heavily weathered these basalts as a whole show moderate to high permeability in the study area.

5.2.2.3 Unconsolidated or reworked volcano- Lacustrine sediments.

In the Nazareth-Dera map sheet, these hydrologic units consist of soil and Reworked volcanic, soil and reworked lacustrine deposits, Talus and lacustrine diatomites. All these unconsolidated deposits are belong to moderate to high permeability group.

The soil and reworked lacustrine deposits are compact and composed of mainly fine to medium grained material. Wonji soil and reworked lacustrine sediments are good ground water potential area with in the study area and the groundwaters are shallow and often exploited via hand-dug wells. In general in this formation gravels and coarse sands are good aquifers where as clay and silt are aquitards. Within wonji lacustrine deposits even though the aquifers are of the same system, there are variable layering of deposition. About 40 hand dug wells and 30 bore wells have been drilled in different places of Wonji area. In this part of the study area about 50m thick lacustrine deposit with clay and silt at the top, sandy to gravel and pebble at the bottom was reported. Although many hand dug wells of lacustrine deposits are of the same system, Alem Tena, Bokugurabo and Kuriftu dug wells show indication of pollution.

As it has been noted from Brothers Flour and Biscuit factory borehole analysis of the drill cutting samples collected at interval of 2 meters revealed that the main water bearing formations are the weathered and reworked volcanic fragments encountered at depth of 144-168 meters. As observed from the drill cuttings, some of the cutting materials are light colored and well rounded with weathered joint walls, which exhibit favorable conditions for ground- water movement. These aquifers have generally moderate to high permeability.

Talus and lacustrine diatomite are also belonging to this permeability group.

Good aquifers can be found at the contact zone of sedimentary formation and bed volcanic rocks within the flood plain near foot slope of fault escarpment of NE side of Gedemsa. This is because the valley fill sediments beneath the Gedemsa Mountain may receive direct recharge from the upper near by recharge zone. BH-17 (Wonji Catholic Church), HDW4 (Batitifu) and HDW7 (Detamo dug well) are located within this area. Ground water table is closer to the surface in the lower elevations of intermountain basins in rugged-terrain. This is also true for Nacid #3 borehole data in the study area. At the locality of the Batitifu (Garagadi) flood plain ground water contours cross the Awash River at 90^0. This implies that the Awash River recharges the groundwater.

Soil and reworked volcanic at Nazareth, West and North West of Nazareth were accumulated as a result of the erosion of the surrounding highland volcanic rocks. The types and development of soil reworked volcanic in any one location within the area is a function of the nature of the parent rock, the climate to which it is subjected and the time of sub aerial exposure, determining the degree of weathering. They are unconsolidated materials consisting of sandy, silty soils, and reworked volcanic products such as Aluminium Sulphate W.#1 aquifer. It was a reworked coarse sand to gravel sized sediments. Their thickness varies considerably from place to place within the study area.

5.2.3 Low to moderate permeability group.

From their hydrogeological nature, all the following lithological units of the study area belonging to this group and they may well contain ground water.

Interarift Acidic Complex of Gedemsa unit (east and north east of Gedemsa):

-Brown co-ignimbrites ash fall deposits about 10m thick, and

-Welded light-green ignimbrite rich juvenile clasts of pantelleritic and basaltic Composition followed by unwelded pumice rich pyroclastic flow about 16m thick.

-Resurgent and fissural pantelleritic and commenditic lava domes.

Dera-sodere unit:

-pantelleritic lava domes and flows interleaving with obsidian layers

-Light-gray pumice fall deposits associated with lava domes and have a thickness of 3-4m.

Keleta unit:

-Mainly welded ignimbrite sequence characterized by fine-grained brown-gray igrimbrite and much welded glassy ignimbrite, thickness: up to 100m.

Boku-Tede unit:

- Highly fractured plagioclase-porphyry pantelleritic lava domes with associated Obsidian layers and pumice fall deposits, embedding discoidal shape Obsidian bombs.

-Unwelded coarse-grained brown ignimbrites rich in pumice clasts and lithic fragments. Thickness: up to 80m.

-Well stratified coarse-grained pumice fall deposits with interlayered paleosols. Thickness: 10m.

Floor complex of Nazareth units:
Welded coarse-grained green ignimbrite characterized by dark vitrophyric fiamme and lithic fragments. Thickness: more than 100m.

All the above volcanic formations are generally considered low to moderate permeability group.
Dhera area consists out crops of Dera-sodere units. These included pantelleritic lava domes and flows of interbeded with obsidian layer; light-gray pumice fall deposits associated with lava flows and mainly unwelded ignimbrite units interbeded with paleosols. Also mainly welded ignimbrite sequence characterized by fine grained brown gray ignimbrite exposed around in Dera-Sodere area. Borehole (Bh-15) was drilled up to 268.2m below ground level in1962 E.C. its location is 5km west of Dera town. The water strike depth was 256m below ground level and the water was found to be hot for drinking purpose. This site was located on an out crop area of fine grained unwedded ignimbrite interbeded with paleosols. This area is characterized by a thin vegetation cover that can not help for infiltration (the process of water entry in to the soil) and percolation (the movement of water within the soil) during precipitation. Besides the top silty clay soils of the area are not pervious as a result giving rise to surface runoff.
Areas south of sodere and the surrounding of Dera town are characterized by very deep and low permeability formations. Due to poor groundwater potential in this particular area, a number of bore wells have been drilled and become non productive.
If we compare the water strike depth of groundwater in wonji and Dera localities from existing drilled boreholes, it shows a great variation in productivities of wells and water strike depth. In wonji area groundwater is very shallow where as in Dhera area the groundwater depth is extremely deep. This phenomenon between these two very nearby areas might be an indication of the presence of a barrier in between them such as NE-SW trend faults. This should be checked by detail and appropriate Geophysical survey studies.

The factors to estimate qualitatively the permeability value of the area are the existing surface structures, geomorphologic conditions, Geology, type of aquifers, total thickness, water strike depth and lithological texture.

In Dhera localities other factors such as secondary infilling of clay and calcite minerals reduce infiltration capacity of the area.

In the study area ryholitic rocks mainly form domes and ridges. The pantelleritic lava domes and flows associated with pumice fall deposits and obsidian layers are largely exposed east and north east of Dera town. They have very poor primary and secondary porosities.

There are also other place of ryholitic lava domes and flows out crops in the study area such as NE and SE of Nazareth, south of Nazareth (Boku ridge). They might be serving as a potential recharge zone. Although Boku ridges are highly characterized by a number of regional faults, the fractures could be closed by weathering products and the deposition of secondary minerals. The hydrothermal activities occurring in Boku area may facilitate the transportation and deposition of secondary minerals that lead to permeability reduction.

In the study area there was no well log that indicates any aquifer made up of rhyolitic lava domes. This implies that these rocks are generally considered to be very poor aquifers and are impervious. They have generally low to moderate permabilities.

5.2.4. Low to very low permeability group

Hydrogeologically the following lithological out crops are not good aquifers. These are:
From intrarift Acidic complex of Gedemsa unit:

- Pumice fall and hydromagmatic wet surge deposits, thickness: 4-5m.
- Pantelleritic pumice fall deposits, thickness: up to 10m
- Densely welded fine-grained & green ignimbrite, Thickness: up to 50m.
- Mainly unwedded ignimbrite units interbeded with paleosols. Ignimbrites are characterized by fine-grained brown- pink matrix containing small pumice clasts and few lithic fragments. They have up to 5m thickness.
- All fresh basaltic, ryholitic and trachytic rock units.

These rocks generally have low to very low permeabilities and porosities. They do not transmit any water; neither does it contain groundwater in appreciable quantities in the area. However locally, these rocks can be permeable due to weathering and the presence of fractures. Besides massive lavas and densely welded ash flows (ignimbrites) present very low permeability.

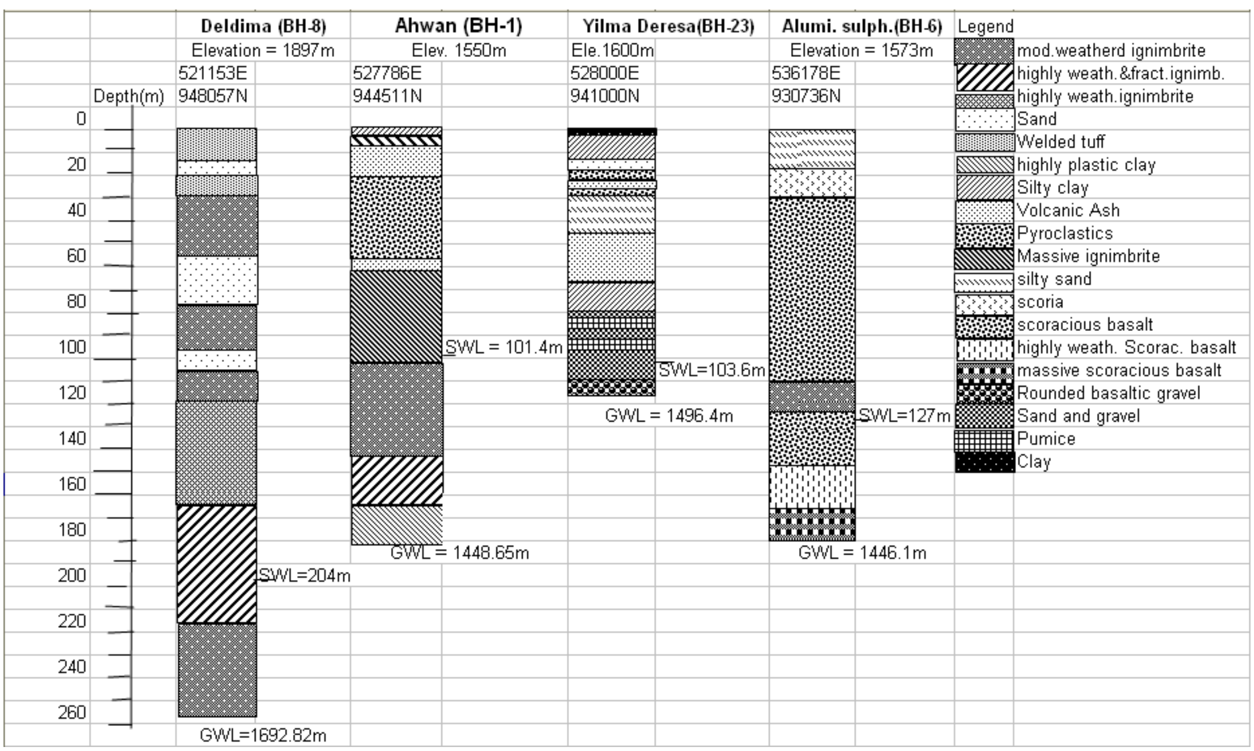


Figure 5.2 Hydrogeologic sections from NW direction of the area to Awash River

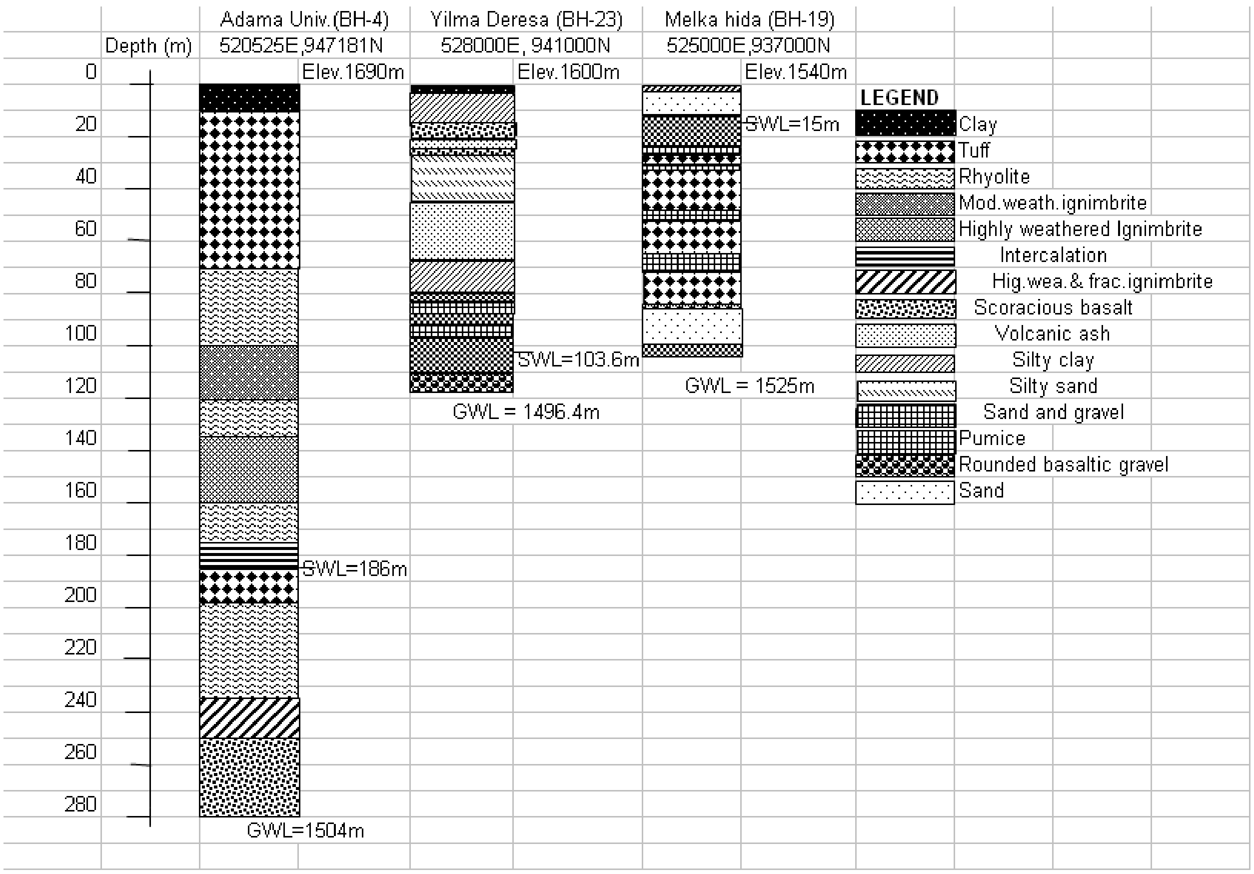
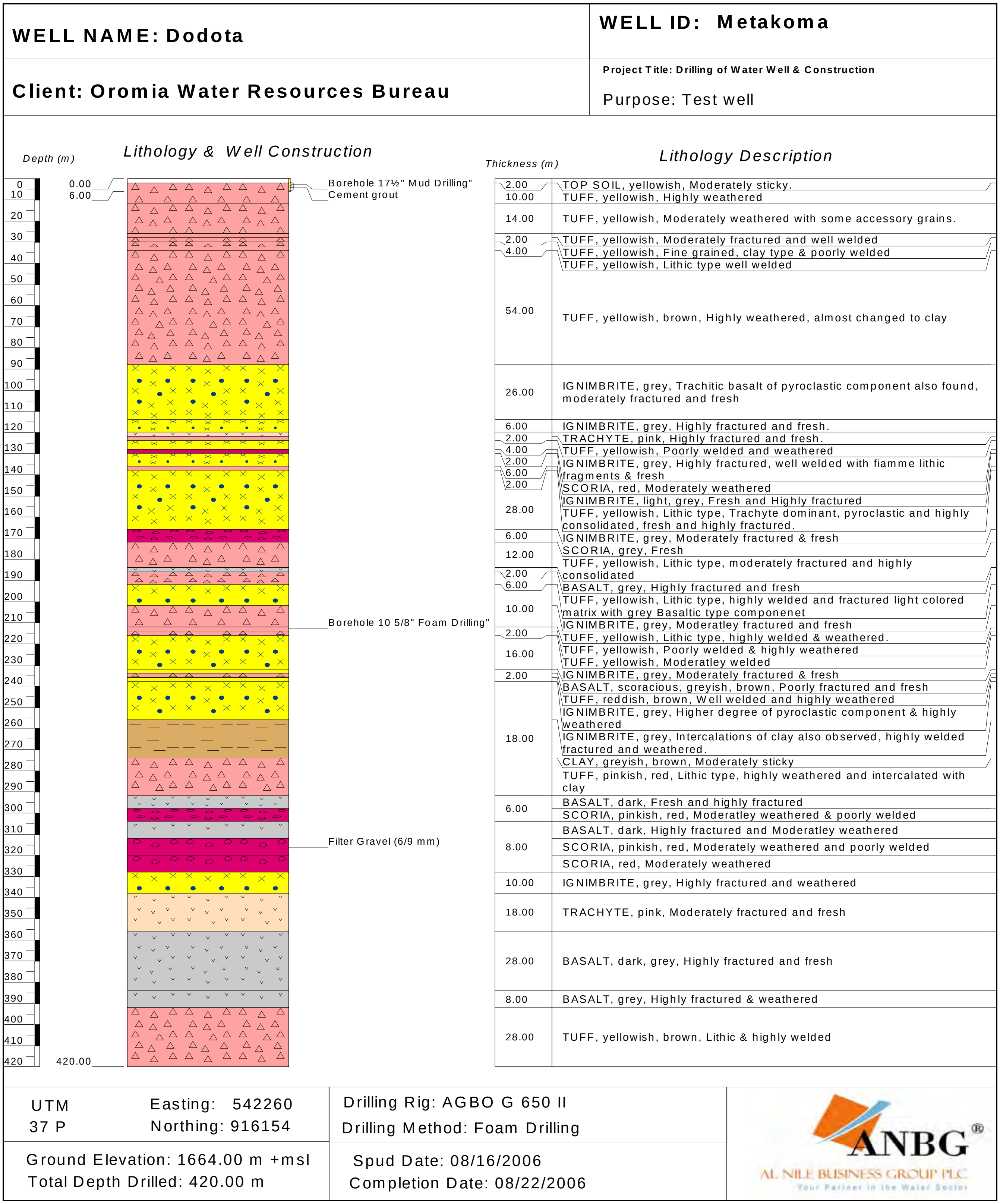


Figure 5.3 Hydrogeologic sections from NE direction of the area to Awash River



Static water leverl = 295.45m

Figure 5.4 Lithologic log of Metakoma borehole (BH-37)

Source: Al Nile Business Group (ANBG)

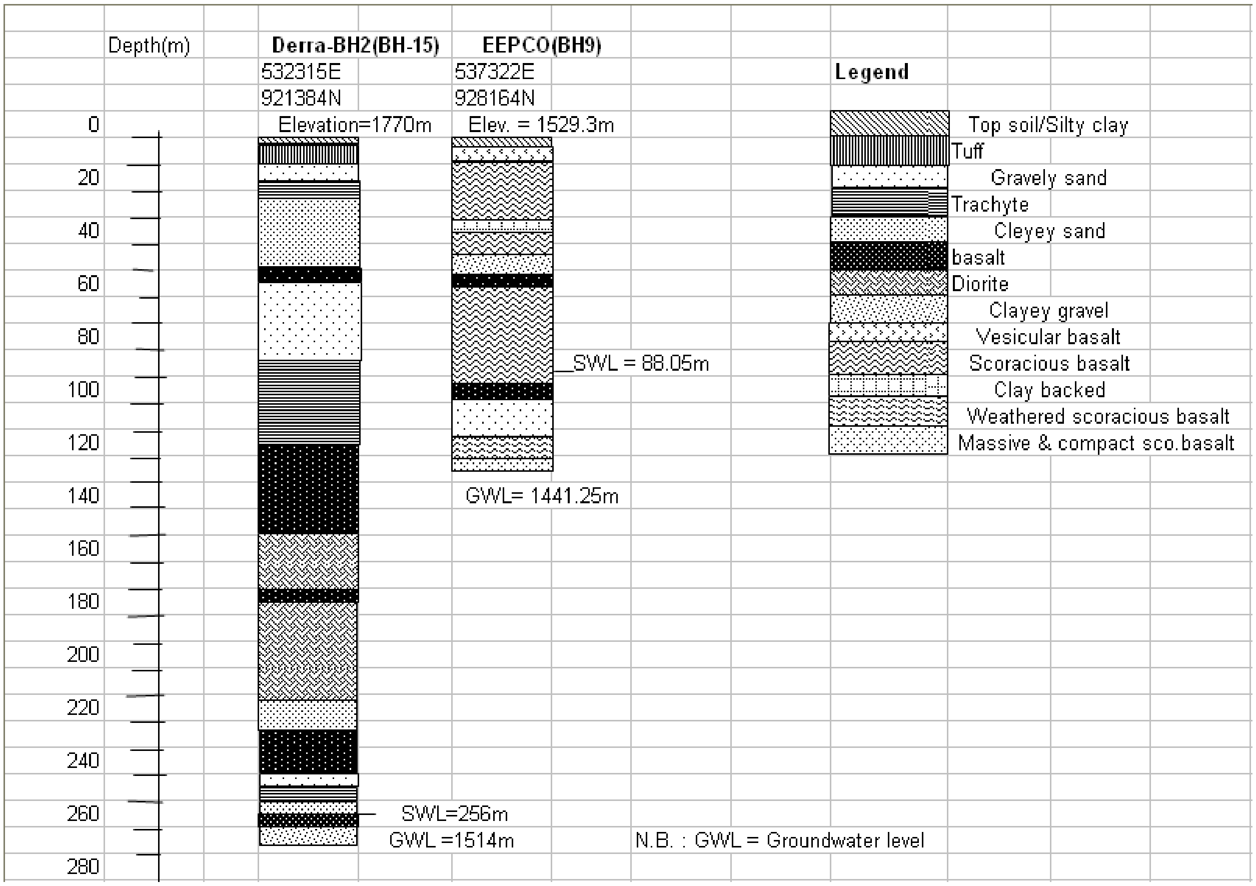


Figure5.5 Hydrogeologic sections from WS direction of the area to Awash River

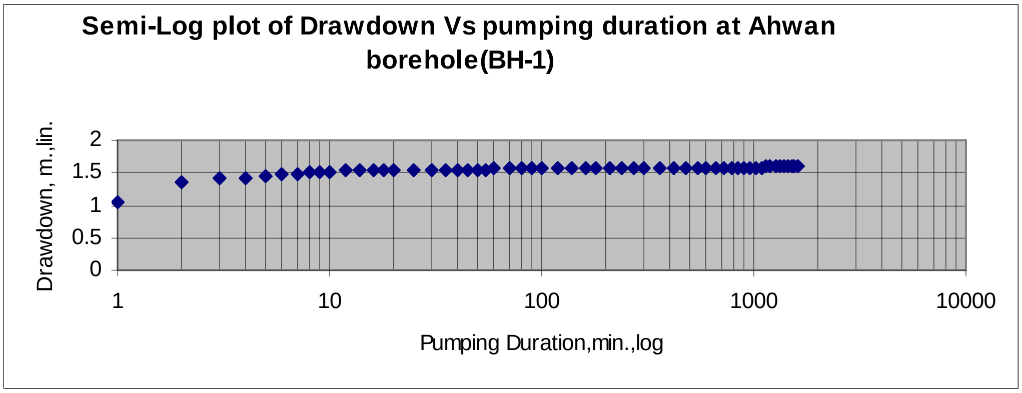
5.3 Types of Aquifers in the study area

5.3.1 Unconfined, Semi-confined and fully confined aquifers in the Catchement

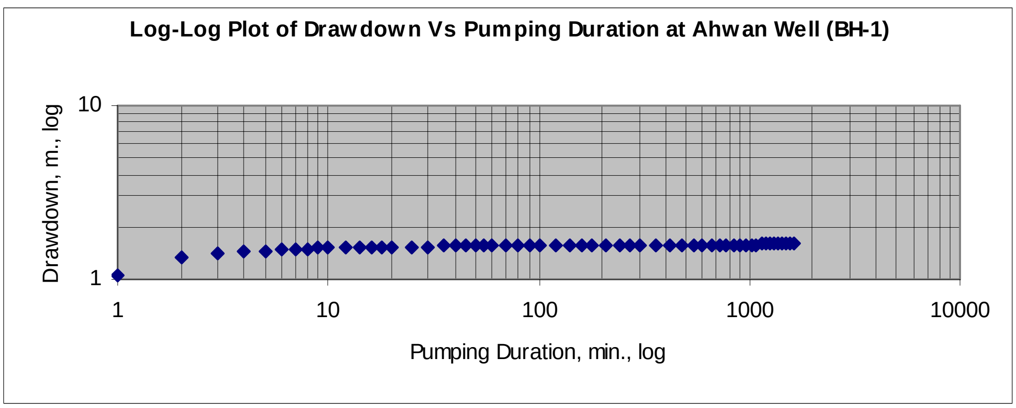
Aquifer classifications in an area have been made on the bases of the following ways.

-The first method utilizes on analysis on geological logs of bore holes and shallow wells that are distributed within the study area. In Wonji area lithological logs of shallow wells situated very near to the surface. The lithological log analysis is supported by the general geological set up of the study area. Most of the deep wells have aquitards as a confining layer. This method of classification of aquifers in an area utilizes aquifer location in the groundwater basin, and the position of their associated water levels.

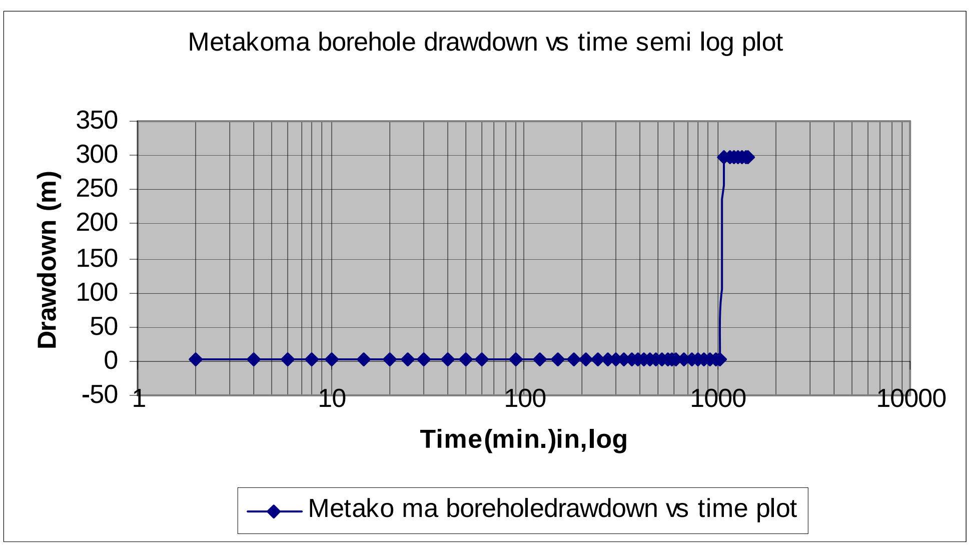
The second approach relies on pumping test records and the construction of diagnostic plots and specialized plots. Diagnostic plots are log-log plots of drawdown versus time since pumping started. Specialized plots are semi-log plots of drawdown versus time; they are specific for a given flow. Both plots must be constructed, because the diagnostic value lies in the typical combination of the log-log and semi-log plots. The choice of the theoretical model is the crucial step in the interpretation of pumping tests. This means that besides the log-log and semi-log plots of the drawdown versus time, all other relevant hydrogeological information, for example, lithology, boundary conditions, should be taken in to account (Look at Fig.5.6 Diagnostic and Specialized semi-log and log-log plots for some representative boreholes).



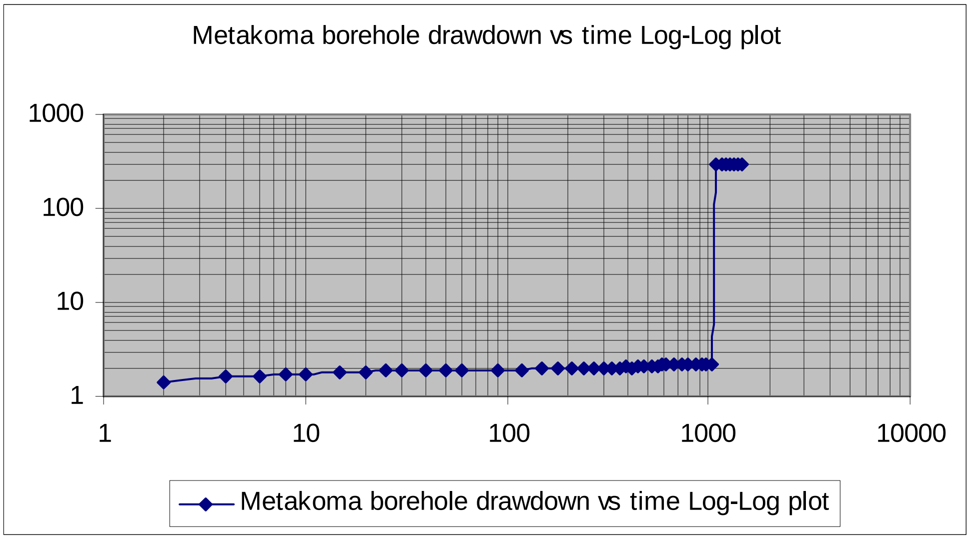
a)



b)



c)



d)

Figure5.6 Diagnostic and specialized plots for some representative bore holes

Comparison and analysis of the plots with the theoretical models show the presence of unconfined, semi-confined and confined aquifers in the investigated area. In the study area there are boreholes drilled by Governmental, Non-governmental and Private Contractors which have proper well completion record. From these well completion reports interpretation on the first water strike depth of the main aquifers and the final water level rests after completion of the drilling process gives a hint to know the aquifer type.

On the bases of the above analysis discussed, three of the aquifer types are precisely known within the study area. The unconfined aquifers (aquifers which are in direct contact with the atmosphere) are extensively crop out in the west south parts of the area which are around Wonji and along Awash River (such as Melka Hida, Gergedi up to Koka Dam) to a depth range of 4-103.6m below ground level. Their phreatic groungwater level varies from 2.5mts up to 62m below ground level. The common aquifers in these part of the study area are mainly alluvium, lacustrine sediments, sand layers, pumice, Tuff, aphanatic fractured basalt and highly weathered pyroclastic rock (sand and gravels). They are underlain mostly by fresh ignimbrite and trachyte.

Semi-confined aquifers are the most common to form the aquifer system of the area. Such type of the aquifer system are out crop in the central and eastern part of the study area at a depth range of 100-130m with an overlying (or underlying) aquitards mainly moderately to highly weathered ignimbrite and scoraceous basalt. Groundwater levels representative for semi-confined aquifers are usually above the top of the aquifer.

The confined aquifers are aquifers which are covered by aquicudes or aquifuges in both at the top & bottom. They are mostly found in the area at a depth, starting mainly below 145m below ground level. When representative groundwater levels are registered in a well penetrating a confined aquifer are well above the top of the aquifer. Borehole drilled up to 202m below ground level at Deka Adi (north of Nazareth) the aquifer is confined which was a highly weathered vesicular basalt. It was fully confined by massive rhyolite at the top and massive aphanatic basalt at the bottom. The static water level is 175m below ground water. The groundwater level generally decreases towards Awash River from south but not from North direction due to the presence of transverse fault barrier. However a higher hydraulic gradient is generally expected from south-east to Awash River. In general, the major aquifers are basalts belonging to different age and ignimbrites covering the rift floor. Ignimbrites belonging to the so-called Nazareth group volcanics (the oldest volcanic rocks underlying the rift) form the deepest aquifers. Ignimbritic layers in between basaltic flows, overlying the older Nazareth group volcanics, form locally important aquifers. Although direct outcrop is not visible, the presence of Mesozoic marine sediments underneath the volcanic cover cannot be ruled out.

5.4 Hydraulic characteristics of aquifers

During groundwater resource potential evaluation of an area, pumping tests are the most important method in analyzing the hydraulic characteristics of aquifers. In the study area most of the time the hydraulic parameters such as transmissivity(T), hydraulic conductivity(K) and storage coefficients(S) have to be determined when there are no piezometers and the water level changes are measured only in the pumped well. Such types of pumping tests are called single well tests. Curve fitting methods and Jacob's straight line methods have been developed to analyze single well tests, even when the early time data are affected by bore hole storage (Kruseman et al., 1990).
Theis non-equilibrium formula could not be applied to calculate the storage coefficient of the aquifers because the pumping tests were conducted without piezometer(s). However the T and K aquifer parameters were determined by graphical analysis of drawdown using Jacob's straight line method. The raw data on constant rate pumping test which have been conducted for some of the wells in the study area are shown (Annex 15A, 15B up to 19A, 19B).

Transmissivity was calculated by using a formula given by:

$$T = \frac{2.3\,Q}{4\Pi\Delta s}$$

Where, Q = the pumping rate in m3/day

Δs = the slope of the time-drawdown curve per log cycle

T = transmissivity m2/day

K = hydraulic Conductivity, K=T/B,

B = Saturated Aquifer thickness

A plot of s' versus t/t' on single log paper (t/t' on the logarithmic scale) will yield a straight line with a slope:

$$\Delta s' = \frac{2.3Q}{4\Pi T}$$

Where, $\Delta s'$ = the slop of the residual drawdown versus time ratio plot per log cycle.

The residual drawdown versus time ratio plot provides more accurate results than its drawdown versus time plot. The interpretation of results from Jacob's graphical method for each of the wells is mainly based on the literatures of Driscoll (1986), and Kruseman and de Ridder (1990).
In the study area all boreholes are pumped at a constant pumping rate for a minimum duration of 24 hours, and discharge rate and drawdown measurements are made on the pumping wells. The absence of piezometer or monitoring well in and around the study area and failures in considering nearby functioning water wells as a piezometer during pumping schedule of the work limits the measurement of storage coefficient that strongly influence on the drawdown in the well and interpret the aquifer system of the area under influence. During constant pumping test type steady

or equilibrium is reached and most of the data analyses were made using the formula developed by Cooper and Jacob, 1946.
Pumping test data are analyzed and evaluated mainly:

-In order to approximate some aquifer Characteristic,

-In order to estimate the efficiency and performance of the well (specific capacity and specific yield).

-In order to select proper pumping equipment.

The pumping test analysis results of different wells are portrayed in figure 5.6 to 5.8).
The Nazareth Ahwan Bore hole was pumped at rate of 3l/s or 259.2m3/day (Q) and the drawdown corresponding to 2880minutes or 48 hrs of pumping is 1.61m. Evaluation of the data by Jacobs straight line method (Fig.5.6) indicates that:

T = 3.3m2/min. == 4746.5m2/day.

Δs = 0.01

B = 25m

K = 0.132m/min.=190.08 m/day, which indicates that the well has very high permeability.

However, from the pumping test data analysis of this borehole, the recovery time was very fast (i.e. 100% in the first 3 minutes and it takes less than one logarithmic cycle).This implies that it is impossible to plot residual drawdown versus time ratio. So computation of data analysis is depending on the result of drawdown data only.

Specific Capacity (S.C) and Safe Yield (S.Y):

S.C=Maximum yield (l/s)/Maximum drawdown (m) = 3 l/s /1.61m=1.86 l/s/m

S.Y=S.C x Available column of water x o.75 = 50.43 l/sec.

The first few minutes of pumping shows the effects of the casing storage on the time drawdown curve. While the later time data the curve reflects recharging boundary effect on the drawdown. That is the slop becomes flatter when recharge to the aquifer occurred. Hence the more horizontal leg on the curve represents the stabilized drawdown at 1.61m (Figure 5.3).

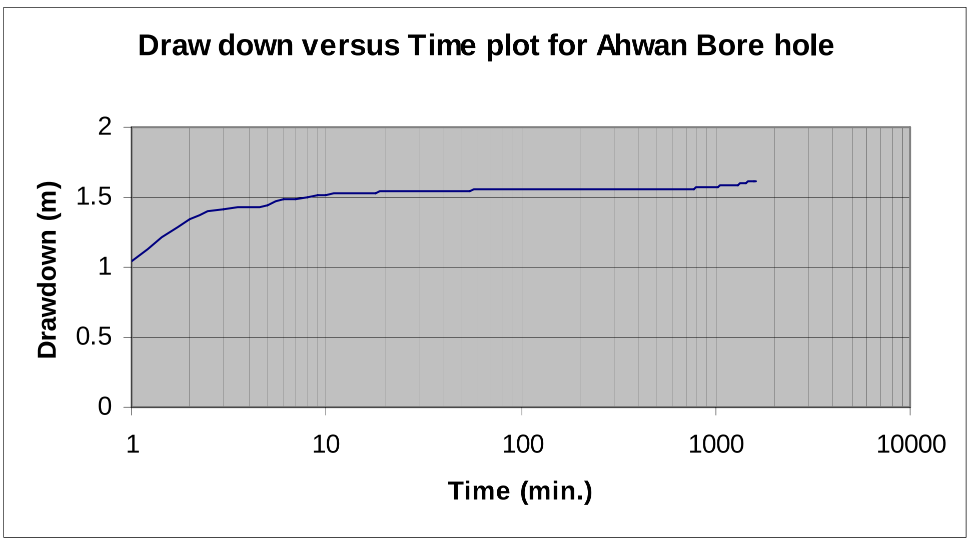


Figure5.7 BH-1 drawdown versus time plot

When recharge within the zone of influence of the pumped well equals the rate of discharge of the well.
The recharge to the aquifer is also explained by the shape of the early part of the residual drawdown versus time ratio plot. This indicates large intercepts at zero drawdown (when a straight line is extended) which is a typical of a recharging effect.

The very fast recovery to the original static water level within a short time in the early portion of the recovery period (almost 91% in one minute) is brought about by recharge.
In general, a recharging boundary was encountered after approximately 1500minutes or 25 hrs continuous pumping of the well.

Awash Melkasa Chemical Corporation bore hole #2:
This deep well was pumped at a rate of 2.5 l/sec or 216 m^3/day. The drawdown corresponding to 1440 minutes or 24 hrs of pumping is only 11.42m.

The following hydraulic characteristics were obtained using straight line method:
From drawdown versus time plot,
Transmisivity = 17 m2/day
Permeability = 0.43 m/day
Specific Capacity (S.C) = 0.22 l/s/m, and
Specific Yield (S.Y.) = 4.52 l/sec.
The computation of the above constant pumping test data analysis depend on the result of drawdown versus time plot only. Because the recovery time is very fast and takes less than one logarithmic cycle.
The graphical interpretation of the time-drawdown measurements (Fig.5.7) indicates that recharge effect occurs after about 1200 minutes or 20 hrs of continuous pumping. The recharge rate is some how equal the pumping as shown by the more horizontal later portion of the time-drawdown curve.

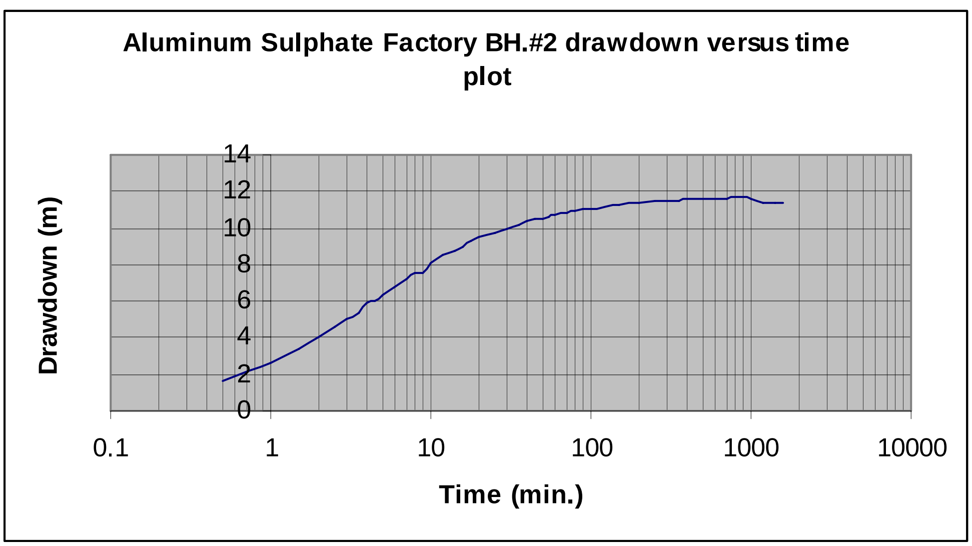


Figure5.8 BH-6 drawdown versus time plot

EEPCO Borehole (BH-9):
The total depth of borehole: 126 mts
Static water Level: 88 mts
Pumping position: 124 mts
Pumping test duration: 48hrs, and
Type of test: Constant

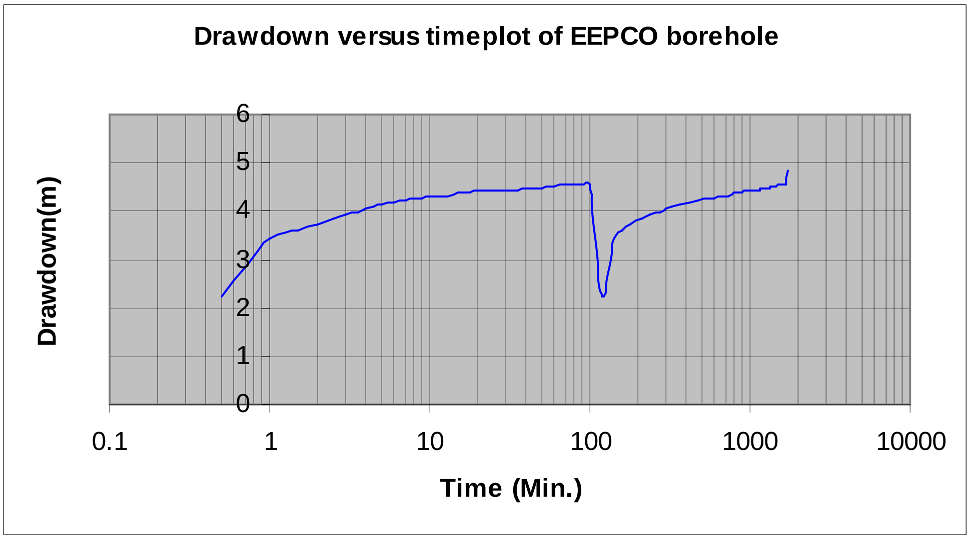
This well was pumped at a rate of 5 l/s or 432m3/day and the drawdown corresponding to 2880 minutes or 48 hrs of pumping is 4.68m. Evaluation of the pumping test data by the Jacob recovery Method (Fig.5.5a and 5.5b) gives that a transmissivity (T) of 332.5m2/day and hydraulic conductivity (k) of 18.45m/day. Specific Capacity after almost 48 hrs of pumping is calculated to be 1.07 l/s/m.
The value of T and K were obtained on the basis of the later part of the residual drawdown plot to avoid positive boundary effect. In this well the drawdown versus time ratio measurements do not provide similar T and K values when computed using Jacob Method. So that in this case it is necessary to take their average value of T and K of the two measurements.
From drawdown versus time plot:

T_1 = 226 m2/day, and
K_1 = 12.5 m/day

From residual drawdown versus time ratio plot,

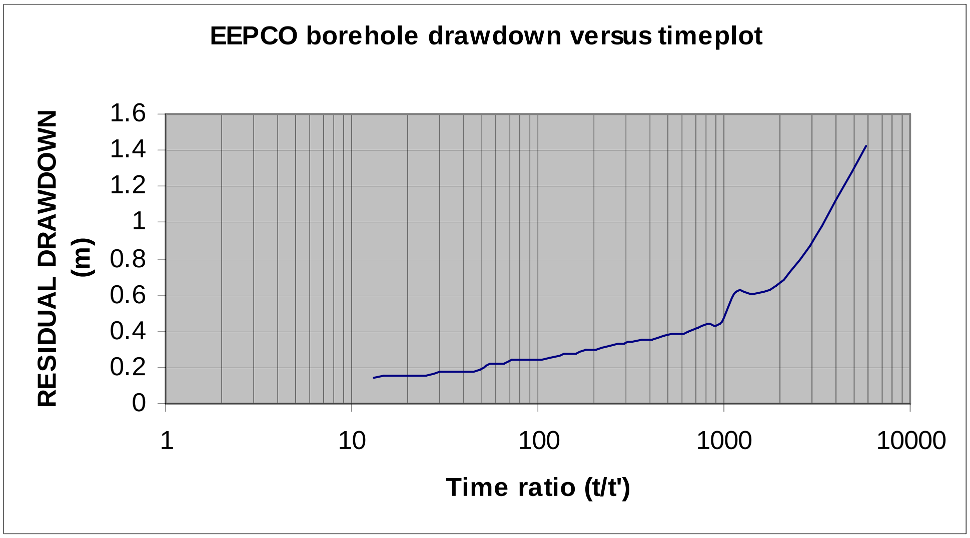
T_2 = 439 m2/day, and
K_2 = 24.39m/day

The average of the two transmissivity values is 332.5m2/day. Similarly the average value of hydraulic conductivity is 18.45 m/day respectively. The specific Capacity and safe yield are 1.07 l/s/m and 28.89 l/sec respectively.



a)

Figure-5.9a: BH-9 drawdown versus time plot



b)

Figure 5.9b: BH-9 Residual drawdown versus time ratio plot

5.5 Groundwater Flow Systems

The flow of groundwater originating from infiltrating precipitation which recharges the groundwater basin in a given recharge area then flows through the basin and may be discharged in areas with a depressed topography at springs, rivers or abstraction wells or it may be transmitted to the regional discharge area in the bottom of the major Valley (Toth, 1966). Unlike many sedimentary basin of Aquifers, which are characterised by groundwater flow continuity over vast regions; the groundwater dynamics and recharge mechanisms conceptualization in volcanic terrain remains a challenging system. This is confirmed by the presence of highly variable groundwater flow patterns, chemistry, groundwater depths, occurrences, and discharge mechanisms.

The general suggestion is that the dominant and even in some cases the sole source of recharge to the aquifers or thermal waters of the area comes from groundwater inflow from the surrounding highlands. Sodere and Gergedi thermal springs are located near known volcanic centers. However, the presence of variable groundwater chemistry, depth and groundwater occurrence in the region suggests a quasi-complex groundwater dynamics. Because of disruption of the lithologies of the area by faults, often aquifers are laterally discontinuous, and flow paths are the function of interplay between tectonic features and secondary permeability related to volcanic structures.

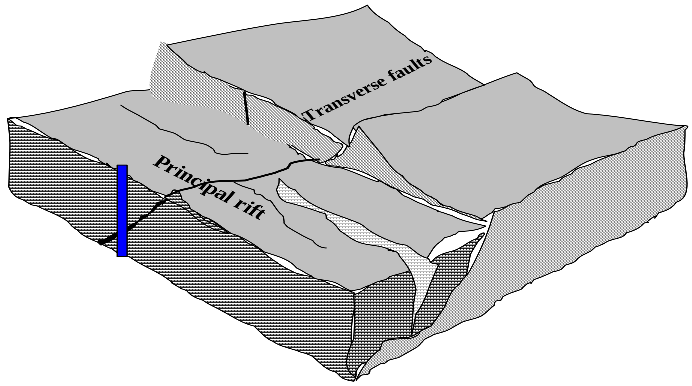
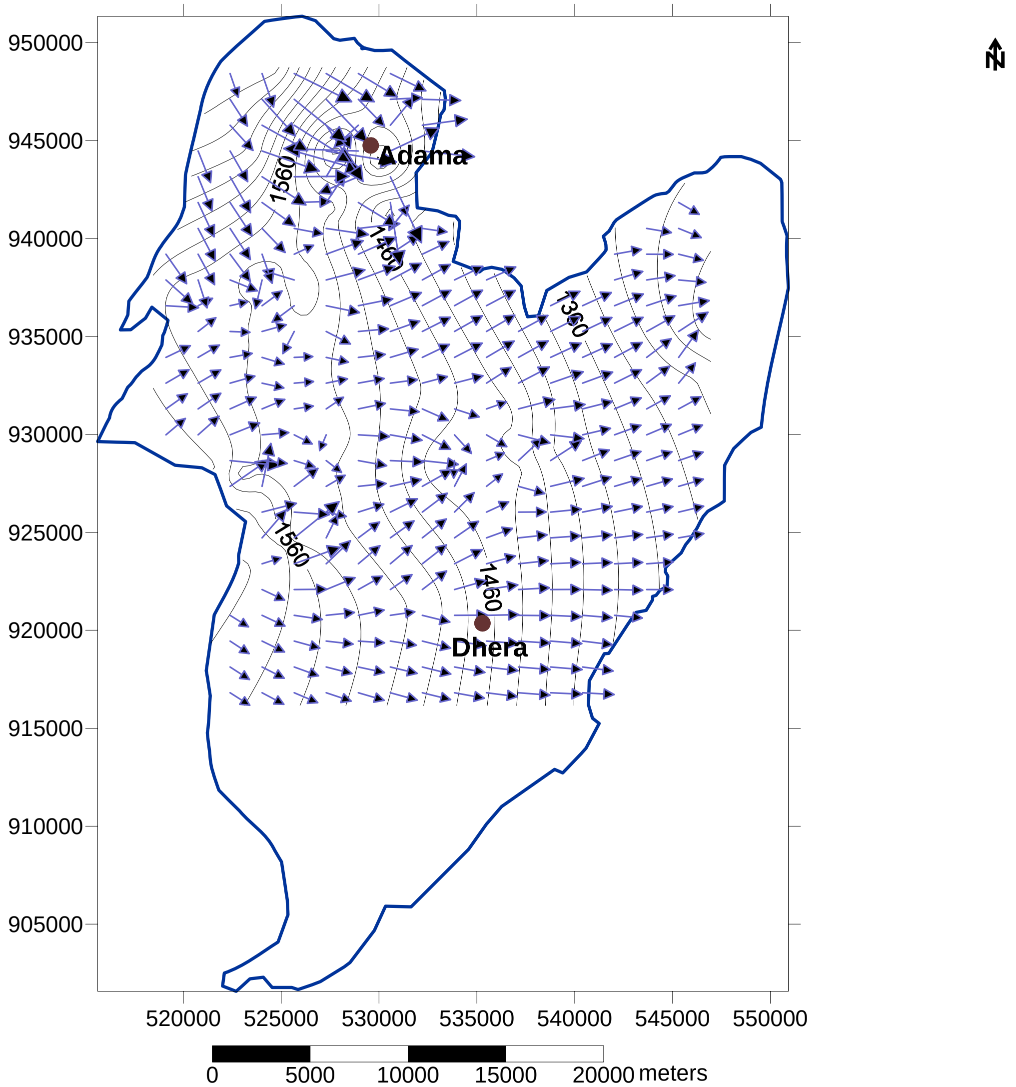


Figure 5.10 Schematic diagrams showing groundwater flows from the bounding high land in to the study area due to cross cutting faults of different orientations.



Legend

Regional groundwater flow directions

Groundwater table elevation contours

Towns

Figure 5.11 Regional groundwater equipotential lines & flow direction map

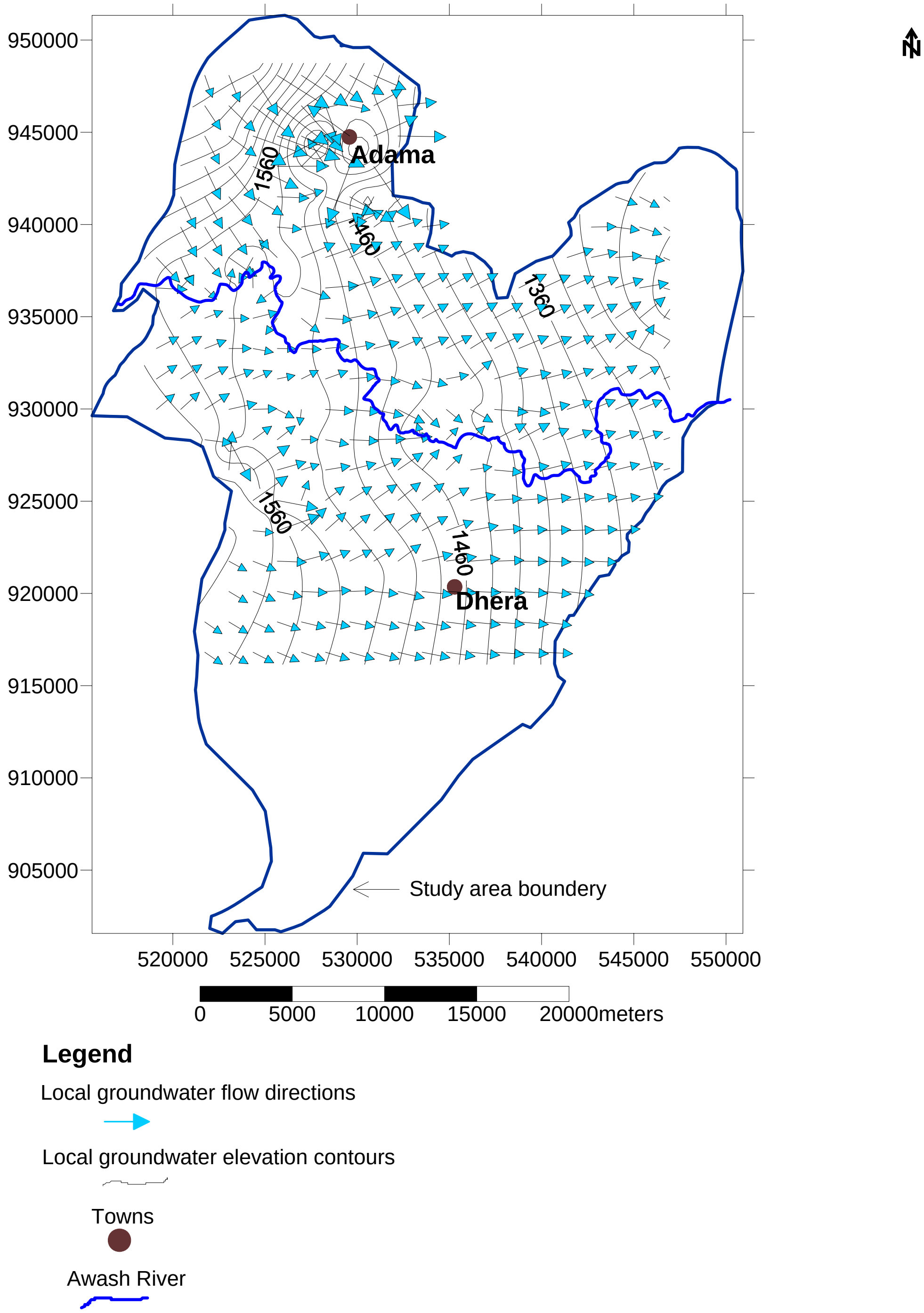


Figure 5.12 Local groundwater equipotential lines and flow direction map

In the study area groundwater flow systems have local, intermediate, and regional components. Due to the presence of tectonic structures such as major and minor faults and fracture systems not only the groundwater occurrence of the region but also flow systems are much complex. Most of the weak zones controlled groundwater of the area flow parallel to the strike direction of the faults. However there exist a groundwater flow across the faults through fracture systems (transverse faults) from the high land recharge area (the plateau groundwater) to the Rift center. This means that in the cases where the Rift margin is cross cut by transverse fault zones, the plateau type waters are channeled in to the Rift Valley and there is the likelihood of higher component of recharge from the plateau.

From the groundwater head contour maps of the area it is possible to understand that regional groundwater flow occurs in the region occupy large areas. This map shows the projections of the equipotential planes of groundwater heads, which are representative for the aquifers in the aquifers system of the study area. Groundwater head contour maps prepared for aquifer systems where the horizontal flow schematization for the aquifers is allowed. With the help of this map, it is possible to determine the precise directions of the horizontal groundwater flows, and, in fact the complete groundwater flow pattern, in an aquifer can be assessed. Since this flow is perpendicular to equipotential planes, the movement is also perpendicular to any projections of these planes in the form of contour lines. In the study area the regional groundwater flow is influenced by local groundwater flow phenomena such as the presence of nearby Koka Dam, water wells (during pumping the wells), dewatering Awash River for Adama water supply and wonji area irrigation etc. These local influences on regional groundwater flow can be observed on groundwater head contour maps.

In the investigated area Volcanic Cones, ridges and fault escarpments act as surface water divide. Faults and fracture systems can act either as barriers or conduits to groundwater flows. However, movement of groundwater at some places is complex and guided by geological structures.

The two primary controlling factors of the groundwater flow systems are topography and geology of the area. Catchments shape, tectonics and structures of the area have also play an important role in the study of groundwater flows, discharge and recharge conditions. Flow nets can be used to study the effect of topography and geology on flow systems. The flow nets of Wonji area follow gentle slop and the groundwater table is parallel to the topography because it obtains much recharge from Koka dam and highlands. Thus a single flow system will be formed. Whereas in the area where the topography consists of rugged terrain (hills and depressions) the flow net shows that several small local flow systems will develop. These show the effect of topography on groundwater flow systems.

On the other hand, in the less permeable layer the flow lines tend to be more vertical and in the permeable layer they are almost horizontal. This shows the effect of geology on natural groundwater flows. From existing springs and geological structures orientation, it is possible to conclude that there is a groundwater inflow to the study area from Koka reservoir. In this area more than 40 boreholes data showed that groundwater in the study area is found at different elevations being coinciding with local zone. The general groundwater flow pattern of the area is towards the low topographic part of the study area from different directions and finally goes out of the basin along Awash River to the east direction.

The Dhera ridge has both intermediate and local groundwater flow systems. At discharge area (around Sodere) the regional flow system may have relatively high water-rock interaction processes and high temperature due to the geothermal gradient (Fetter, 1988). The evidence for this flow systems are the presence of Sodere hot springs of the area (North of Dera ridge) which yield large quantity of water from fault zone that intercepts regional groundwater table from the upper slopes, having high temperature and TDS. Most of the E-W trending major fractures cross the NE-SW faults and act as connector for different groundwater flow systems. Boku Ridge and Gedemsa major NE-SW trending faults don’t have springs. Since their foot slopes were covered by sedimentary deposits and these faults transmit water directly to the low laying formations in the area.

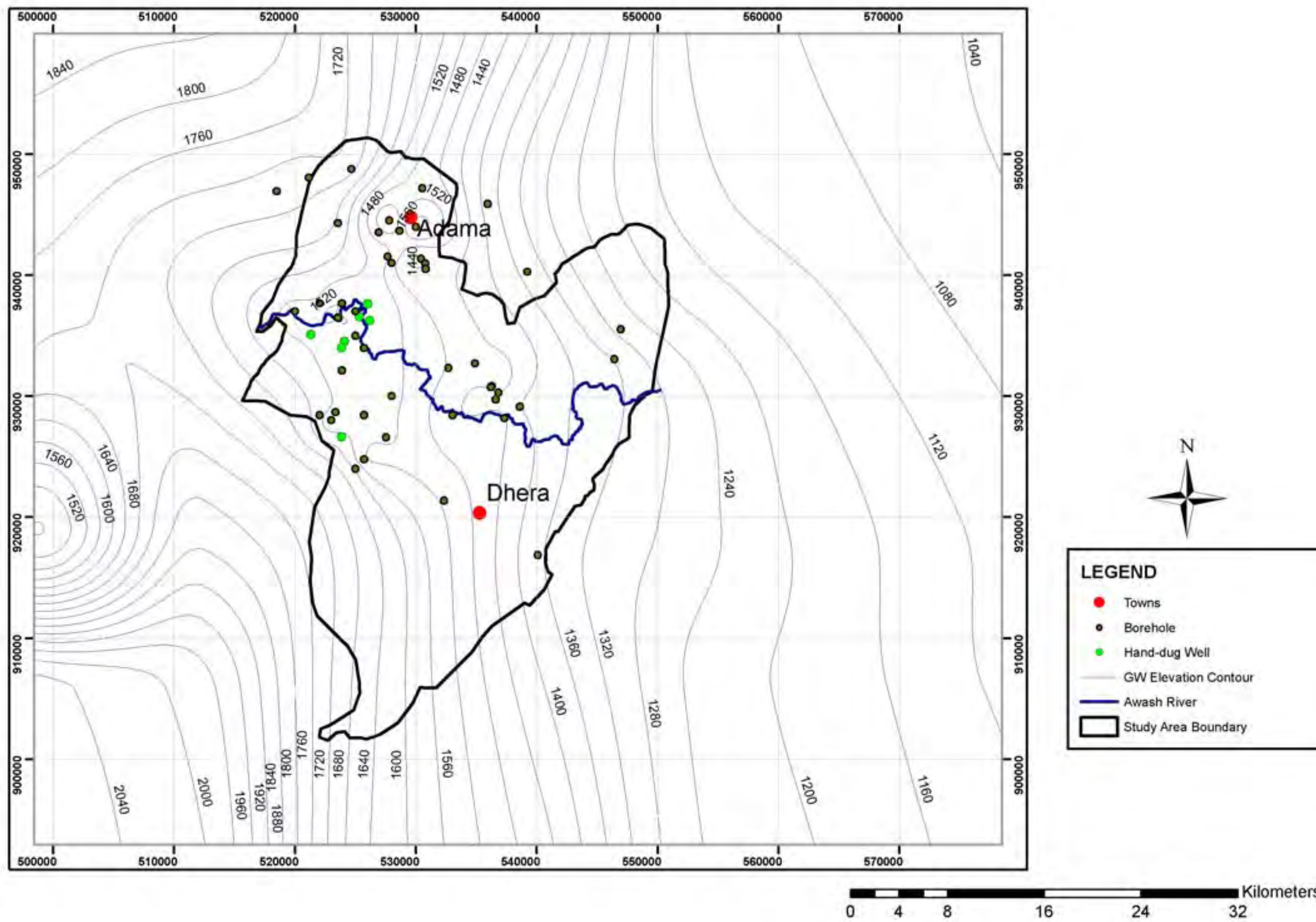


Figure5.13 Regional groundwater eqipotential contour lines map of the study area

5.6 Groundwater Recharge and Discharge Zones

Groundwater recharge is the downward flow of water reaching the water table, entering to the groundwater reservoir. It can be localized, direct or indirect. Recharge occurs to some extent in even the most arid regions and as aridity increases direct recharge is likely to become less important than localized and indirect recharge from the point of view of total aquifer replenishment. The interaction of climate, geology, morphology, soil conditions, and vegetation determines the recharge process. In general, groundwater recharge in arid and semi-arid areas is much more susceptible to near-surface conditions than in more humid regions (Jacobins J. de Varies and lan Simmers, 2002).

There are five basic types of indicators of recharge and discharge areas which include topography, soil and land surface feature, peizometric patterns, hydrochemical trends and environmental isotopes (Myboom,1966a and Toth,1966). According to Freeze and Cherry, 1979, topography is the simplest indicator and groundwater head measurements are the most direct one. Areas with a higher topography are related to recharge areas and areas with a lower topography are point to discharge areas.

The properties of unsaturated soil zone of the soil and the movement of water in discharge and recharge zones assist in making correct assessments for the saturated groundwater basin. Discharge areas may be indicated by abundant vegetation, seepage zones and springs shown on the map.

The groundwater table contour map helps to locate groundwater recharge & discharge Zones. From differences in groundwater head recharge and discharge areas can be identified as well as the depth to which recharging water infiltrates in to the geological formations. The flow vector lines (Fig.5.11 and Fig.5.12) tend to diverge from recharge areas and converge toward discharge areas. The convergence of the flow lines is clearly observed in the down stream of Koka Dam, Central Wonji, around Melkasa area, Melka Hida, Sodere and Western and eastern Nazareth parts of the study area, and the divergence of the flow lines is seen in the Boku and SE of Boku Ridge, WE of Gedemsa, and South part of the study area.

Maps showing TDS values or chemical constituents of groundwater can contribute to the identification of the flow systems in combination with geological maps and sections. Isotopes like ^{2}H, ^{3}H, ^{14}C, and $^{18}O_2$ concentrations are a measure for groundwater travel times which may be used to delineate groundwater flow patterns.

In the flow system approach the meaning of the' hinge line' is the line separating the recharge and discharge areas in a flow system. The lateral boundaries to the flow system are called groundwater divides.

According to Toth (1962, 1963) a selection of the flow system properties, which play an important role in the mapping and identification of flow systems in a groundwater basin, is as follows:

-In the recharge areas of flow systems, groundwater movement has substantial downward components. In between the recharge and discharge areas, groundwater flow may be horizontal or sub horizontal. This may be especially true for the deeper parts of the groundwater system. In discharge areas, there are essential upward flow components.

-The flow directions in the unsaturated zones in the recharge areas the net flow is downward. The flow is upward in the unsaturated zones in the discharge areas.

-Groundwater movement is slow at certain zones along groundwater divides.

-There may be several flow systems nested into each other.

-There may be an increase in the total dissolved solids content (TDS) of groundwater when it moves through the flow system. This means that in the recharge areas the TDS content is relatively lowand in the discharge zones it is relatively high, and

-A flow system has its own specific chemical composition. This means groundwater in other flow systems may be quite different in chemical composition.

In general by giving due consideration to the distribution of TDS values, groundwater types and travel times flow systems can be identified.

5.6.1 Groundwater Recharge Zones

Recharge of groundwater depends on many factors such as the presence of nearby water bodies and weak zones, the permeability of geological formations, water table depth, vegetation cover and slope of the area. In the area the major source of groundwater recharge are Koka Lake and Awash River. In general groundwater recharge is possible from three different sources:

- -Through NE-SW oriented main open fractures which used as conduits in the area
- - Local precipitation during rainfall season around the area, which is less important than localized and indirect recharge from the point of view of total aquifer replenishment.
- - The Awash River and Koka Reservoir

From wells drilled in the area, it is possible to classify the groundwater system in to two major types. These are shallow groundwater from the alluvial and lacustrine deposits and deep circulating groundwater system below these deposits. Therefore the main recharge for shallow aquifer system comes from Awash River and Koka Lake whereas the deep groundwater system originates from the highlands which are mainly controlled by fractures. The principal source of aquifer recharge in the area is seepage of water from the Awash River and Koka Lake. Direct infiltration of rain fall to the groundwater system is not a major component of recharge to aquifers due to small rainfall amount and high evapotranspiration.

Wonji area which is situated within a series of SW-NE trending closely set parallel extension faults (Which control the groundwater flow and occurrence) is one of groundwater discharging areas and categorized as a high groundwater potential area.

In the area the water table is below the water surface this suggests that recharge occurs by influent conditions. Groundwater heads merge with the river close to the Koka Lake. But groundwater cannot be extracted in some parts of the study area up to 256mts below ground level such as Dhera.

In the area volcanic cones, ridges and fault escarpments, which act as surface water divide, are the main recharge zones. Recharge of groundwater can take place in several different forms. During rainy season one form of recharge in the area is deep percolation which is caused by excess rainfall. Recharge rates related to deep percolation depend on precipitation rates and varies significantly from place to place in the investigated area. However, the permeability of the soil, the geological formations and evapotranspiration rates of the area also play a significant role.

Another form of recharge in to the groundwater basin originates from Awash River and Koka reservoir. This flow in the study area is a result of a reservoir water and Awash River level being at a higher elevation than the groundwater table (Seleshi Mamo, 1995).This conditions are called influent conditions. This groundwater recharge rate is determined by the difference in Awash River or Koka reservoir level and groundwater table, the wetted surface area of the River or reservoir bottom, and the permeability of the geological formations adjoining the surface water

body. Inflow conditions may even be reversed to groundwater outflow conditions due to seasonal variations in surface water level.
The last form of inflow of surface water into the groundwater basin from water losses is caused by the result of over irrigation in Wonji area. Losses from Wonji area irrigation means water seeping down to the groundwater table due to leakage from cracking canals or due to inefficient irrigation on the cropped land itself. Over irrigation is the surplus amount of water applied to the land in order to maintain a proper salt balance in the soil. This process helps to flush out extra salts in order to avoid their accumulation in the soil.

5.6.2 Groundwater Discharge Zones

The possible groundwater discharge areas within the study area are Wonji area near Awash River and down stream of Koka Dam and through tectonic structures. However, much of the groundwater of the area within the cachment discharged in the alluvial deposits of the Awash River Plains of Gergedi and Sodere. The high discharge area is near down stream of Koka Dam where the groundwater system is controlled by tectonic structures.
It is the area where the outflow of groundwater took place at the upper boundary of a groundwater basin. First of all, spring is a form of groundwater discharge in the study area. An energetic Hydrogeologist is usually able to interpret the location of the spring (discharge area) by picturing it within the geological framework. Around Sodere, Gergedi areas, in the vicinity of Wonji Chatholic Church, Wonji Area and near Koka Dam down stream side, Western and Eastern Nazareth part of the study area are discharge areas.
Another form of groundwater discharge is the capillary rise of water from shallow groundwater tables. In the soil zone this water evaporates directly from the soil skeleton transpires through the roots and leaves of the plants. The rate of capillary rise depends on the depth to groundwater table and the type of soil or rock material. Except loamy soils for most soil types the capillary rise (upward flow rate) from groundwater tables deeper than 1m below the root zone almost non-existent. The capillary rise of loamy soils is in the order of 2mm/day from water tables as deep as 1.5 to 3m below the root zone. The groundwater discharge in the form of capillary rise is usually a local and temporal Phenomenon. It is local because the process only takes place in areas with shallow groundwater tables, and temporary because it happens on during dry periods.
A third form of groundwater discharge is the outflow of water from the groundwater basin into surface water bodies (Awash River and Koka Lake).This discharge is the result of Awash River, Koka lake level being at a lower elevation than the groundwater table. This is called an effluent condition.
The last form of groundwater discharge in the study area is the abstraction of groundwater using artificial means. In the region, the community exploits subsurface water both by boreholes and Hand dug wells. The main factors that determine the abstraction rate are the permeability and thickness of the groundwater basin. The other factors are the extent of the groundwater basin, the recharge into this basin, the available drawdown, to a certain extent the dimensions of the wells.

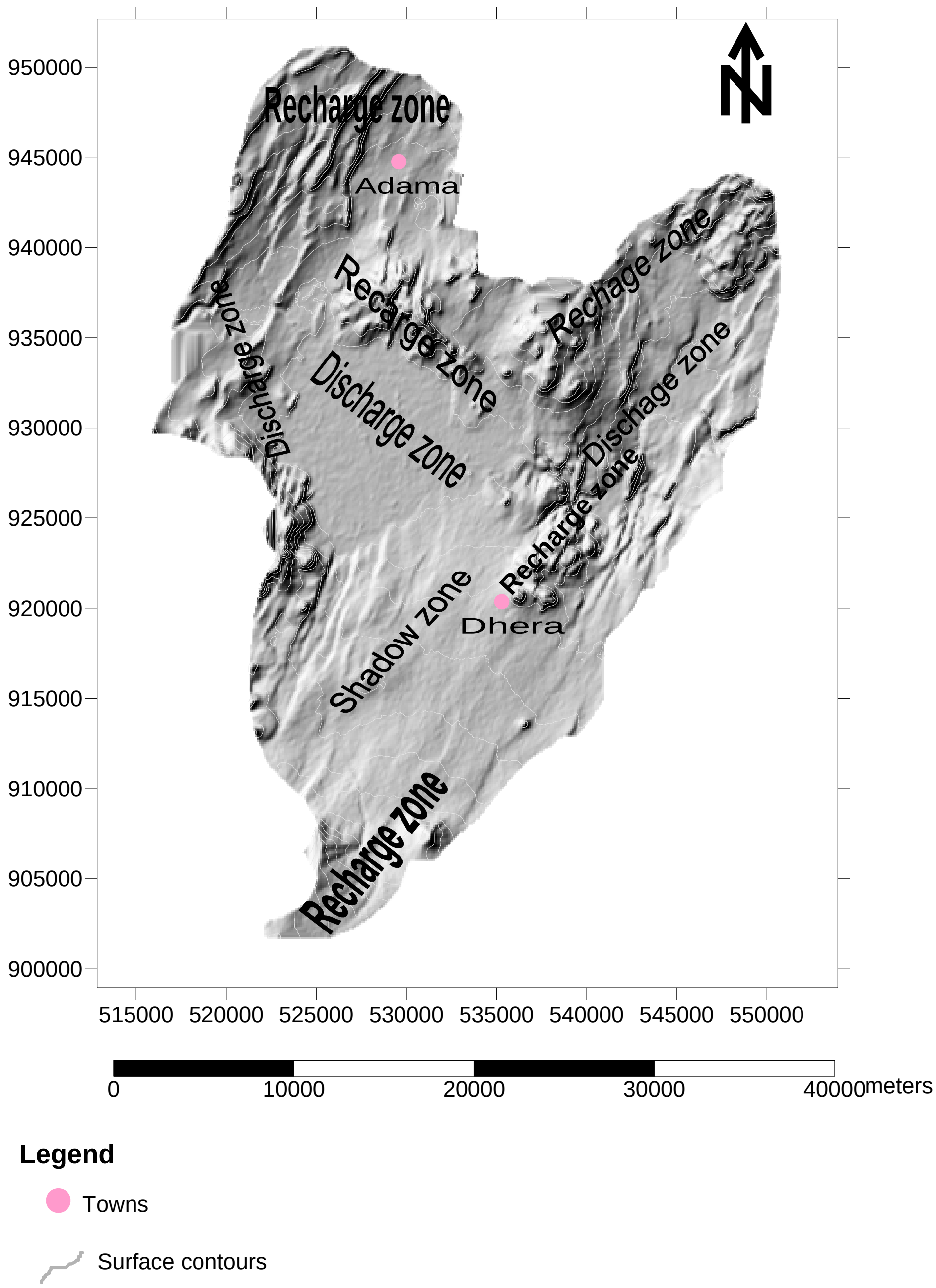


Figure 5.14 Recharge and discharge zones in inferred from surface elevation contours

5.7 Groundwater-Surface water interactions

Surface water and groundwater are not isolated components of the hydrologic system, but instead interact in a verity of physiographic and climatic landscapes (Sophocleous, 2002).
In many regions most surface water features generally interact with groundwater. Measurement of water level is important to determine the interaction between ground and surface waters. The basic principle and relationship to show the interaction of groundwater and surface water in the study area is stated in the following way. According to Winter et.al., 1998 groundwater and rivers generally interact in three basic ways- streams gain water from groundwater through the stream bed (gaining stream), outflows of water from Rivers to groundwater through the stream bed (losing stream), or they do both, losing and gaining at different reaches, as river levels change with the seasons. In all cases based on the hydraulic head, water flows from higher elevation to lower elevation. Water can flow to or from an aquifer which is in continuity with a river, depending on the relative water levels in the river and aquifer. Low water levels in the rivers can induce groundwater flow to the river, and high water levels can reverse the flow and produce losses from the river to the aquifer. The interaction of these two systems can be checked by looking at the flow vector directions of the groundwater tables contours overlapped with the drainage networks.
In the upper part of the study area most parts of the Awash River are gaining water from the groundwater system. By comparing the groundwater table and the stream beds elevations, it is possible to know that some lower parts of the streams in the study area lose water to the sub-surface flow systems. However, there is no well recorded and documented existing data for the Awash River water withdrawals to the Wonji irrigation development activities to determine a long term groundwater-Awash River interaction.

5.8 Possible alternative of water sources for Dhera area

According to Hydrogeology of Nazareth scale 1:250,000 compiled by Getahun Kebede, E.I.G.S. (1985), the Dhera area is characterized by hydro geologic materials of permeability low to very low of $K < 0.1 m/d$.
Rainwater harvesting (for its country-side area) is mostly useful to supply water in such area especially for country side around Dhera. It is possible in areas with as little as 50-80mm average annuls rain (MOWR, 2000). This implies the annual rain fall of Dhera area is 807 mm which is more than the minimum rainfall limit to execute rain water harvesting techniques in that area.
Rain water harvesting is when the precipitation is collected from a small/large surface area (cathement) and directed through channels to a storage facility or to a near by field or retained at the site itself (in-situ) (Pacey and Cullis, 1986). Runoff water harvesting is best known and practiced in the semi-arid areas where annual rainfall is in the range between 400 and 600mm (Getachew Alem, 1999). The most commonly used rainwater harvesting techniques in Ethiopia are runoff irrigation (runoff farming), flood spreading (Spate irrigation), in situ water harvesting and roof water harvesting (Getachew Alem, 1999).

5.9 Effects of structures on the groundwater systems in the area

The presence or absence of geological structures plays an important role to control the rate of groundwater dynamic and groundwater flow direction. The disruption of lithologies by cross cutting faults; and the variability in volcanic structures make the hydrogeology of the region very complex. In the area numerous closely spaced Wonji Fault Belt which makes the axial portion of MER has a significance implication in the control of groundwater flow systems. It is characterized by a number of minor and major normal types of faults running almost parallel to each other in a NNE-SSW direction. Besides tectonic structures are also other factors to control flow direction of the groundwater in the area. The faults of the floor which are part of the Wonji Fault Belt (Mohr,1960), form several tectonic depressions like the ones found in the area of Boku, Wagillo, Dera, Eastern side of Koka and at Gedemsa.

In Wonji area bore holes and hand dug wells are numerous and the static water level is very shallow. However, alluvial and lacustrine deposits are the main aquifers above the bottom ignimbrites. In this part of the study area these geological structures are not clearly observed and may be covered by soil and reworked lacustrine deposits.

On the other hand, a transverse fault in the area which starts from Wonji area and extends straight south side along Awash River and passes over Dhera-Sodere structural land forms. It acts as a flow path for the groundwater systems across other faults (Bekele Abebe, 2007). This fault may be deep towards Awash River and acts as barrier for groundwater flow from Awash River towards Dhera basin. Depending on their orientations faults in the area act as barrier or as conduit for groundwater movement.

The main reason for groundwater depth variations between Wonji basin and Dhera basin may be the presence of structural barrier between them. From Wonji side, there are closely spaced NE-SW oriented faults and are barriers for groundwater movement from Wonji area to Dhera. In Dhera area the deep aquifer (highly weathered and fractured basalt) can get groundwater recharge from Arsi high land area (Eteya and Huruta area) which is considered as the main source of recharge for the groundwater system of the area. Due to deep nature of groundwater in Dhera basin, there is no any water supply source developed yet to the community of the area. According to two drilled bore holes data around Dera area, the static water level of groundwater ranges from 256 to 296m below ground level.

The Dhera area is characterized by volcanic ejectas that are found overlain by lake deposit, Illuvial and alluvial soil overburden material of varying thickness. The volcanic ejecta found exposed in the area is pyroclastic materials of basic, intermediate and acidic in composition.

In general, in the study area the NE_SW trending normal faults highly favors acting as a conduit to recharge the deep groundwater aquifers. On the other hand, the presence of these faults and other tectonic structures in the area causes for the geothermal waters and fumaroles to come to the surface. This is because most of the thermal waters and fumaroles in the study area are found in these fault lines.

Chapter Six

6. Hydrochemistry

6.1 General

Hydrochemistry can be used to interpret the general occurrence of the various constituents in natural waters, controlling factors and the relation of these constituents to water use. The physical, chemical and biological characteristics of water determine its usefulness for various purposes. Hydrochemistry plays an important role to provide information both in space and time related to origin, quality and history of natural water. The composition of the geological formations which may consist of various rock types influences water chemistry. Composition of water represents the results of rock water –interaction based on the rock-type, temperature, existing mineral, solubility, $_{P}$H and rates of geochemical reactions. The change of water composition through reactions may provide information about the environment through which the water has circulated. This in turn can be used to investigate the correlation water quality (type) and the geological environment (Lathern et.ai., 1990).
Groundwater circulation in a basin usually takes place within one or more flow systems. Within each flow system, recharge zones and discharge zones can be distinguished. The atmospheric chemical composition of rain water, the composition and chemical conditions of the soil and geological formations determine the chemical composition of the chemical of the groundwater in the basin, further down a flow line. Also the effect of changes in groundwater circulation on the hydro chemistry of an aquifer is visible in places where human activities have taken place. This implies that different hydro chemical conditions in the past can strongly influence the development of groundwater chemistry. Hydrochemistry can help to take a look at some ways in which the protection and management of groundwater resources can be achieved. In general, the water chemistry at any point in a groundwater basin relates to the hydro chemical history of the basin, the composition of the geological formations, the groundwater circulation of the basin etc.

6.2. Water Sampling and Analysis

The distribution of the different sources of water (Boreholes, Hand dug wells, springs and Awash River) in the field has been examined and sampled within the study area. During sampling the sample bottles were carefully cleaned with distilled water and have been washed in the field by the water to be sampled. The primary samples were reached to the laboratory within two days and laboratory measurements are then carried out. Some properties of water, such as in situ measurement of pH, temperature and electrical conductivity have been done with the help of scientific instruments. Sampling from deep wells was carried out soon after pumping out of water just near the well head before entering the reservoir except boreholes of Aluminum Sulphate Factory, which is from reservoir during pumping. From Awash River and springs (Sodere and Gargadi) were collected from appropriate sampling sites.
Measurements of the main in-situ parameters that dually help in cross-checking the validity of the laboratory results and in understanding the geochemical environ has been carried out using PH-meter and Ec-meter, which are well calibrated in the laboratory with proper calibration regents. Measurements of major cations (such as Na, K, Ca and Mg), and anions (such as SO4, Cl, HCO3,

F, NO3, and PO4) and minor ions like Fe and Mn have been made in the water works design and Supervision Enterprise Laboratory Service. Additional data were collected from different previous works to make rich the chemical information (Annex: 1-9 the result records of the chemical analyses of all samples from the area).

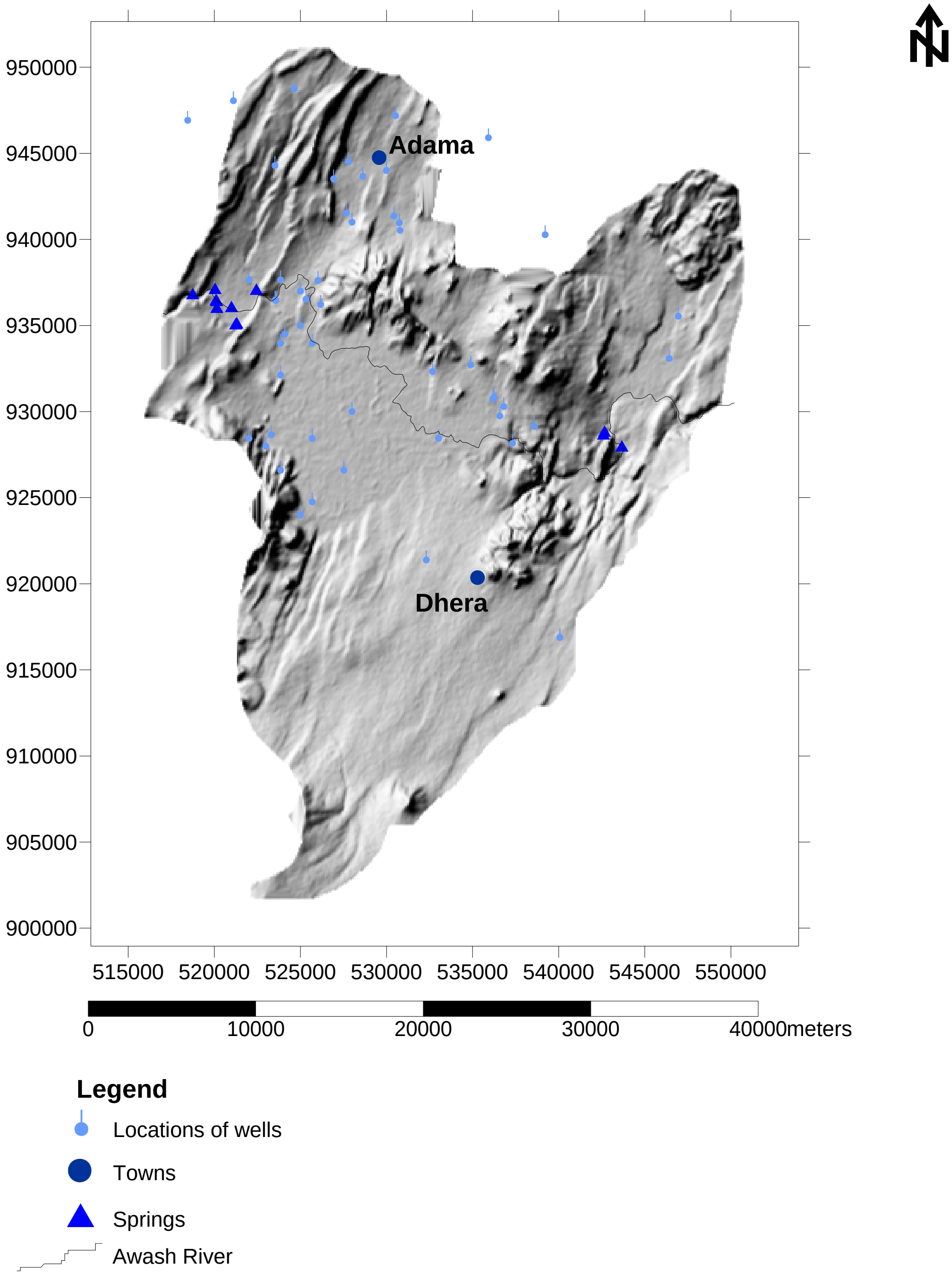


Figure 6.1 Location map of wells and springs

6.2.1 Accuracy of chemical Analysis

The accuracy of the analysis for the major ions can be estimated from the electro neutrality conditions, that is,

$$\text{Electro neutrality} = \frac{(\text{sum of cations + sum of anions}).100\%}{(\text{sum of cations - sum of anions})}$$

Where, anions and cations are expressed in meq/l. According to Appello and Postma, 1993 almost in all water laboratories differences in electro neutrality of up to 2% are inevitable.
Before classification is executed, the accuracy of the analysis for major ions should be checked from the Electro Neutrality condition because the sum of positive and negative charges in the water must balance. Differences in electro neutrality between major anions (SO_4^{2-}, NO_3^- , HCO_3^-, and Cl^-) and cat ions (Na^+, K^+, $Mg2^+$and $Ca2^+$) should not be greater than five percent. But at deviation more than five percent the sampling and analytical procedures should be examined (Appolo and Postoma, 1994). The reaction error can be determined by the following relations:

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

6.3. Interpretation of Water Quality Parameters

6.3.1 Physical and chemical Data

6.3.1.1 Major Physical Properties of water samples

During hydrological and hydro geological investigations, the physical properties of water have to be carried out to characterize natural waters. The main physical properties of waters are temperature, density, Viscosity, Surface Tension, Compressibility and specific Weight.

6.3.1.1.1 Temperature

In physical analysis of water samples, temperature is usually expressed in ^oC. The viscosity, Surface Tension and the compressibility of the water decreases as the temperature increases. The average annual air temperature of the study area is 21.4 ^oC. Temperature plays an important role to distinguish surface water and groundwater in the area. The temperature of surface waters is influenced by latitude, altitude, season, time of day, air circulation, cloud cover and the flow and depth of the water body. As water temperature increases, the solubility of gases, such as O2, CO2, N2, CH4 and others in water decreases. Surface waters are usually within the temperature range 0^oC to 30^oC although 'hot springs' may reach above 40^0C. All groundwater temperature that were measured in situ or immediately after collecting the water sample, are much higher than that of the mean annual air temperature of the investigated area. The minimum measured temperature is 17 ^oC at wakemia bore hole with a maximum of 64 ^oC at Sodere Hottest spring. In the study area groundwater below about 200mts ground level attains higher temperature (thermal waters). Within the Cachment, the area such as northern Boku ridge (hot springs steams), sodere,

Gargadi, and places at the foot of volcanic centers such as gedemsa Caldera are under the influence of thermal activities. The CO_2 concentration recorded in the area is high (this geothermal activities may be the cause of the higher temperature value of the region). Geothermal gases such as CO_2, H_2S, and CH_4 are generally indicative of deep aquifer origin (ELC, 1987).
It is possible to calculate the minimum possible depth of thermal water circulation at Sodere springs. Since groundwater is commonly temperature equilibrated with the aquifer rocks (Mazor, 1991).

The formula is given by:

$$\text{Depth (m)} = \frac{Tm - Ts}{\Delta T/6} \qquad \text{---------} \ (6.1)$$

Where, Tm = Temperature of the spring or well measured in the field.
Ts = Local average annual air temperature
ΔT = Local geothermal heat gradient $1^0C/6m$

Temperature value of Sodere hot spring (64^0C) is used to calculate depth of thermal groundwater circulation .The thermal source of hot springs is then at minimum depth of 246m below the ground level.

6.3.1.1.2. Colour, Odour, Suspended Matter and Turbidity

Turbidity is an expression of certain light scattering and absorbing properties of the water sample. It is caused by the presence of suspended matter, clay, silt, colloidal organic particles, plankton and other microscopic organisms (WHO, 1984a).
The colour and turbidity of water determine the depth to which light is transmitted. This controls the amount of primary productivity by controlling the rate of photosynthesis of the algae present. Natural minerals such as ferric hydroxide and organic substances such as humid acids give true colour to water. Apparent colour is caused by coloured particulates and the refraction and reflection of light on suspended particulates. Polluted water may have a very strong apparent colour.
The presence of volatile organic compounds, decaying organic matter, industrial and human wastes can create odours. Warm temperatures increase the rate and production of odour causing metabolic and decay products.
The type and concentration of suspended matter controls the turbidity and transparency of the water. Suspended matter consists of silt, clay, fine particles of organic and inorganic matter, soluble organic compounds, plankton and other microscopic organisms. The most reliable method of determination of turbidity uses nephelometry (light scattering by suspended particles) by means of turbidity meter which gives values in Nephelometric Turbidity units (NTU).

6.3.2. Major Chemical Properties of water Samples

6.3.2.1. Hardness

The hardness of natural waters depends mainly on the presence of dissolved Calcium and Magnesium salts. The total content of these salts is known as general hardness. Hardness can be further divided in to two types: carbonate hardness (determined by concentrations of calcium and magnesium hydro carbonates), and non-carbonates hardness (determined by calcium and magnesium salts of strong acids). Temporary hardness is due to the presence of carbonate with HCO3 ion small amount of CO3 ion and it can be removed by boiling, which precipitates Ca and Mg carbonates and sulphate minerals. Whereas the hardness remains in the water after boiling, it is called constant or permanent hardness (Non-carbonate hardness, which is the difference between total hardness and carbonate hardness).

Hardness of water may vary over a wide range. River water hardness often reaches highest values during low flow conditions and the lowest values during floods. However, groundwater hardness is generally less variable.
Durfere and Becker (1964) define range of hardness concentration in mg/l and proposed the following classification.
Table 6.1 Classification of water on the bases of Hardness:

Hardness, CaCO3	Description
0 -- 60	Soft
61 -- 120	moderately soft
12 -- 180	Hard
> 180	Very Hard

Source: Principles of Hydrogeology by Tenalem and Tamiru, June, 2001.

Hardness of water is the sum of calcium and magnesium expressed as equivalent amount of calcium carbonate (CaCO3) (Chow, 1964).The unit of hardness is generally given by mg/l.
Analytical hardness (H) is given by the formula:

$$H = 2.5Ca + 4.1Mg$$

Where, Ca and Mg are given in mg/l.

Based on the above classification, almost all groundwater in the area are belongs to moderately soft to very hard (BH-33, 476.90 mg/l CaCO3). The total hardness of boreholes ranges from 66.69mg/l CaCO3 for Metakoma (BH-37) to 476.9 mg/l CaCO3 for Wonji camp-M (BH-33). While the dug wells values ranges from 15.77mg/lCaCO3 for Bokogurabo (HDW-5) to 72.02mg/l CaCO3 for Kuriftu (HDW-8) within Wonji area.
Besides, Awash River and all springs except SP-13 and SP-15 (which are hard) are within the range of soft to moderately soft water.Thermal springs at Sodere (SP1) and Gergedi (SP3) area shows the values 72.6 mg/l and 19.8 mg/l respectively. Whereas for Awash River within the study area from up stream to down stream sides shows variation from 77 mg/l at Melkasa Reservoir (AR2) to 85.8 mg/l at down stream of Sodere (AR1).
Very high values of local Ca concentration might be associated to local variations in litho logy and also the presence of Perched ground waters, which could be due to small ground water movements and its longer residence time.

6.3.2.2 pH

The pH is defined as the negative of the logarithm to the base ten of the hydrogen ion concentration. The pH scale runs from 0 to 14 (i.e. Very acidic to very alkaline) with pH = 7 representing a neutral condition at 25^{o}C. The hydrogen ion activity is controlled by geological formation types and the hydrogeochemical reactions that produce or use hydrogen ions. Among the factors that control the pH values of natural waters are biochemical processes. The hydrogen ion activity indicates the intensity of the acidic or basic character of a solution & is controlled by the balance between the free CO2, carbonate and bicarbonate ions and other natural compounds such as humic and fulvic acids. Humus is formed as a result of the chemical and biochemical decomposition of vegetative residues and from the synthetic activity of microorganisms. The pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body and all processes associated with water supply and treatment.

The acidity and alkalinity nature of water can be determined in situ with the help of scientific instrument called pH-Meter. As pH is temperature dependent, the water temperature also measured in order to determine the pH accurately. In this research for cross-checking, about twelve samples from site were transported to the laboratory in completely full and tightly stopper bottles.

The natural acid –base balance of the water body can be affected by industrial effluents and atmospheric depositions of acid-forming substances. The pH of most natural waters is between 6.0 and 8.5. However, in the area the pH of all ware sources ranges from 6.8, Melkahida BH-1 (BH-18) to 8.71, Goro wagilo (BH-29).

In the study area most ground waters have pH values ranging from 7.0 to 8.8. Davis (1966) noted that pH >8.2 is a measure of carbonate ions present. If pH < 8.2, it is a measure of bicarbonate ions. PH below 4.5 indicates most of the bicarbonate ions are converted in to carbonic acid molecule. From the water sample analysis results, it can be conclude that the bicarbonate ions in the area are the dominant ions whereas the concentration of CO_3 is almost none. The pH levels of each of the water sources tend to increases toward the discharge areas. There is some variation between the pH values of boreholes, dug wells, springs and Awash River.

Table: 6.2 pH ranges among different sources of water.

Sources	Minimum pH	Maximum pH	Average
BH	6.8	8.71	7.76
HDW	7.6	8.67	8.14
SP	7.13	8.4	7.77
AR	7.3	8.0	7.65

6.3.2.3. Electrical Conductivity

Electrical conductivity of water is a measure of the ability of water to conduct an electric current or it is the ability of the water to conduct an electric current at a specified temperature (Weast, 1968). It is sensitive to variations in total dissolved solids, mostly mineral salts such as the degree to which they dissociate in to ions, the amount of electrical charge on each ions, ion mobility and temperature of the solution.

Conductivity is expressed as micro siemens per centimeter (µs/cm) and, for a given water body, is related to the concentrations of total dissolved solids and major ions. TDS (in mg/l) can be obtained by multiplying the electrical conductance by a factor which is commonly between 0.55 and 0.75. This factor must be determined for each water body, where for estimating TDS of saline water the factor is usually higher than 0.75 for acidic water it may be much lower. It is obvious that the relationships between the electrical conductivity and ionic concentration of water is directly proportional and most of the data set fit a straight line regression closely (correlation coefficient = 0.65). From water analysis result, it has been observed that most hot springs and deep boreholes have a higher EC values. However, Sodere thermal springs have the highest values. These values are progressively decreasing for shallow source of water.

Table 6.3 EC values in µs/cm for the different water sources.

Sources	Min.	Max.	Total no. of samples
BH	428 (BH-8)	2892 (BH-34)	33
HDW	908 (HDW-1)	2170 (HDW-9)	7
SP	933 (SP-4)	2916 (SP-2)	4
AR	242 (AR-2)	497.25 (AR-2)	4

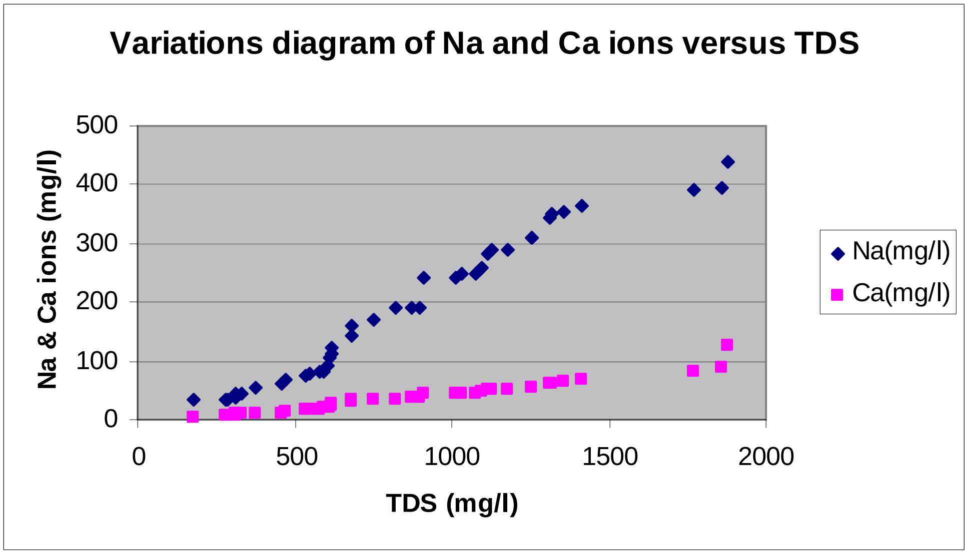
A two dimensional contour plot of the electrical values explains an increase in the EC values in the north, east and central parts of the study area.

The above data shows EC values are getting higher and higher towards the discharging zones and their values are generally lower in the recharging zones of the area. Pure water has a very low EC value because it consists small amount of ions in solution. At some localities of Wonji area, especially in densely populated area, there is relatively higher EC values; corresponding to higher NO3 concentration. This can be an indication for the presence of pollution sources at this locality. In general, EC shows variation in the study area, however, the maximum EC values are around Sodere hot springs whereas Awash River has a minimum value.

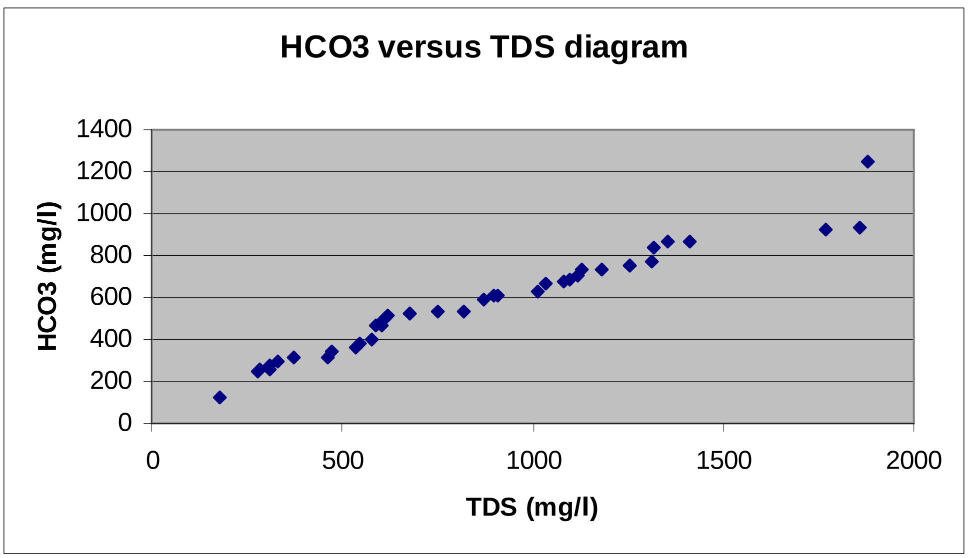
6.3.2.4. Total dissolved Solids

Total dissolved solids referred to as the total filterable residue in natural waters consists mainly of carbonates, bicarbonates, chloride, sulphate, calcium, magnesium, sodium & potassium (AWWA, 1982).

The total dissolved solids in the analyzed water samples are determined by summing up the concentrations for all ions for various dissolved constituents in the water. Total dissolved solids correspond to filterable residue. During water flow through geological formations or on the land's surface, it can dissolve many salts and their amount in natural water can determine the water quality. Anthropogenic activities can also be added dissolved materials. The TDS values have direct correlation to the EC; however, it shows zonal variation in the study area. Sodere thermal springs have highest TDS content, next to them; the shallow aquifers area of wonji irrigation has higher TDS values.



a)



b)

Figure6.2 Variation diagram of sodium, Calcium and bicarbonate ions versus TDS.

TDS of groundwater in the Wonji sugar Plantation ranges from 534.38mg/l, Melka hida (BH-18) up to 1880.26mg/l (BH-34) while in the rest of the study area it ranges from 176mg/l for Metakoma (BH-37), which is the deepest bore hole in the area, up to 1116mg/l for Dire degaga (BH-10).

Water from hand dug wells in Wonji area has TDS ranges from 616 mg/l (HDW-1) to 1411.2 mg/l for (HDW-9).

The thermal springs at Sodere have total dissolved solids up to 1897mg/l (SP-2).

The total dissolved solids in the Awash River ranges from 154 mg/l (for AR-2) from up stream side to 306.72mg/l (AR-3) for down stream side within the study area.

Table 6.4 Simple groundwater Classification based on Total Dissolved Solids

Water Type	TDS (mg/l)
Fresh Water	0 ---1000
Brackish water	1000 ---10,000
Saline Water	10,000 ---100,000
Brine Water	>100,000

Source: Freez (1979).

Gergedi area's thermal springs show smaller TDS, which is 584 mg/l as compared to Sodere springs. This might be due to dilution from base flow of Koka Lake.

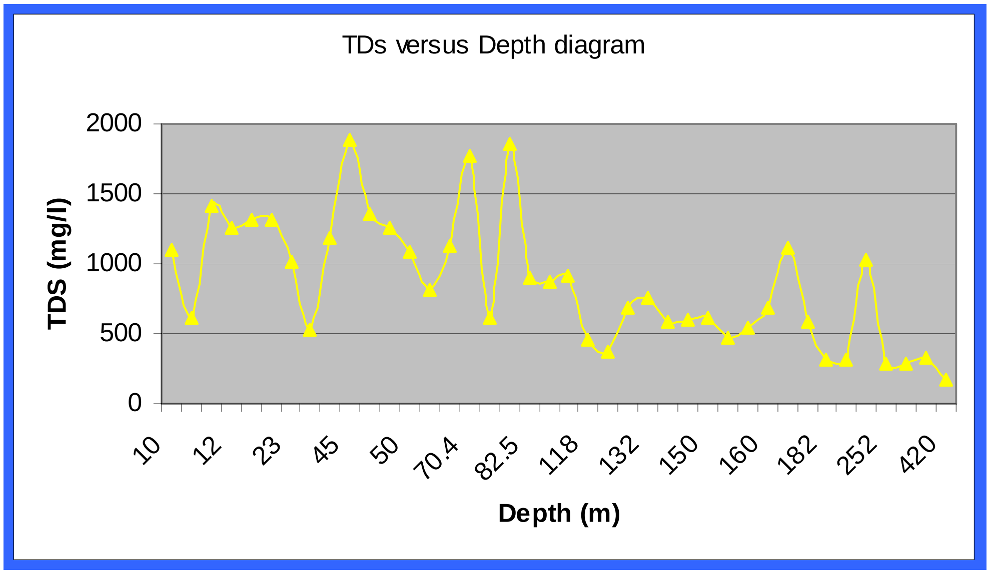


Figure 6.3 TDS versus wells of the study area

6.3.2.5. Redox Potential (Eh)

Redox Potential characterizes the oxidation- reduction state of natural waters (UNESCO, 1992). For chemical reactions in which electrons are transferred from ion to another (redox reactions), the oxidation potential of an aqueous solution is called the Eh (Drever,et.al.1997).Oxygen, iron and sulfur, as well as some organic systems are the most influential in determining Eh. High Eh is generally the direct result of dissolved oxygen in the water. The presence of hydrogen sulfide is usually associated with a sharp decrease in Eh and is evidence of reducing conditions.

The Eh may vary in natural waters from -500mV to +700mV. Surface watersand groundwaters containing dissolved oxygen are usually characterized by a range of Eh values between +100mV and +500mV.

Eh is determined potentiometrically and may be measured in situ in the field. As Eh depends on the gas content of the water it can be very variable when the water is in contact with air. Therefore, determination of Eh should be made immediately after sampling whenever in situ determination is not possible, and for groundwater it is recommended that Eh is measured "in-line" in the flowing discharge of a pump.

6.3.2.6. Dissolved Oxygen (DO)

The oxygen content of natural waters varies with temperature, salinity, turbulence, the photosynthetic activity of algae and plants and atmospheric pressure. The solubility of oxygen decreases as temperature and salinity increase.

Variations in DO can occur seasonally, or even over 24 hour periods, in relation to temperatureand biological activity. Waste discharges high in organic matter and nutrients can led to decreases in DO concentrations as a result of the increased microbial activity (respiration) occurring during the degradation of the organic matter.

Determination of DO concentrations is a fundamental part of a water quality assessment since oxygen is involved in, or influences, nearly all chemical and biological processes within water bodies. The measurement of DO can be used to indicate the degree of pollution by organic matter, the destruction of organic substances and the level of self purification of the water. DO is of much more limited use as an indicator of pollution in groundwater. Besides, the determination of DO in groundwater requires special equipment and it has not been widely undertaken. Nevertheless, measurement of DO is critical to scientifically understanding the potential for chemical and biochemical processes in groundwater. Water that enters groundwater systems as recharge can be expected to contain oxygen at concentrations similar to those of surface water in contact with the atmosphere. In aquifers where organic materials are less plentiful, groundwater containing measurable concentrations of DO can be found. In general, the highest oxidation potentials are in sallow groundwater of recharge areas and it is found to decrease with increasing length of flow towards the discharging areas. This implies that as the water travels through the aquifer, the oxygen is chemically reduced by contact with reducing species resulting in the lowering of Eh.

6.3.3. Major Cations and anions

6.3.3.1 Major ions and their Evolutions.

Major ions (Calcium, Magnesium, Sodium, Potassium, Chloride, Bicarbonates and Sulphate) are naturally very variable in surface and groundwaters due to local geological, climatic, and geographic conditions. In the study area Sodium, Calcium and Bicarbonates are the dominant ions in both surface and groundwaters. The main cations in water samples of the study area in the decreasing order are: Sodium, calcium, potassium and magnesium. Similarly, bicarbonate, chloride, sulfate, fluoride and nitrate for anions.

Concentrations of this ions show variation both in space and time. These can be checked by looking primary and secondary water samples analysis results.

6.3.3.1.1 Sodium ions (Na^+)

All natural waters contain some sodium since its salts are highly water soluble & their concentrations in natural waters vary considerably. The WHO guideline value for sodium in drinking water is 200mg/l. However the Ethiopian guideline value is a little bit higher which is 358 mg/l. Many surface waters have levels well below 50mg/l. This is also true for Awash River. However, groundwater concentrations frequently exceed 50mg/l. Sodium is commonly measured where the water is to be used for drinking or agricultural purposes particularly for irrigation.

In the study area, all groundwater samples shows similar increasing trend from recharge (highland topography) to discharge zones such as Wonji area. The concentration of Sodium in groundwater samples analyzed is within the range from 33 mg/l (BH-3) to 1200 mg/l at Wonji (BH-22). From primary water samples analysis result the concentration of sodium in the hottest spring at Sodere (out side the compound) and Gergedi is 600mg/l and 196mg/l respectively. From primary water analysis result of borehole waters within the study area sodium concentration ranges from 33mg/l for Kechema Sebeko deep well (BH3) in the recharge zones to 240mg/l for Bofa #2 bore hole (BH13) in the discharge zones. In Wonji area dug wells its concentration ranges from 190mg/l at Melkahida (HDW1) to 440mg/l at Bokogurabo (HDW5). The concentrations range of sodium in Awash River Varies from 20.5 mg/l at (AR2) to 40.8 mg/l at down stream of Sodere (AR-4). In general Sodium evolution trend shows that at sodere thermal spring its concentration is higher next to Wonji Boreholes. Next to springs, which have an average range is followed by hand dug wells and then Awash River has the least sodium concentration. This implies that sodium evolution doesn't show regular pattern in the area. The much higher concentration of sodium than potassium in the study area may be due to cation-exchange process. Cation exchange is the chemical reaction frequently cited to explain the high percentage of sodium compared to calcium and magnesium in water (Lee, 1981; Woessner et.al., 1986). Cation exchange is a reaction in which the calcium and magnesium in the water are exchanged for sodium that is adsorbed to aquifer solids such as clay minerals, resulting higher sodium concentrations (Hem, 1985).

The general reactions are given by (Hem, 1985)

$$Na_2X + Ca^{2+} \Leftrightarrow CaX + 2Na^+$$

$$Na_2X + Mg^{2+} \Leftrightarrow MgX + 2Na^+$$

Where, X = aquifer solid

6.3.3.1.2. Calcium ions (Ca^{+2})

Calcium is present in all waters as Ca^{+2} and is readily dissolved from rocks rich in Calcium minerals. This cation is abundant in surface and groundwaters in the area. Acidic rain water can increase the leaching of calcium from soils.

From the water sample analysis results in the study area the concentration of Calcium in groundwater sources shows variability and is generally from 8.9mg/l at Goro Wagilo (BH-29) to 87.32 mg/l at Chemical Corporation (BH6). Next to Boreholes, Awash River has calcium concentration ranges from 27.3 mg/l at Koka Dam (AR4) to 26.5 mg/l at down stream of Sodere (AR1). The most thermal springs at Sodere and Gergedi have 15.88mg/l and 6.17mg/l calcium concentration respectively. Hand dug wells have the least calcium values ranges from 4.5 mg/l at Wonji/Bokogurabo (HDW5) to 18.78 mg/l at Gefersa /Badhadha Bune (HDW8).

6.3.3.1.3 Bicarbonate ions ($HCO3^{-2}$)

The presence of carbonates and bicarbonates influences the hardness and alkalinity of water. The weathering of rocks contributes carbonate and bicarbonate salts. The relative amounts of carbonates, bicarbonates and carbonic acid in pure water are related to the pH. As a result of the weathering process, combined with pH range of surface waters, bicarbonate is the dominant anion in most surface waters.
In the study area bicarbonate concentration in boreholes ranges from 243 mg/l for Kechema Sebeko (BH3) at recharge area NW of Adama to 1250mg/l for Wonji camp-F (BH31) at discharge zones of the area. Wonji state plantation areas and Thermal springs of Sodere (SP1) (out side the compound) records very high bicarbonate concentration. The dug well waters around Wonji area show relatively high concentration of bicarbonate ranging from 502 mg/l for Wonji/Melkahida (HDW1) to 930 mg/l for wonji/Kuriftu (HDW2). While Awash River has relatively low value and its concentration ranges from 123 mg/l at Awash Melkasa Reservoir (AR2) to 183 mg/l at Wonji Bridge sampling sites.
In the investigated area Concentration of bicarbonate in Bore holes, springs (fromGargedi to Sodere) and Awash River (from Koka Dam to down stream of Sodere) in general increases from recharge areas to discharge zones. Almost all hand dug wells are found at Wonji area (which is the discharge area) and their carbonate concentration is nearly the same.

6.3.3.1.4 Magnesium ions (Mg^{+2})

Magnesium is common in natural water as Magnesium ion, and along with calcium, is a main contributor to water hardness. In the study area, Magnesium arises mainly from the weathering of rocks containing Ferro magnesium minerals. From sample analysis result of different water source bodies, the concentration of Magnesium is generally less than that of Calcium. The concentration of Magnesium in the analyzed borehole waters range from 3.6 mg/l for HVA Wonji Village-E (BH21) to 45 mg/l for Wonji camp-A (BH34). While in the hottest spring of sodere (out side the compound) (SP1) and Gergedi spring (SP3) the Magnesium value are 1.08 mg/l and 8.1 mg/l respectively. In Awash River it ranges from 2.7 mg/l at Awash Melkasa Reservoir (AR2) to 4.9 mg/l at down stream of Sodere. In Wonji area Kuriftu (HDW2) and Bokogurabo (HDW5) have the same minimum Magnesium concentration Value whereas the maximum value is at Gefersa Badhadha bune (HDW8).

6.3.3.1.5 Potassium ions (K^{+})

Potassium is found in low concentrations in natural waters since rocks which contain potassium are relatively resistant to weathering. It is usually found in the ionic form and the salts are highly soluble. In the study area the much higher concentration of Sodium than Potassium is observed. This may be due to cation exchange process.

The concentration of potassium in the analysed borehole samples ranges from 8 mg/l for Wake Tiyo (BH11) to 26.5 mg/l for Goro wagilo (BH29). While in the dug well waters at Wonji it ranges from 8.8-36.5 mg/l for Kuriftu HDW2 and HDW3. The most thermal Sodere and Gergedi springs have Magnesium concentration 30 mg/l and 12.8 mg/l. From Awash River sample analysis results at different location within the area this ion ranges from 4.8 mg/l at Awash Melkasa Reservoir (AR2) to 6.9 mg/l at downstream side of Sodere (AR1).

6.3.3.1.6 Sulphate ions ($SO4^{-2}$)

Sulphate is naturally present in surface waters as sulphate ion. It arises from the atmospheric deposition and the leaching of sulphur compounds, either sulphate minerals such as gypsum or sulphide minerals such as pyrite, from sedimentary rocks. The concentration of sulphate in borehole waters ranges from 2.67 mg/l for Kechema Sebeko (BH3) to 466 mg/l for Wonji camp-A (BH34). From analysed Hand dug well waters at Wonji have sulphate concentration ranges from 17.4 mg/l for Melkahida (HDW1) to 60 mg/l for Alem tena Detamo (HDW7). While sample analysis results show that Sodere & Gergedi thermal springs have sulphate concentration 133.5 mg/l and 24.05 mg/l respectively. The water sampling from Awash Reservoir and down stream of Sodere shows that this ion has value 8.24 mg/l and 17.09 mg/l respectively.

6.3.3.1.7 Chloride ions (Cl^-)

Most chlorine occurs as chloride (Cl^-) in solution. It enters surface waters with the atmospheric deposition, with the weathering of some sedimentary rocks, mostly rock salt deposits, and from industrial and sewage effluents, and agricultural and road run-off. As chloride is frequently associated with sewage, it is often incorporated in to assessments as an indication of possible faecal contamination or as a measure of the extent of the dispersion of sewage discharges in water bodies.
In the investigated area high chloride concentration is found in the down stream side of the area (thermal spring of Sodere) which is 160.3 mg/l, where as at Gergedi thermal spring has a value of 27.8 mg/l. While borehole waters in the area shows average range concentration of chloride ranging from 2.9 mg/l for Gudedi (BH7) to 90.2 mg/l for Dire Degaga (BH10). The concentration of chloride in the analyzed hand dug well waters range from 16.5 mg/l for MelkaHida (HDW1) to 86mg/l for Alemtena Detamo (HDW7). From water sample analysis of Awash River at Awash Melkasa reservoir and down stream of Sodere, chloride concentration has a value 17.3 mg/l and 8.64 mg/l respectively.

6.3.4 Minor Constituents

6.3.4.1 Nitrate ion (NO_3^-) and Nitrite ion (NO_2^-)

The nitrate ion is the common form of combined nitrogen found in natural waters. It may be biochemically reduced to nitrite (NO_2^-) by denitrification processes, usually under anaerobic conditions. The nitrite ion is rapidly oxidized to nitrate. Igneous rocks, land drainage and plant and animal debris are natural sources of nitrate to surface waters. The natural concentration may

be enhancing by municipal and industrial wastewaters, including leachates from waste disposal sites and sanitary landfills.
In the investigated area especially around wonji area the use of inorganic nitrate fertilizers are significant sources. Nitrate levels in surface waters in excess of 5mg/l NO3-N, usually indicate pollution by human or animal waste, or fertilizer run-off. As the World Health Organization (WHO) recommended maximum limit for drinking water is 10mg/l NO3-N, waters with higher concentrations represent a significant health risk.
Nitrate occurs naturally in groundwaters as a result of soil leaching but in areas of high nitrogen fertilizer application it may reach very high levels.
In the study area nitrite concentrations in all water sources are in trace amount and very low. High nitrite concentrations are generally indicative of industrial effluents and are often associated with unsatisfactory microbiological quality of water.
In general the water sample results of nitrate and nitrite gives a general indication of the nutrient status and level of organic pollution.

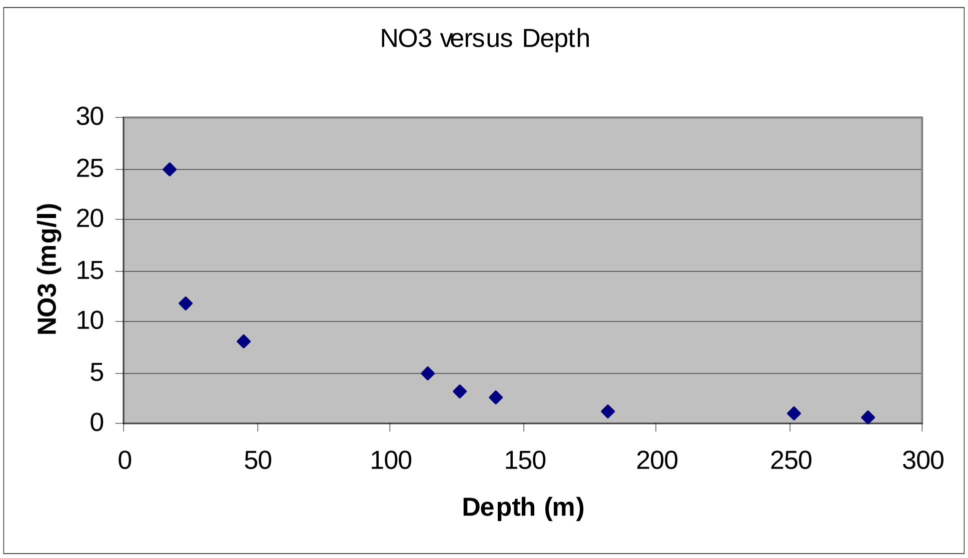


Figure6.4 Diagrams that shows Nitrate ions amount within dug, shallow and deep wells from left to right respectively.

6.3.4.2. Fluoride

Fluoride exists abundantly in the earth's crust and originates from the weathering of fluoride-containing minerals and enters surface waters through run-off and groundwaters through natural processes. Liquid and gas emissions from certain industrial processes can also contribute fluoride ions (F^-) to water bodies. Fluoride mobility in water depends, to a large extent, on the Ca^{2+} ion content, since fluoride forms low solubility compounds with divalent cations. This implies that fluoride levels can be related to changes in calcium concentration. Other ions that determine water hardness can increase F^- solubility. According to Hem (1992), rocks rich in alkali metals and obsidians are higher in fluoride content than most other igneous rocks. Besides he noted that fluoride often is associated with volcanic or fumarolic gases. In the study area these are true because, acidic volcanic rocks such as ignimbrites, ryholites, obsidian, pumice, pyroclastic

deposits are the dominant lithologic units. Boku area fumarolic gases are active in the region and give rise to much concentration of fluoride in the area.
Very high levels of fluoride, far exceeding the WHO guideline value of 1.5 mg/l, are encountered in the study area within the volcanic aquifers at Bofa area and even found a little bit higher in water sample from down stream of Awash River. Localized occurrences of high fluoride in groundwater associated with lacustrine deposits of Wonji area up to 15.2 mg/l are also recorded.
Measurement of fluoride content is especially important when a water body is used for drinking water supply. At high levels fluoride is toxic to humans and animals and can cause bone diseases. However, a slight increase in natural concentration can help prevent dental caries although, at high concentrations (above 1.5-2mg/l), mottling of teeth can occur (WHO, 1984b). High fluoride levels provide a constraint on the use of groundwaters for potable supply. Once encountered, fluoride levels are unlikely to change with time. Where fluoride is known to occur, it is an essential variable in surveys where community water supplies are being planned. In the area the fluoride data analysis result shows that it is generally decreases as depth of wells increases (Figure6.5).

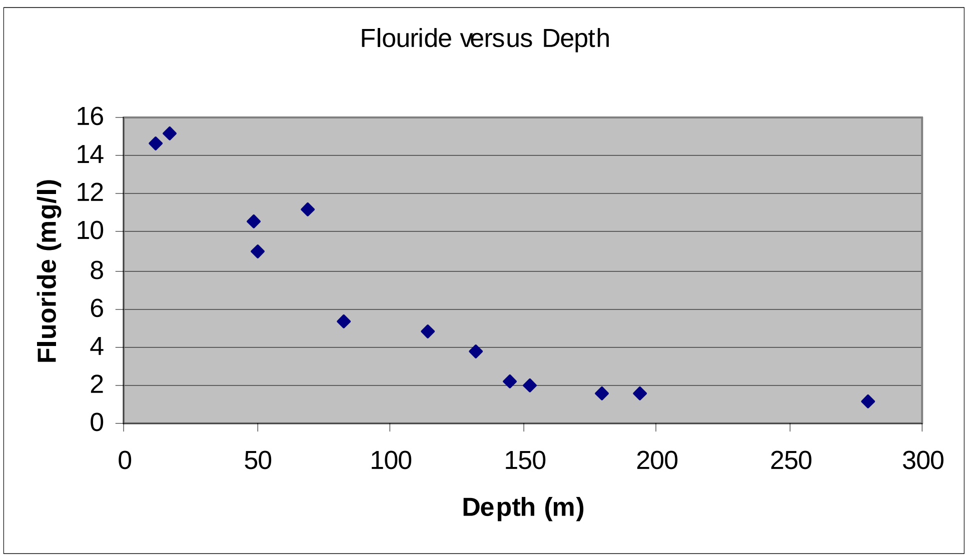


Figure6.5 Diagram that shows fluoride decreases with depth of wells

High concentration of fluoride in the rift is due to high temperature, the very recent nature of the volcanics and fumarolic activities existing in the area. The high fluoride content of Bofa Borehole#2 seems to be associated with the high temperature and the presence of nearby volcanic products from Boset volcanic mountains. During precipitation rain water that infiltrates can dissolve fluoride from the recent volcanic products such as obsidian, etc which later on joins the groundwater in the bofa area. Similarly, at wonji area in the vicinity of gedemsa volcanic the level of fluoride is very high. This is because in that area the deposits of clay and gravel have been derived from the nearby Gedemsa volcanic products which have high fluoride content. The same is true for Gergedi areas.
The concentrations of fluoride show many variations from recharge area to discharge zones. As it has been noted by Dereje Ayalew (1994) it increases sharply passing from intermediate to acidic rocks reaching concentration of some thousand ppm at Gedemsa Caldera and there is also the secondary enrichment process evidenced by the presence of fluorite filling cavities.

As we move from the rift floor to the escarpment areas such as NW of Nazareth, fluoride concentrations are getting smaller and smaller. Among all water sources in the study area, Awash River has least fluoride concentration.

Shallow sedimentary aquifers in Wonji area show relatively lower Calcium level than deep volcanic aquifers, which have relatively higher concentration.

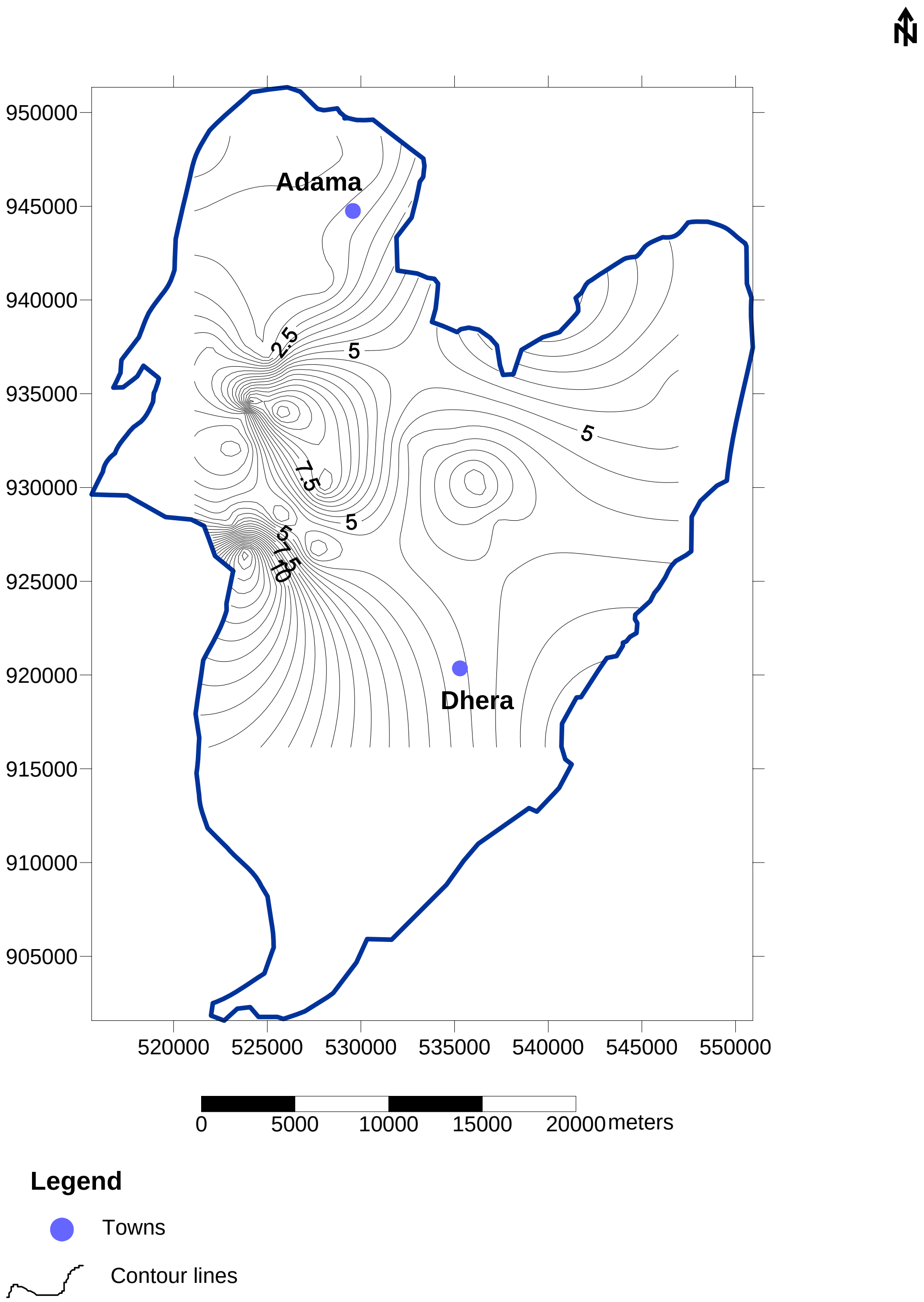


Figure6.6 Diagram of Fluoride map of the study area

6.3.4.3. Phosphate ion ($PO4^{3-}$)

It is recommended that phosphate concentrations are expressed as phosphorus, i.e., mg/l PO4-P (and not as mg/l $PO4^{3-}$). Phosphorus is an essential nutrient for living organisms and exists in water bodies as both dissolved and particulate species. In the Study area especially around awash Melkasa Reservoir, it is the limiting nutrient for algal growth and, therefore, controls the primary productivity of a water body. Artificial increases in concentration due to man's activities are the principal cause of eutrophication. In pure water the equilibrium of the different forms of phosphate occur at different pH values. i.e., during high phosphorus levels and acidic condition $H_2PO_4^-$ is formed and at low phosphorous levels HPO_4^{2-} will be formed. Where as, in the presence of alkaline condition and low phosphorous level, PO_4^{3-} will be formed.

Natural sources of phosphorus are mainly the weathering of phosphorus bearing rocks and the decomposition of organic matter. Domestic waste waters, particularly those containing detergents, industrial effluents and fertilizers run-off contribute to elevated levels in surface waters. Phosphorus is rarely found in high concentrations in fresh waters as it is actively taken up by plants and it shows seasonal fluctuations in concentrations in surface waters.

High concentrations of phosphates can indicate the presence of pollution and are largely responsible for eutrophic conditions. The management of a reservoir or a lake, particularly drinking water supply, requires knowledge of the concentrations of phosphate in order to control the rates of algal growth.

6.3.4.4. Ammonia

Ammonia occurs naturally in water bodies arising from the breakdown of nitrogenous organic and inorganic matter in soil and water, excretion by biota, reduction of the nitrogen gas in water by micro organisms and from gas exchange with the atmosphere. It is also discharged into water bodies by some industrial processes such as ammonia based Pulp and Paper Factory and also as a component of municipal or community waste.

Unpolluted waters contain small amounts of ammonia usually less than 0.1mg/l as nitrogen. Higher concentrations could be an indication of organic pollution such as from domestic sewage, industrial waste and fertilizer run-off.

6.3.5. Other inorganic Variables

6.3.5.1. Sulphide

Sulphide enters groundwaters as a result of the decomposition of sulphurous minerals and from volcanic gases. Sulphide formation in surface waters is principally through anaerobic, bacterial decay of organic substances in bottom sediments and stratified lakes and reservoirs. Trace of sulfide ion occur in unpolluted bottom sediments from the decay of vegetation, but the presence of high concentrations often indicates the occurrence of sewage or industrial wastes. Under aerobic conditions, the sulphide ion converts rapidly to sulphur and sulphate ions.

Dissolved sulfides exist in water as non ionized molecules of (H_2S), hydrosulfide (HS^-) and, very rarely, as sulfide (S^{2-}). The equilibrium between these forms is a function of pH. Sulphide concentrations need not be considered if the pH is lower than 10. If pH is greater than 10, Sulphide ions will increase. When appreciable concentrations of sulphide occur, toxicity and strong odour of the sulphide ion make the water unsuitable for drinking water supplies and other uses. Sulfide determination should be done immediately after sampling. During sampling, aeration of the sample must be prevented.

6.3.5.2. Silica

Silica is widespread and always present in surface and groundwater. It exists in water in dissolved, suspended and colloidal states. Dissolved silica (SiO2) or sometimes as silicate (H4SiO4) mainly arises from chemical weathering of siliceous minerals. Silica may be discharged in to water bodies with wastewaters from industries using siliceous compounds in their processes such as Potteries, glass works and abrasive manufacture. Silica also an essential element for certain aquatic plants (principally diatoms). It is taken up during cell growt hand released during decomposition and decay giving rise to seasonal fluctuations in concentrations, particularly in lakes.
The silica content of rivers and lakes usually varies within the range 1-30 mg/l. Concentrations in ground and volcanic waters are higher and thermal waters may reach concentration up to 1 gm/l or more.

6.3.5.3. Boron

It is a natural component of fresh waters arising from the weathering of rocks, soil leaching, volcanic action and other natural processes. Industries and municipal wastewaters also contribute boron to surface waters. Besides, agricultural run-off may contain boron, particularly in areas where boron is used to improve crop yields, or as a result of pesticide applications. Boric acid, which does not readily dissociate, is the predominant species in fresh waters.
Despite its widespread occurrence, boron is usually present in natural waters in comparatively low concentrations. Higher concentrations of boron (up to 48 mg/l) are found in some mineral waters which are sometimes used for some special health-related bathing, but not as drinking water. Maximum allowable concentrations of boron in water bodies used as sources of drinking water vary from total absence up to 5 mg/l in different countries. Recommended concentrations of boron in waters used for irrigation vary from 0.5 mg/l for sensitive crops to 6 mg/l for short term irrigation or for tolerant crops. Analysis is normally by photometric methods.

6.3.6 Water Type Classification

Among different methods of water type classification, the method based on the dominant ions is the best for practical purposes. It uses a percentage of milli equivalents per liter and combines two main constituents of chemical families (anions and cations) to classify the water type.
Classification of the water types in the study area according to the tri-linear piper diagram plots helps to show mixing effects between waters. Most of the bore hole waters (about 17 samples are

Sodium bicarbonate type and followed by 13 samples Sodium Calcium bicarbonate type. Only two borehole samples BH-5 and BH-11 are Sodium-Calcium-Magnesium-Bicarbonate type. Among springs only two are Na-Ca-HCO3 type and all the rest springs are Na-HCO3. All hand dug wells in Wonji area are Na-HCO3 water type. All Awash River samples are Na-Ca-HCO3 water types. The borehole results signifies the dominancy of volcanic terrain. Generally groundwater types variation are due to the presence of different aquifer types, mixing of these aquifers each others and their interaction with Awash River.

Total dissolved solids (TDS) of Natural water range from less than 10ppm of dissolved solids for rain and snow, to more than 300,000ppm for some brine (Tenalem and Tamiru, 2001).
According to their TDS value, the water types obtained in the area falls in fresh water, with TDS values in the range of 0 -1000ppm (Freeze and Cherry, 1979). In the area TDS increases spatially as a general trend from high land area (such as Dildima and Eteya areas) to lowland Sodere and Wonji areas.

Figure 6.7 Schoeller diagram depicts the dominant ion type in specified water sources (BH, HDW, SP and AR) and their principal ionic concentrations expressed in milliequivalents per liter, are plotted on six equally spaced logarithmic scales in the arrangement shown below.

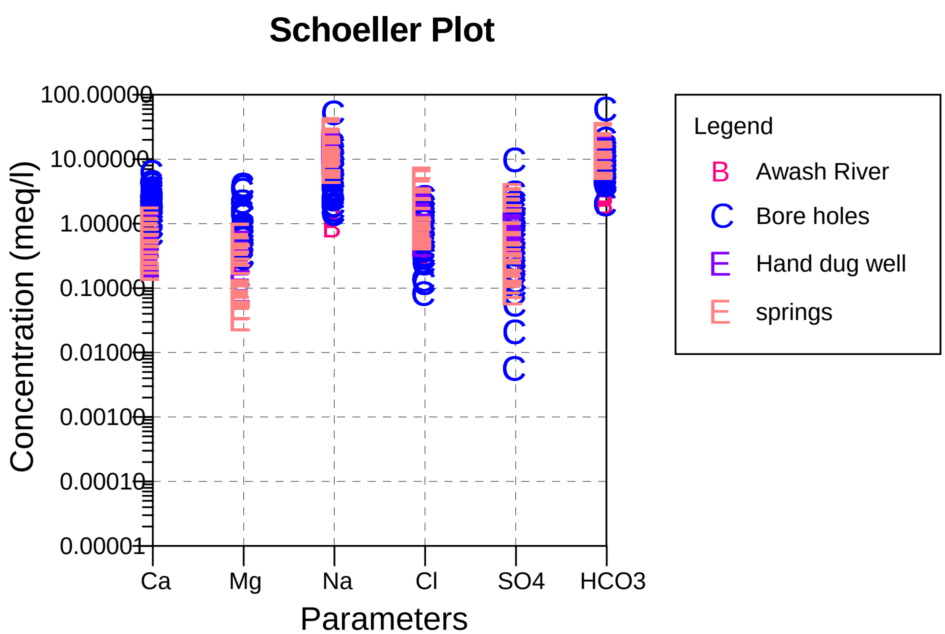
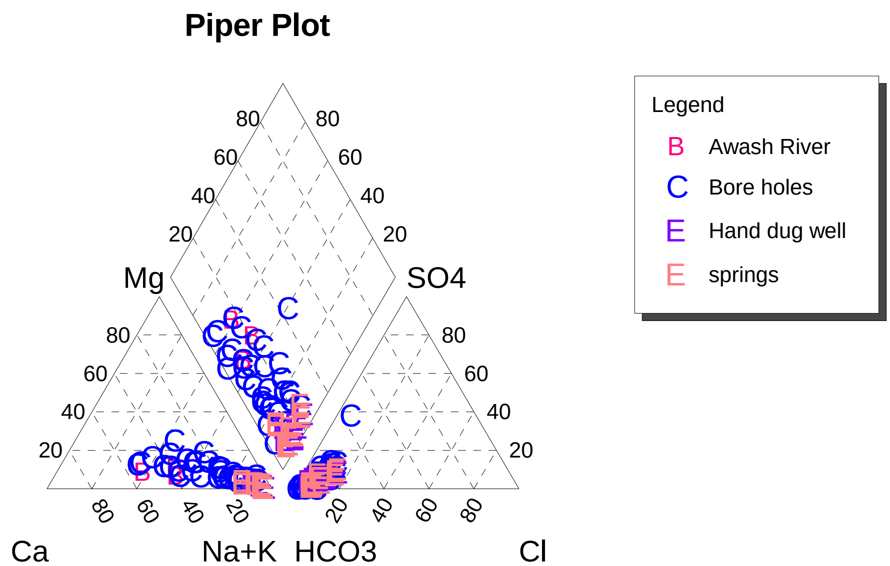
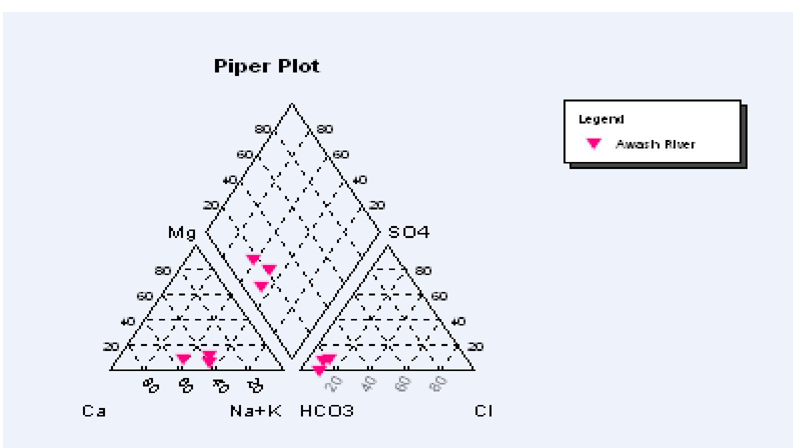


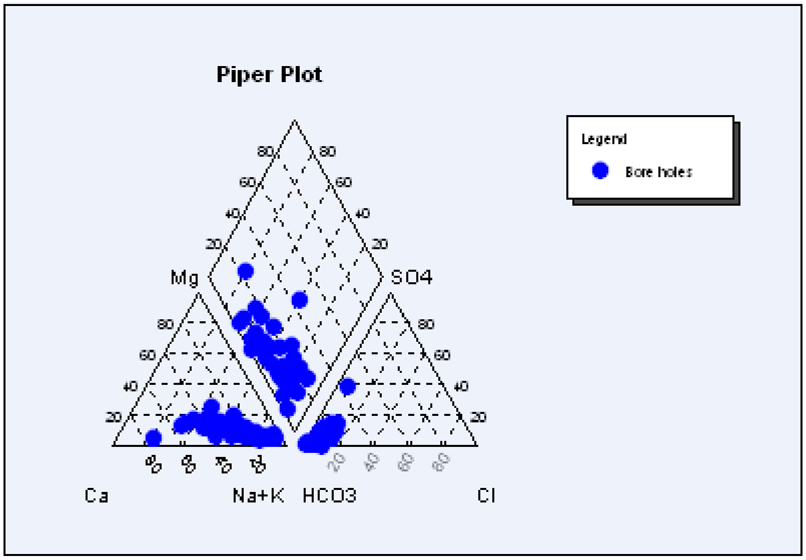
Figure 6.7 Schoeller diagram for all water sources


Piper Plot
Legend
B Awash River
C Bore holes
E Hand dug well
E springs
Mg
SO4
Ca
Na+K
HCO3
Cl

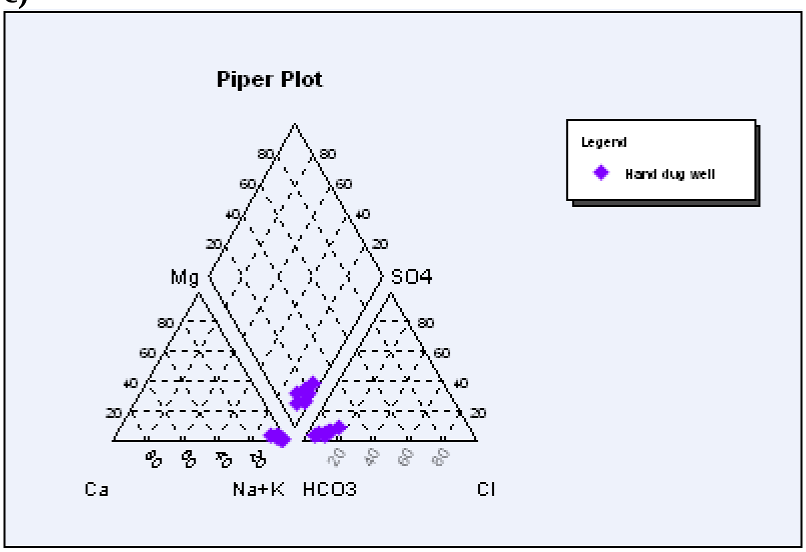
a)


Piper Plot
Legend
Awash River
Mg
SO4
Ca
Na+K
HCO3
Cl

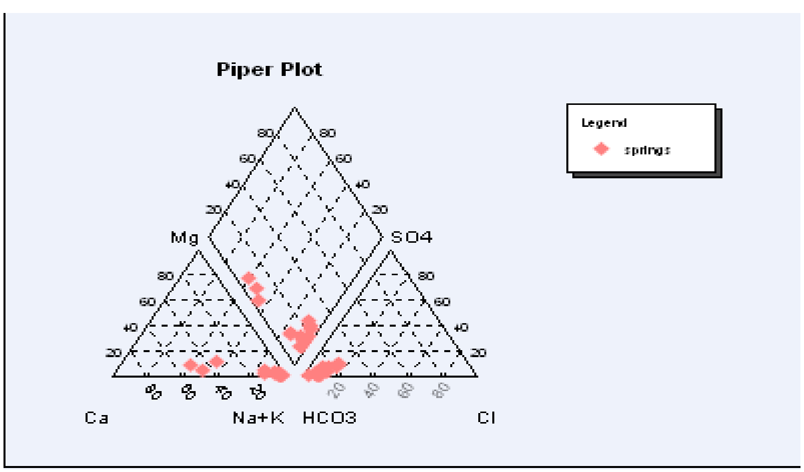
b)



c)



d)



e)

Figure 6.8 Piper tri-linear plots of different water sources

6.3.7 Water Quality

According to Davis, 1966 the study of water quality (water chemistry) gives important indications the speed and direction of water movement, the geologic history of the enclosing rocks and the presence of hidden ore deposits. The groundwater quality of Ethiopia is both anthropogenically and naturally affected and in some cases in urban centers, the chemistry of groundwater is controlled by the quality of surface water due to hydraulic connection (Tamiru Alemayehu et al (2006). The main water quality controls are geology, climate, geomorphological and geographical conditions, physio-chemical factors, biological factors and anthropogenic influences. Measurement of physical, chemical, biological and radiological constituents must be specified to establish quality criteria, as well as standard methods for reporting and comparing results of water analysis (Todd, 1980). In the study area it is possible to classify the general water quality for public supplies, irrigation and industry based on the major cations and anions analysis results.

6.3.7.1 Quality of water for public use

According to WHO and its member states101is that “All people, what ever their stage of development, social and economic conditions have the right to get an adequate supply of safe drinking water”.

The main objective of purification and water treatment is to get pure water from available sources and subject it to processing which will ensure water of good physical quality, free from unpleasant test, or odor and containing nothing which might be determined to health (Punmia, et al, 1995).

According to Punmia (1995) the main requirements of water quality for public supply are as follows:

- ✓ It should be free from objectionable odour, taste, and dissolved gasses and reasonably soft.
- ✓ It should be free from disease producing organisms.
- ✓ It should be free from harmful salts.
- ✓ It should be colour less and sparkling clear.
- ✓ It should not lead to scale formation and non-corrosive.
- ✓ It should be free from objectionable minerals and other poisons metals.
- ✓ It should be free from radioactive substances such as radium, strontium etc.
- ✓ It should be free from phenolic compounds, fluorides, chlorides and iodine.

Ethiopia has its own standard guideline values, but recognizes the WHO standards as a target for drinking water. The suitability of water of the study area for drinking purposes has been checked in reference to the standard for drinking water quality set by WHO (1984) and Ethiopian guideline value (Table 6.5-6.7). The Ethiopian guideline values are higher than the WHO maximum allowable concentration standards for drinking water quality.

In the study area evaluation of water samples from bore holes, shallow wells, hand-dug wells, springs and river (totally 55 sources) is analyzed and compared with the Ethiopian guide line value. These water values are analyzed with respect to sodium, fluoride and TDS (Table 6.5 Comparison of groundwater chemistry of the study area with drinking water quality standards).

Regarding the chemical quality of the water in the study area, sodium ion is a major problem in Wonji area. Of all the inventoried water sources about 13.7% exceeds the Ethiopian guide line value, which is 358 mg/l.

Fluoride ion from all samples collected in the study area it has been observed that 52.9% exceeds the Ethiopian guide line value, which is 3 mg/l. In the study area all water samples from all water sources in Wonji area including Sodere and Gergedi springs except Awash River & some groundwater wells, their fluoride values exceed the Ethiopian guide line values. In the area the highest fluoride concentration value is observed from Wonji area groundwater samples. That is why the people residing around Wonji are exposed to more serious effects of high fluoride content in the water such as mottling of teeth and skeletal fluoroisis.

Similarly, the TDS value of the water samples in Wonji groundwater and Sodere thermal spring show a higher value than the Ethiopian guide line value, which is 1776 mg/l. Accordingly, 12.2% of all the water samples analyzed in the area exceed the Ethiopian standard value.

Concerning Iron in the area only one bore hole has value greater than the Ethiopian guide line value, which is 0.4 mg/l. Similarly, manganese also only two bore holes of all water samples analyzed in the area exceed the Ethiopian guide line value, which is 0.5 mg/l.

In general in the study area concerning the water sources quality for drinking purpose, in terms of the higher values of sodium, fluoride and TDS possess quality problems, in which some of the waters analyzed shows that they exceed the maximum guideline values of WHO standards and Ethiopian standards.

In the study area faecal contamination is still the primary water quality issue in Awash River and hand dug well especially in Wonji area, where human and animal wastes are not yet adequately collected and treated. Human and animal wastes are a primary source of bacteria in water. These source of bacterial pollution include runoff from feedlots, pastures, and other land areas where animal wastes are deposited. Additional sources include seepage or discharge from septic tanks, sewage treatment facilities, and natural soil / plant bacteria.

Examination of water samples for the presence of faecal bacteria is a sensitive technique indicating recent faecal contamination. The higher the coli form count, on the other hand indicates, the more likely the water is to contain some pathogenic agent from faucal contamination.

Bacteriological examination of water samples (Both from Awash River and Hand dug wells) showed the presence of excess coli form organism, which indicates the presence of faecal contamination (Table 6.5).

Parameter	**Chemical**									**Biological**		**Remarks**
Type	TDS	Na	F	Total Fe	Mn	NO3	Total hard.	Cl	SO4	Faecal coliforms	Total coliform	
WHO standards	1000	200	1.5	0.3	0.1	45	500	250	400	0 in 100milli liter	3 in 100 milli liter	
Ethiopian standards	1776	358	3	0.4	0.5	50	392	533	483	0 in 100 milli liter	0 in 100 milli liter	
Water samples % above Eth.standa.	12.2	13.7	52.9							100 for both hand dug &River	100 for both hand dug & river	

Table6.5 Guideline values for drinking water standards
Source: WHO, 1984a and MoWR, 2002

Hud-dug wells						**Analysis result**	**WHO standards**	**National standards**	**Remark**
Site	**Index**	**UTME**	**UTMN**	**E.(m)**	**Ana.Date**	**Faecal colifoms**	**Faecal colifoms**	**Faecal colifoms**	
Wonji/ Kuriftu	**HDW2**	523850	933968	1548	21/12/07	**30**	**0 in hundered milli letter**	**0 in hundered milli liter**	
Wonji/Bokogurabo	**HDW5**	526178	936223	1556	22/12/07	**45**			
Alem Tena(Det.DW)	**HDW7**	523854	936223	1556	22/12/07	**15**			

Table 6.6 Bacteriological Analysis result of Hand- dug wells in Wonji area

Awash River						**Analysis result**	**WHO standards**	**National standards**	**Remark**
site	**Index**	**UTME**	**UTMN**	**E.(m)**	**Ana.Date**	**Faecal colifoms**	**Faecal colifoms**	**Faecal colifoms**	
AR at treatment Plant	**AR5**	**519740**	**937135**	**1562**	**8/4/2005**	**TNTC**	**0 in hundered milli letter**	**0 in hundered milli liter**	
AR at end of Wonji plantation	**AR6**	**535352**	**927868**	**1561**	**9/4/2005**	**50**			
AR at Melkasa Reservior	**AR2**	**537005**	**928388**	**1544**	**10/4/2005**	**160**			

Table 6.7 Bacteriological Analysis result of Awash River in the study area

6.3.7.2 Water Quality criteria for Irrigation

Irrigation waters are surface and ground waters that are used to irrigate farm land, the suitability of water of the area for irrigation should be examined. With poor water quality, various soil and cropping problems can be expected to develop. Water used for irrigation always contains salts. The amount and kind of salt present will determine the suitability of water for irrigation. A salinity problem related to water quality occurs if the total quantity of salts in the irrigation water is high enough that salts accumulate in the crop root zone to the extent that yields are affected (Ayers and Westcot, 1979).

In evaluating the quality of water for irrigation, the concentration of sodium is an important factor. This is due to the effect of sodium on the physical properties of the soil resulting in reduced permeability. It is expressed in terms of percent sodium (% Na), given by

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

Where, concentrations are in meq/l.

It is possible to classify irrigation water on the basis of % Na (soluble sodium %) and electrical conductivity.

Water class	% Na	Specific conductance (in µs/cm)
Excellent	< 20	< 250
Good	20 - 40	250 -750
Permissible	40 - 60	750 - 2000
Doubtful	60 - 80	2000 - 3000
Unsuitable	> 80	>3000

Table 6.8 Classification of water for irrigation (after Wilcox).

According to the above table, most of the water samples of the study area have good or permissible quality for irrigation. But, water samples from Wonji area have unsuitable quality for irrigation.

6.3.7.2.1 Sodium adsorption Ratio

When a soil is in exchange with irrigation water, its percentage of exchangeable sodium will closely be related to the calculated sodium adsorption ratio (SAR) of the water (Ciacco, 1971). The SAR is used to evaluate the suitability of water for irrigation. The ratio estimates the degree to which sodium will be adsorbed by the soil. High value of SAR implies that the sodium in the irrigation water may replace the calcium and magnesium ions in the soil. Sodium tends to disperse soil collides which results in loss of good soil structure and permeability. SAR is a useful index of the sodium hazard of irrigation water and the sodium hazard effect can be calculated by the sodium adsorption ratio (SAR) using the following formula:

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

Where, the concentration of sodium, Magnesium and Calcium are expressed in milliequivalents per liter (meq/l).

Source	Maximum	Minimum	Average
Bore hole	17.98 (BH-10)	1.14 (BH-3)	9.56
Shallow well	30.27 (BH-22)	1.20 (BH-18)	15.74
Hand dug well	48.22 (HDW-5)	14.87 (HDW-8)	31.55
Spring	36.05 (SP-16)	1.36 (SP-15)	18.71
Awash River	1.98 (AR-3)	0.99 (AR-2)	1.49

Table 6.9 SAR values for different water sources

Most of the borehole waters in the study area have low SAR values as compared to shallow wells, dug wells and springs. Although the groundwater in the study area especially away from Awash River has higher values, it is within the range of good water class and can fit for irrigation purposes. Awash River has excellent water quality for irrigation. While hand dug wells in Wonji area show the highest SAR values. Some springs are next to hand dug wells. The SAR values of most springs and shallow bore holes are nearly the same.

All the waters of hand dug wells in Wonji area have high SAR values and can not fit to irrigation purposes. For irrigation purposes waters with sufficient calcium and magnesium help soils to maintain good permeability. Other wise using appropriate fertilizers will correct this risk.

According to Todd (1959) recommended the following water classification for SAR is:

SAR	Water Class
<10	Excellent
10-18	Good
18-26	fair
>26	poor

This implies that most of the water points (boreholes, hand dug wells, springs, Awash River samples are in the range of excellent for irrigation purposes.

parameter	**units**	**Degree of restriction on use**		
		None	**Slight to moderate**	**severe**
Ecw	DS/m	< 0.7	0.7 – 3.0	> 3.0
TDS	Mg /l	<450	450 - 2000	> 2000
pH	Normal range 6.5 – 8.5			

Table 6.10 Water Quality Guidelines for Irrigation
Source: FAO, 1985

Salinity class & description	EC range (μS/cm)	TDS (g/l)
C1 **Low salinity water** can be used for irrigation with most crops on most soils, with little likelihood that a salinity problem will develop.	<250	<0.2
C2 **Medium salinity water** can be used if a moderate amount of leaching occurs. plants with moderate salt tolerance can be grown in most instances without special practices for Salinity control.	250 - 750	0.2-0.5
C3 **High salinity water** cannot be used on soil with restricted drainage. Even with adequate drainage, special management for salinity control may be required & plants with good salt tolerance should be selected.	750-2250	0.5-1.5
C4 **Very high salinity water** is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances.	>2250	1.5-3.0

Table 6.11 USDA Classification of irrigation water quality
Adapted from Richards (1954, p 76)

6.3.7.2.2 Water Quality for Agricultural uses Based on SAR values

Salinity and toxicity are water quality problems in irrigation area. Excessive salinity occurs due to an accumulation of salts in top soils. Most sodium in natural water originates with the release of soluble products during the weathering of plagioclase feldspars and its minor amounts may come from the mineral halite (NaCl).

6.3.7.2.2.1 Awash River

In the study area the calculated SAR for all the Awash River water collected at various localities lies in the range of C1S1 to C2S2 within the lower and higher values. Based on the guide lines developed by the united state Department of Agriculture, the calculated SAR values for Awash River water at different localities of the study area shows that, it has an excellent water quality for irrigation. But, due to silty clay soils of alluvial and /or lacustrine origins of the irrigable land in the area, characterized with low permeability values along with the presence of high rate of evaporation favor for the possibility of the occurrence of sodium hazard. To control the sodium extent in the soil as a result of its exchange for Ca ion and high rate of evaporation of irrigation water as a result of improper application of water in to the cultivated land, a proper irrigation efficiency schemes such as drip irrigation, crop per drop irrigation and sprinkle irrigation should be used.

6.3.7.2.2.2 Groundwater from Bore holes

In the study area the calculated SAR values from these water sources varies between C2S1 and C4S3. Where as, bore holes relatively located close to Awash River have lower values of SAR, this may be due to a chance of getting dilution of high groundwater salinity by infiltrating river water.
From the plot of SAR versus EC on figure 6.3 for the classification of irrigation water, the groundwater from bore holes, falls in the category of C2S1 and C3S2.
Therefore, the groundwater from bore holes of the area seems to be suitable for agricultural irrigation under normal conditions.

6.3.7.2.2.3 Thermal Springs

The calculated SAR values for Sodere and Gergedi hot springs are C3S4 and C4S4 which classifies them as water with not good quality for irrigation. But on the basis of EC value they represent high to very high salinity hazard and on the basis of SAR value they represent very high Sodium hazard. Therefore, it is difficult to use them for irrigation.

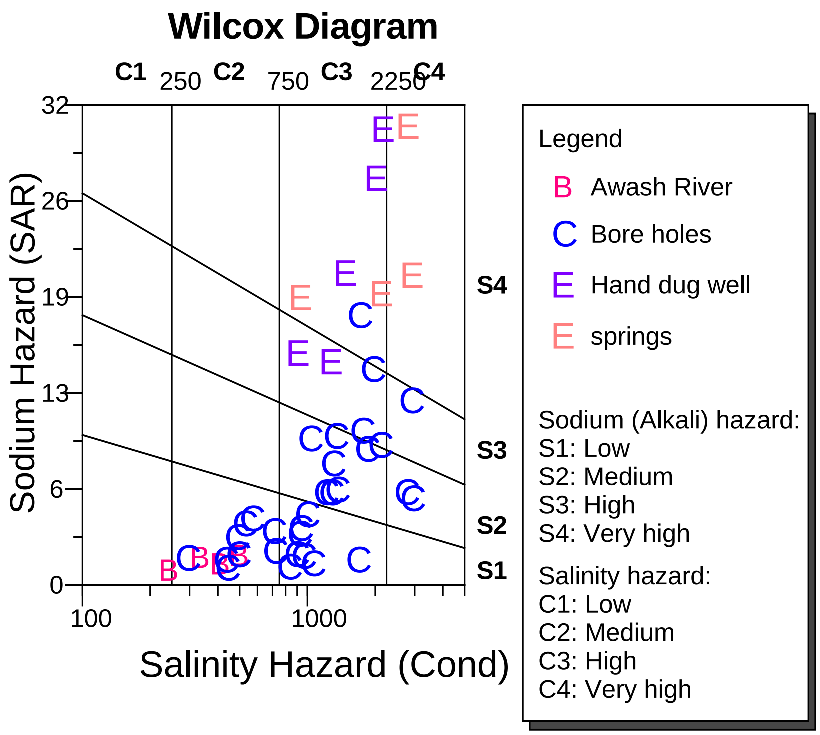


Figure 6.9 Diagram for classification of irrigation water

6.3.7.3 Industrial water Quality Assessment

The water quality criteria for industrial use depend on the type of industry. The three main parameters that usually important while dealing with the quality of water for industrial purposes are salinity, Hardness and silica (Todd, 1980).

According to Adama urban master plan of 1995, the area is mainly consisting of small and medium scale industries of different types. Medium scale industries are as follows: two Oil Factories, eight Flour Mills, one Printing Press, three Textiles and one Soap Factory. Among small scale industries: ninety seven Flour Mills, five Metal works, one wood work, forty five Oil processing mill and one plastic factory. Therefore, the water of the area has been examined in comparison to the recommended quality criteria set for these and other industries.

Industrial water for food, drink processing, and medical drug industries is similar to that of for potable water. In the study area most of the groundwater samples (for fluoride) and some of the groundwater samples have (for bicarbonate, TDS, sodium, fluoride and silica contents) which are generally above the recommended limits. This implies some groundwater of the area has doubtful quality for food processing industries. However, in the study area except some wells, there are suitable industrial waters at different location and for future industrial developments in the area, based on the general trend of major ions together with hydrogeological conditions, it is possible to say that quality of water for different other industries is promising for many industries as it is confirmed from water chemical analyses results.

6.3.8 Water Pollution

The term pollution is reserved for situations where contaminant concentrations attain levels that are considered to be objectionable (Freeze and Cherry, 1979). All solutes introduced in to the hydrologic environment as a result of man's activities are referred to as contaminants, regardless of weather or not the contaminations reach levels that cause significant degradation of water quality.
In the study area the principal sources and causes of groundwater pollution are categorized in to four categories: municipal, agricultural, industrial and miscellaneous. However, the common possible sources of pollution in the area are agricultural activities and municipal wastes. Agricultural sources and causes include fertilizer (urea, phosphate, etc and pesticides as well as through the infiltration of waste from septic tanks, and solid waste disposal associated to human settlement related to agricultural activities. Nitrogen dissolved to form nitrate ($NO3^-$) is gating increasingly wide spread in Wonji area hand-dug wells because of agricultural activities and disposal of sewage on or beneath the land surface. Dissolved nitrogen also occurs in the form of NH_4^+, NH_3, (nitrite) NO_2^-, N_2, (nitrous oxide) N_2O and organic nitrogen.
Pollution can be divided to two general sources; point and non point sources. Point sources are any discernible, confined and discrete conveyance, including, but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, animal feeding operation, or vessel or other floating craft, from which pollutants are, or may be, discharged. Where as, non point source of polluting is caused by diffuse sources that are regulated as point sources. In practical terms, non point source pollution does not happen at a specific, single location (such as a single pipe), but generally results from land run off, precipitation, air borne particles, or water percolating through contaminated materials. Examples of non point sources include run off from agricultural land, forestry activity, urban areas, and construction sites. Such pollution result in the alteration of the chemical, physical, biological, or radiological quality of the water. In general, the unconfined aquifer in the wonji area & city centers is vulnerable.

6.3.8.1 Source of pollution by Agricultural sources in the area

In the area sinceWonji plain is active agro-industry area, groundwater is exposed to pollution. Agriculture for the most part of the study area can be characterized as non-point sources of pollution. The main agricultural sources of groundwater pollution are: chemical fertilizers such as urea, Phosphate and potassium fertilizers, pesticides and septic tanks from agro-industries or domestic sources.Pesticides are the collective name of herbicides and insecticides. The liquid and solid waste generated from livestock, feaces, urine, livestock yards and related activities are the sources of water contamination in the study areas. Since agricultural activities in Wonji estate farm are intensive and need man power, large numbers of population are living in Gafersa, Kuriftu, Alemtena and Awash Melkasa areas. As a result there are many septic thanks in the area, which could be sources of nitrate pollution for shallow aquifer water.

In the area the common impacts of agricultural activities are groundwater quality degradation in wonji farm land area, eutrophication and salt concentration (TDS) that resulted from agricultural water evaporation.

6.3.8.1.1 Eutrophication

Eutrophication means the biological effects of an increase in concentration of plant nutrients usually nitrogen & phosphours (Harper, 1992). Eutrophication process in the down stream of Wonji plantation is a result of water pollution. The main sources of these nutrients in Awash river are agricultural fertilizers from Wonji sugar estate farm and domestic sewage in the area and may result in excessive growth of algae. Algae blooms are observed near Awash River edges and at Awash Melkasa reservoir. On the other hand, the density of algae blooms in the up stream side of estate farm such as around Adama water supply treatment plant were very small. In general, eutrophication from agricultural activities and domestic wastes has little impact in the area.

6.3.8.2 Municipal wastes

In the study area present situation shows that the Majority of the population in Adama, Wonji, Awash Melkasa and Dera towns, Koka camp at Koka dam, Bofa village and Sodere recreation center uses pit latrines, mostly simple dry latrines. The rest of the study area has no sanitary facilities at all. Within the Towns the non- domestic sector such as restaurants, hotels and institutions has predominantly septic tanks with over flows to the roadside drains, resulting in stagnant sullage waters in the open drains.
The solid waste collection system in Adama, Wonji and Dera is not adequate resulting in random garbage piles and dumping in drains within the towns. As maintenance on the open roadside drains is also limited, a poor drainage situation develops during the wet season.
Solid waste management is an important factor for the improvement of the health situation in the towns. Acording to Adama Master Plan, 1995 urban households in towns like Adama typically generate about 250grams of garbage per person per day (g/c/d).

The solid waste collection efficiency very much depends on the performance of the collection service. When the garbage collectors do a good job nearly all waste will be collected. When garbage collectors do a poor job then much waste will remain in the town: in ditches & drains, on vacant plots or burned in people's yards.
The sludge that is generated must be disposed of to a sanitary landfill site. Landfills are designed to minimize adverse of waste disposal (miller 1980).
Dried sludge will be covered with soil excavated from within the landfill area. Approximately two years after the landfill cell has been filled, all bacteria, viruses, and Helminths eggs will be dead. The material could then be extracted for use as a fertilizer. Regular extraction of dried sludge will significantly reduce the area required for the sanitary landfill.
In landfill site selection several criteria shall be considered, such as:

- Proximity to the town (distance from 5-10km).
- Accessible from a good all-weather road,
- Not too close to the settlements, also in the future.
- Down wind of settlements
- Attention to potential pollution of surface water and the need for remedial measures
- Attention to potential contamination of groundwater, its possible impact and optional remedies.
- The availability of soil in the proximity, to be used for covering fresh wastes (especially important when there are people living close to the dump.)

It is strongly recommended that the site selection, design of its construction and of operation procedures, and the environmental impact assessment are carried out in one study.

Septic tanks and cesspools are to be designed to discharge domestic wastewater in to the subsurface above the water table. Most of the urban dwellers use dry latrines and open field to dispose their waste excreta. Fore example in Nazareth town there are only six public latrines constructed by the city council (DEVECON, 1992). In the near future the principal sources of wastewater (flow and pollutants) will be the residential districts, predominantly institutional, commercial and recreational facilities, Hotels, laundries, hospitals, etc

By constructing a sewer system and connecting residential houses, publicand communal facilities, hotels, industries and institutions, wastewater will be generated. This waste water should be collected and transported through the sewer system to the wastewater treatment works.

6.3.8.3 Waste Disposal from Industries

Industrial wastes are variable in nature. The impact of industrial discharges depends not only on their collective characteristics, such as biochemical oxygen demand and the amount of suspended solids, but also on their content of specific inorganic and organic substances. Industrial sewage is very much dependent on the particular type of industry in terms of Biochemical Oxygen Demand (BOD), Nitrogen (N), and Phosphorous (p).

The study area is mainly consisting of small and medium scale industries of different types havinf unregulated waste disposal systems.

Name of Industries	Number of Industries
Medium Scale	
Oil Factory	2
Flour Mill	8
Printing press	1
Textile	3
Soap Factory	1
Small Scale	
Flour mills	97
Metal Work	5
Wood work	1
Oil processing mill	45
Plastic Factory	1

Table6.12 Description of industries in Adama town
Source: Adama Master plan studies, 1995.

According to Adama Master Plan, 1995 to evaluate the current status of the industries, an inventory has been made in 2003. The 3 largest industries of Adama, being an Oil Factory, the Abattoir and the Soap Factory were visited. There is also Aluminum sulphate factory around Awash Melkasa area.

On the other hand, In Wonji areas there are four factories: two sugar processing factories, Sweat and Paper producing industries. It is useful to avoid waste products of these factories properly. Otherwise, groundwater in Wonji area underlying shallow aquifers may be generally considered as highly vulnerable to any type of pollution.

In general the most known medium and small scale activities producing dangerous refuses in the area are:

- Car wash centers,
- Garages,
- Petrol stations,
- Chemical factories,
- Market centers,
- Textile factories, etc.
- Hospitals,
- Oil mills,
- Flour mills,
- Metal works,
- Cemeteries

Chapter Seven

7. Synthesis

7.1 Available Groundwater Sources in the area

Bore holes, Shallow wells, hand dug wells, springs and Awash River are available water sources in the area.

7.1.1 Boreholes

Both deep AND shallow boreholes are drilled in the investigated area by Governmental, Non-Governmental and Private Contractors. There are more than 60 boreholes (those that possess a depth beyond 60m) in the study area. The deepest borehole in the area is Metakoma that has a depth of 420m drilled in Dodota woreda at Metakoma Village which is about 11km south-east of Dhera town along Sire road.

The main aquifer formations of deep boreholes are highly weathered and fractured basalt varieties, highly weathered and fractured ignimbrites having a variable thickness and variable weathering and fracturing intensity. Their aquifer thickness and permeability ranges between 12m up to 88m thick and > 4.5 to 0.1 m/d respectively and yield of the aquifers are greater than 2 l/s. In the study area the static water level of the wells lies within the range of 4.7m to 295.5m below ground water level.

In the area as can be confirmed from laboratory and secondary data Analysis results for those bore holes their depth range varies from 60 –268m, the ground waters are generally characterized by relatively higher electrical conductivity (EC) values. Where as the total dissolved solids (TDS) lies a little bit corresponding lower values as compares to shallow bore holes.

Water from bore holes far from Awash River reveals an over all increasing trend in EC and TDS. This seems to occur due to chemical and biochemical interaction between groundwater and the geological formations through which it flows. The major cation constituent of the bore holes water of the area is represented by sodium ions. The higher sodium ion concentration corresponds to water with high TDS Value. Where as, the corresponding Potassium ion occurs at their relatively lower proportions.

Calcium ion represents as the second constituent of the major cations of the borehole waters of the area. The corresponding magnesium ions are occurred at their relatively lower proportions. Manganese and Iron total are also occurring in many borehole waters of the area in minor proportions. Regarding the major anions, the borehole water of the area composed of HCO_3^-, SO_4^{2-}, Cl^- ions, occurring generally in descending order in their relative concentration. As a whole, bicarbonate ion represents the major constituent of an ion through out the spatial distribution of the waters within the study area.

Fluoride (F-), carbonate (CO_3^{2-}), Nitrate (NO_3^-), Ammonia (NH_3) and Phosphate (PO_4^{3-}) ions are also other anion constituents of the borehole water of the area and these ions are more or less occurring in all borehole water within the specified corresponding ranges with the exception of occasional missing of some minor ions in few waters in the area.
The pH of all bore hole waters lie in the ranges from neutral to alkaline type. The temperature of BH-3, BH-11, BH-13, BH-24, BH-25, BH-26 and BH-27 of these waters belongs to a groundwater with temperature close to local average surface temperatures and as a result they are expected to belong to unconfined aquifers. Where as the hardness of these waters can be classified as water types with moderately soft to very hard (> 180 mg/l of $CaCo_3$ per liter of water).
In general from the above description of physio-chemical properties of waters, the groundwater of the area can be classified as the member of sodium-Calcium-Bicarbonate water family. Besides, the Metakoma borehole, water from very deep fresh and fractured aquifers, its water quality analysis result proved that in the study area the water from deep volcanic aquifers are categorized as fresh water like Awash River.

7.1.2 Shallow wells

In the study area there are more than 20 shallow bore holes that have a depth below 60m.
These include all the shallow wells in the range of 30 m up to 60 m depth below ground level. In the study area shallow wells are concentrated around Melka hida & Wonji areas.The main aquifers for these local groundwater systems are sand layer with pumice and basalt interbeds, gravel with pumice and tuff intercalation, alluvial and lacustrine deposits and aphanitic fractured basalt. Their static water levels vary from 2.5m to 14m. Even though their geological environment is the same, they show variable chemical composition may be due to the presence of some subsurface local variations. BH14, BH16, BH17, BH18, BH20, BH21, BH22, BH34, BH35 and BH40 are belongs to these wells group. In one way or another, they have interaction with Awash River. The TDS, EC & Fluoride values of Wonji shallow wells& hand-dug wells are higher than those shallow wells located along Awash River such as Melka hida shallow wells.

7.1.3 Hand Dug Wells

There are more than 40 hand dug wells in Wonji localities which is one part of the study area. In these area hand dug wells are not used for human drinking purpose instead extensively the community used them for washing and other domestic water supplies etc. They are not generally very deep because they can’t readily be sunk far enough below the water table. Dug wells are necessarily relatively large in cross-section, and they have correspondingly large storage capacity.

The abstractions of the majority of the hand dug wells are carried out by simple pulley system. Depths of dug wells vary from 4m - 23m. However, the majority of the dug wells less than 20m deep with variable static water levels of 1.67-16m below ground level. They generally yield only small supplies of water from aquifers of rather low permeability near the top of the zone of saturation. The major aquifer formation is known to be soil and reworked lacustrine deposits and recent alluvial deposits. All of the dug wells provide a perennial source of water and they show some seasonal fluctuation of the static water levels, Most of the dug wells are constructed in the

discharging zones (Wonji locality) of the study area. Those very shallow dug wells in to the zone of saturation fail in times of drought when the water table is reduced. They have poor groundwater quality due to fluoride.
Alemtena (Detamo dug well), Wonji Kuriftu and Boko gurabo hand dug wells show sanitation problem and a sign of water pollution. All indicated the presence of Bacteria with the higher load of 15, 30, 45 faecal coliform per 100ml respectively.

The wells are simply developed by open excavation with no lining by bricks or concrete rings. The existing soil seems harder type that it did not cave when subjected to vertical cut. These dug wells have not only the bacteriological quality problem but also their physiochemical results show bad water quality for drinking purposes. Fluoride content, PH, TDS, turbidity, Color, Mn are all above the maximum permissible limit. Particularly the higher fluoride content could be the main reason of rejection for drinking purposes.The rise of turbidity and color is caused due to open excavation of the well with no lining by bricks or concrete rings.

All hand-dug wells (only seven have been inventoried) are located around in Wonji residential areas. Their depth ranges varies from 4 m–23m below ground surface and the chemical analyses result show that all dug wells in Wonji area are Na-HCO3 water type. Some have high concentration of nitrate up to 25mg/l and this is due to the presence of groundwater pollution from septic tanks around settlement area. In Wonji area due to the presence of irrigation and continuous use of fertilizer, through time there will be an increase of NO3 concentration. Due to evaporation effect, wells in Wonji irrigation area have relatively higher TDS than those outside the irrigation area.

7.1.4 Thermal and Cold Springs

They are mostly found in Gergedi, Sodere areas and around Silasse Church. Most of them are poorly protected; some are developed in a good condition like Sodere Abadir. Many of the springs are discharging water through out the year however; their yield highly fluctuates with seasons. This is checked by an interview made with the local people during field visit.
The springs in the area are emanating mainly from Koka Lake through tectonically active zones which are affected by fracturing. Group of springs are located within the down stream side of Koka reservoir. Both hot and cold springs are found in the area. All hot springs within the study area are located near to the volcanic centers. In Gergedi area some started to die out in hot season and considered as seepage zone, where discharged groundwater not developed to flowing springs. Seepage zones are marked by local swampy lands and covered by ever green grass lands. Totally there are more than 16 springs in the study area. Discharge variability of some of Gergedi springs have been measured by floating method, ranges from 3 l/s to 6 l/s and their maximum measured temperature ranges up to 45.5 ^{0}C and the corresponding total solids105^{0}C of this sample equals 626mg/l. The hot thermal springs are often used for washing, livestock watering and curative purposes. Such thermal waters are locally known as ‘Tsebele’. Similarly Boku fumaroles also serve for steam paths as a curative purpose. Some cold springs are used for drinking purposes. The thermal group of springs was located at Sodere and its surroundings. The maximum measured temperature of the Sodere group ranges up to 63 ^{o}C and the total solids 105^{o}C of this sample has 1892mg/l. The discharge of this group is also the same as Geregedi springs.

In general, in the investigated area, spring will be located at the point where a groundwater table intercepts the atmosphere through a fault zones. Springs may be classified according to the groundwater basin they are associated with, the magnitude of their discharge or the chemical composition of its water. Many small springs are known to disappear in a prolonged dry season.
In all springs the dominant anion type is bicarbonate and cations are dominated by Sodium ion. The Sodere thermal springs located at a distance about 20 km south-east from Adama and are emanating at the base of rhyolitic lava dome with temperature ranges from 50 to 63^{o}C. In the area next to sodere, there is Gergedi hot spring and they are located near volcanic centers, Boseti and Gedemsa respectively. The highest TDS values recorded at Sodere and Gergedi are 1897 and 1387 mg/l respectively. Similarly, their highest EC values are 2916 & 2132 mg/l respectively. The composition of Sodere hot springs is the result of the composition of the rocks (ryholitic domes) and deep circulating water. According to Mohr, 1970 the hot spring waters are primarily dominated by local geochemistry. Sodium ion is the major cation in the range of 196 – 600 mg/l with potassium ion is the second to the extent between 12.8 to 32 mg/l. Regarding the major anion, $HCO3^-$ is the dominant constituent in the range between 460 to 1405 mg/l and followed by Cl^- and $SO4^{2-}$ ions. The fluoride content of this thermal spring is between 4 to 17 mg/l, which is beyond WHO standard for drinking water. The pH of this hot spring water lies in the alkalinity range varying in the range of 7.13 to 8.4. Among springs only two are Na-Ca-HCO3 type and all the rest are Na-HCO3 family.

Cold springs in the area are situated at Gergedi, Wonji area and they emanate through weak zones from Koka Lake.

7.1.5 Awash River

The Awash River that rises to the west of Addis Ababa at an elevation of about 3000m in the central high lands passes through the study area.
In the investigated area, even though it is the source of fresh water, as a consequence of agricultural, industrial and waste disposal activities, the quality of Awash River is supposed to be affected through out its course. Analysis of its spatial and temporal variations seems to be complex. Due to absence of well recorded temporal data, it is very difficult to see the temporal quality of this river. However, from the assessment of chemical analysis data of the water sampling collected from river Awash at different localities within the area such as at the down stream side of Sodere, at Awash Melkasa Reservior, at Wonji bridge and at near Koka dam, it is possible to see spatially that there is no significant increment of major and minor ions.
In general, Sodium, Calcium and Bicarbonate in the river samples are relatively the dominant ions, and the potassium, magnesium, sulphate and chloride are occurring in their lower proportion. The fluoride content shows an increasing trend along the course of Awash River in the area. All Awash River samples are Na-Ca-HCO3 water types. It is the major resource for both domestic and agricultural uses. Therefore, due attention should be given to Awash River, both in proper utilization and preservation of its quality.

7.2 Water Scarcity in Dera area

During the field work, within the study area it has been observed that there is a big problem of potable water supply especially for Dera town and its vicinity. Nazareth town, Wonji area and development activities such as factory, irrigation as well as live stock in the area use water from Awash River. Except Dera town and its surroundings, all the rest part of the study area has water supply for their domestic use. Localities of Boku ridge are also not promising areas for groundwater developments. The static water level of groundwater around Dera area is 256m-295m below ground level and it is hot water (BH#15 and BH #37). In the area the fluoride content has been noted to range between 0.02 to 16.9 ppm and TDS range also between 154 – 1896.96ppm. The ground water occurrence has been estimated to be deep greater than 250mts. Consequently they are imposed to use ponds and runoff during time of precipitation. The ponds in the area are getting dry after few months that cannot end till the next rainy season. As a result during the long dry period they take very long distance on foot walk in search of water. Apart from this, the land though fertile, due to shortage of precipitation, plant and crop dries soon with out reaching ripping stage.

Women and girls are found to be the most victimized who are taking the full responsibility of fetching water in addition to the tiresome housework. They are suffering a lot to fetch the water from such a long distance.

The only alternative for Dera town and its surroundings is groundwater development from very deep aquifers up to 420m for the town water supply. There exist surface water potential source in the area. During time of precipitation, there occurs relatively high quantity of run - off draining in the area towards Awash River. Further more, the overlaying silty clay and clay soil material due to the high plasticity and of reasonable thickness deserves potentiality of the area for surface water / runoff harvest. The surface water can be harvested and could be used by constructing appropriate ponds at ideally favorable sites to collect and store runoff.

Having the soil low infiltration capacity, the runoff process in the area strongly influenced by rainfall intensity. Even though these is no recorded flooding data in Dera area, information from local People reveals that during precipitation there was an extreme surface runoff over the land surface both from steep and low land of the area towards the Awash River. In general during precipitation, the bare silty clay soil of the area subjected to intense rainfall Suffers a very quick reduction in the infiltration rate on account of the combined effect of reduction in the soil moisture deficiency, compaction due to rainfall and in washing to fine particles.

In general the low infiltration capacities of the soils and low perm abilities of the underlying geological formation of Dera area are associated with high runoff which is reflected in a surface water network of low density.

7.3 Irrigation in Wonji

In the area Sugar cane is highly successful crop produced by the Sugar Corporation at Wonji with the help of Awash River, which is very suitable for irrigation. The salinity of water in conjunction with the type of soil to which the water applied governs their suitability for crop irrigation. The most commonly used method to evaluate salinity is determination of electrical conductivity (in microS/cm) and Sodium hazard determination(SAR), which is obtained from the available relative concentration of Na+, Ca2+ and Mg2+ ions. To control the sodium extent in the soil as a result of its exchange for Ca ion & high rate of evaporation of irrigation water as a result of improper application of water in to the cultivated land, a proper irrigation efficiency schemes such as drip irrigation, crop per drop irrigation and sprinkle irrigation should be used.

7.4 Flooding in Adama

Runoff in the study area occurs during rainy events mainly during large storms. Hurton overland flow is the main producer of this storm runoff. Runoff from Western cachement of Adama town leaves the area and flow in to Awash River through a big canal than Eastern cachement, which is believed to contribute more to evapotranspiration and infiltration than runoff. This Eastern catchment has a serious storm water drainage problem, since there is no natural outlet for storm water runoff. All the storm water runoff will accumulate in the depression within the town boundary and ultimately inundate vast built up areas.

The main cause of flooding problem of Adama town is high concentration of rains in a short period of time and the geomorphology of the town. Therefore, additional properly developed sewerage system is the only alternative in order to protect the town from future sudden and unexpected intensive rainfall during rainy months of July and August.

In general the volume of surface runoff in the study area depends generally on the:

-Duration and the intensity of precipitation,

-The presence or absence of the vegetation cover,

-The infiltration capacity of the soil,

-The slop and roughness of the land surface.

Chapter Eight

8.0 Conclusion and Recommendation

8.1 CONCLUTION

- The Nazareth-Dhera area located in the Upper Valley of the Awash Basin has a total area of 941sq.km and is characterized by plains, gently sloping to highly rugged topography. The main target of the research is to understand and evaluate the basic hydrogeological factors controlling the occurrence, movement and storage of groundwater and hydrogeochemical condition of the area and the effect of irrigation, municipal and industrial wastes on groundwater quality of the area.

- The area is within semi-arid to semi-humid climatic zone with a mean annual temperature of 21.47 c^o and from long term mean monthly precipitation the area gets 807mm mean annual rainfall. Effective aerial depth of precipitation obtained from three different methods show low variations. The median of the three results has been taken inorder to incorporate the effects of each method.

- The actual evapotranspiration is quantified by applying both empirical formulae and the Soil-water balance approach. Turc, Thornthwaite and Crowe- Thornthwaite methods yield 726.55, 221.41 and 171.17mm respectively. The results obtained from the last two methods under estimates the actual values. Result obtained from Turc is more representative AET value for the study area. However, result obtained by soil- water balance developed by Thornthwaite and Mather 1957 which is 994mm/annum thought to over estimate the actual evapotranspiration of the study area.

- The potential evapotranspiration is also quantified by three different ways. Pan Evaporation method, Thornthwaite (1948) and the Penman approach yield 2523, 1094.09 and 1979.1mm per annum respectively. The thornthwaite values tend to under estimate the potential Evaporation where as the Pan Evaporation Method tend to over estimate the result. Therefore, the PET obtained from penman combination method seems to be more representative and for further water balance calculation the annual PET in the analyzed area assumed to be 1979.1mm. Almost 66.7% of the rainfall in the area occurs in the months of June, July, August and September. The amount of PET is higher than that of the rainfall through all months of a year except in rainy months of July and August. This shows that generally rainfall has least contribution to groundwater recharge in the area.

- The total annual estimated surface runoff value that leaves the cachement area is about 175.72×10^6 m^3.

- By deducting the annual water abstraction of Adama water supply and Wonji irrigation, the annual groundwater recharge is estimated to be 298.38MCM. Huge amount of groundwater inflow from Koka reservoir recharges the groundwater through big fractures trending in West-east direction.

- Assessment of hydrogeology and hydrogeochemistry of the area is done by conventional geological and hydrogeological description and mapping of different permeability lithologic units, analysis of hydrometrological data, Awash River discharge and hydrochemistry of different water sources were executed.

- Based on aquifer characteristics comparison from hydrogeological point of view, four hydrogeologic units (permeability groups) are mapped in the area. These are high to very high permeable with permeability value of above 4.5m/day, moderate to high permeable with permeability value from 2 m/day up to equal to 4.5m.day, from low to moderate permeable with permeability value 0.1m/day up to equal to 2m/day and finally low to very low permeability with less than 0.1 m/day. The very high permeability units in the area are alluvial and lacustrine deposits intercalated with pumice and tuff along Awash River and low elevated Wonji basin and weathered and fractured basalts. While deep seated weathered and fractured ignimbrites, Vesicular and scoracious basalts and reworked volcano-lacustrine sediments are belong to moderate to high permeability groups. The low to moderate permeability groups include those Gedemsa, Boku-Tede, Floor complex of Nazareth and Keleta units such as Brown co-ignimbrites ash fall deposits, Welded light-green ignimbrite followed by un welded pumice rich pyroclstic flow, lava domes and flows, pumice fall deposits and mainly welded fine and coarse grained igrimbrite and much welded glassy ignimbrite. Finally Pumice fall and hydromagmatic wet surge deposits, pantelleritic pumice fall deposits, densely welded fine-grained and green ignimbrite, mainly unwedded ignimbrite unit interbeded with paleosols, all fresh basaltic, ryholitic and trachytic rock units are belong to low to very low permeability groups. In general, the variation in the permeability of the aquifer units in the study area is controlled by secondary processes mainly weathering and fracturing.

- In the study area some hydrogeological cross sections show that geological structures act as groundwater conduit and as groundwater barrier and some groundwater movement was expected across NE-SW trending fault lines. From a plot of the hydraulic heads of the available groundwater data in the area, the general regional flow of the groundwater system is generally to the East wards, and local flow systems are observed in the in the WS zones and to the East direction.

- Recharge areas for the cachement are those areas the high elevated escarpements, ridges, lava domes and flows (Boku, Dera-Sodere units), NE part of Gedemsa Caldera edges, Eteya area, SW part of Boseti volcanic mountain and eastern cachment of Adama town. Where as, areas below Koka dam, Wonji, Sodere, Adulala area and Adama western cachement are both recharge and discharge zones. The plain areas around Dera are Shadow zones, which is neither recharge zone nor discharge zone. The rest of the study area can be considered as transitional zones.

- Analysis of the hydrochemistry of different water sources show that generally two types of water are identified based on their TDS value. The dominant water type is Na-HCO3 type followed by Na-Ca-HCO3. All dug wells in Wonji area and all samples from Awash River are Na-HCO3 and Na-Ca-HCO3 types respectively. Concerning chemical water quality, except TDS, Na, Fluoride and Fecal coli form (for dug wells and Awash River), surface and groundwater sources are within the limit of acceptable value of both WHO water quality standards and National standards for water supply excluding trace elements which are not analyzed in this research.

- Although there is application of inorganic fertilizers continuously year to year in Wonji sugar estate farm, from sample analysis result there is no unique high concentration in the ground and surface water except higher TDS, Na and Fluoride above the water quality standards for Wonji groundwater. This could be water dilution effect from groundwater inflow of Koka reservoir and also surface irrigation. The presence of high evapo transpiration and evaporation from Wonji estate farm increased concentration of Sodium ions and TDS than the surrounding areas. This can be minimized by using a proper irrigation efficiency schemes such as drip irrigaton, sprinkle irrigation and crop per drop irrigation. Besides dug wells in densely populated Wonji area and nearby Awash River show some higher value of fecal coliform above the standard limits from anthropogenic waste such as septic tanks etc.

- Concerning SAR, Awash River has excellent water quality for irrigation and groundwater from bore holes of the area seems to be suitable for agricultural irrigation under normal conditions. However, all the waters of hand dug wells in Wonji area have high SAR values and can not fit to irrigation purposes. Some springs in the area are next to hand dug wells.

- The water quality criteria for industrial use depend on the type of industry. The three main parameters that usually important while dealing with the quality of water for industrial purposes are salinity, Hardness and silica.

- In the study area concerning water supply, there is one treatment plant that supply treated potable water from Awash River for both Adama and Wonji. There are more than 60 productive boreholes distributed in the area with a minimum well yield of 1.5l/s.Highly productive aquifers are located around Wonji and Melka hida area and along Awash River plains. All shallow wells and dug wells are concentrated in Wonji–melkahida area. From the analyses of the available pumping test data and previous studies, transmissivity (T) of the aquifers found in the area ranges reaches up to 1355.2 m2/day. And the hydraulic conductivity (K) of the aquifers in the area ranges from 0.1 to 78.50m/ day.

- The possible groundwater depth variation reasons between Dhera basin and the rest of the study area is due to the presence ofgeological structures as barrier along NE-SW direction down stream of wonji side and East-West transverse fault south side along Awash River that dip towards north direction.

8.2 RECOMMENDATION

The following recommendations are suggested based on the hydrogeological and hydrogeochemical assessments made in the area:

- In order to evaluate the area fully, there is no sufficient productive bore holes especially around south and southwest of Dhera area and additional deep bore holes like Metakoma productive borehole up to 400meters below ground level are recommended as test wells and data should be properly stored for future use.
- Although deep wells drilled up to 250mts, all of them are non productive and yet there is no any water supply source developed to Dhera area. As a result they imposed to use ponds and runoff during precipitation and due to high evapotranspiration and evaporation in the area the ponds in the area are getting dry after few months that cannot end till the next rainy season. Consequently, plants and crops dry soon without reaching ripping stage. Therefore, the community in the area needs to use rain water and runoff harvesting techniques for the time being and the regional government should take the responsibilities by incorporate the issue in its development plans and programs, encourage non- governmental organizations to incorporate the water supply development activities in their programs to create lasting solution for shortage of water for both domestic, animal and farm land of Dhera area.
- Observation pipes should be installed in the existing and newly constructed boreholes.
- Before conducting pumping test, check the existence of nearby boreholes, it there exists within the anticipated area of influence, measurements should be taken.
- In order to assess and evaluates the prevailing deep ground water potential in Dhera area geo- electric vertical sounding survey especially in the West-East and South-North direction of Dhera town are recommended.
- In the study area down stream of Wonji plantation along Awash River especially Dhera plain land is so fertile expansion of Wonji irrigation with the help of surface pump is recommended.
- Since the study area is faulted terrain, bore hole site selection should need careful observation on the identification and mapping of conduit and barrier faults or fracture traces.
- Taking in to consideration the underlying unconfined shallow aquifers groundwater in Wonji area and alluvial aquifers along Awash River may be generally considered as highly vulnerable to any type of pollution. So it must be protected from agricultural, industrial and domestic liquid and solid wastes. This is because it is difficult to clean polluted aquifers.
- Eutrophication process in the down stream of Wonji plantation is a result of water pollution.

- Well recorded and documented daily data for Wonji irrigation water consumption from Awash River should be properly stored to determine a long term groundwater-Awash River interaction.
- Planning of an area should take in to account in order to protect the recharging area from pollution.
- The impacts of solid waste disposal on groundwater quality in the area should be handled by properly identified sanitary landfills.
- In the context of the rift valley geology and climate to conceptualize the recharge and the groundwater dynamics of the region further studies based on tracing techniques such as noble gases and groundwater age indicators are recommended in addition to conventional tracing techniques such as stable isotopes and major ion geochemistry.

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Annexes

Annex 1 Data on water points of the study area

Index	Site Name	UTME	UTMN	Elev.(m)	Depth(m)	SWL(m)	GWL (m)	DWL(m)	Temp.(oC)	Yield(l/s)
BH1	Ahwan FF	527786	944511	1550	182	101.35	1448.65	103.46	34.5	3
BH2	AdamaRasHotel well#2	528620	943662	1632	140	100	1492	_	40	3
BH3	Kechema Sebeko	524648	948746	1898	252	209	1690	_	27.4	
BH4	Adama Univ.Well #2	530525	947181	1690	280	186	1504	18.8	39.2	3.1
BH5	Alumin.Sulph.W#1	536248	930836	1576	153	125.2	1450.8	125.6	31.7	4.4
BH6	Alumin.Sulph. W#2	536178	930736	1573	180	126.9	1446.1	138.32	31	2.5
BH7	NACID#3	523527	944294	1753	194	119.95	1633.05	142.6	48	5
BH8	Dildima	521113	948057	1897	259	204.18	1692.82		31.5	
BH9	EEPCO Power Station	537322	928164	1529.3	126	88.05	1441.25	92.73	_	5
BH10	Kilo Degaga	546950	935538	1420.6	168	153.2	1267.4	_	_	
BH11	Wake Tiyo	533027	928447	1550	127	103.5	1446.5	_	27	5
BH12	AM Palace	538581	929142	1553.4	180	150	1403.4	_	_	
BH13	Bofa #2	546420	933081	1343.4	82.5	26.37	1317.03	31.58	29	4.2
BH14	Wonji Hospital(Cam.B)	525685	933969	1540	49	12	1528	_	_	5.4
BH15	Dhera BH.(5km west)	532315	921384	1770	268.2	256	1514	_	_	
BH16	HVA koka Dam s1	520000	937000	1546	60.7	2.5	1546	_	_	
BH17	Wonji Cath.Church	522014	937652	1560	50	11.01	1548.99	_	_	7
BH18	Melka hida BH1	525000	937000	1540	24	10	1530	_	_	3
BH19	Melka hida BH2	525000	937000	1540	103.6	14.9	1525	17.56	_	9.1
BH20	HVA wonji Explora.BH2	525000	935000	1540	47	14	1526	14.3	_	2.7
BH21	HVA wonji village E	528000	930000	1540	50	12.4	1527	_	_	3
BH22	HVA shoa Sug.Es.A ho.	523000	928000	1540	58	10.9	1529	16.8	_	5.8
BH23	Yilma Deressa well #2	528000	941000	1600	117.5	103.6	1496.4	106.6	_	2.5
BH24	Adula Hate Wofe	534890	932712	1581.8	160	132.85	1448.95	_	20	
BH25	Wakemia	532673	932328	1558.3	132	82.26	1476.04	_	17	
BH26	Awash Melkasa Town	536580	929743	1548.7	150	113.25	1435.45	_	26.3	
BH27	Awash Melkasa PA	536813	930293	1555.5	145	116.3	1439.2	_	21.2	
BH28	AlemTenaTown	525000	924000	1650	76	56.6	1593.4	_	_	
BH30	Nazareth Agr.BH-1	530000	944000	1600	150.6	31.2	1568.8	43.4	_	2.75
BH31	Wonji Camp-F	525688	928442	1534	81	10.64	1523.36	_	31	3
BH32	Wonji Camp-k	525690	924757	1534	69	5.26	1528.74	_	32	5.5
BH33	Wonji Camp-M	527524	926601	1530	70.4	4.71	1525.26	_	25	
BH34	Wonji Camp-A	523851	932126	1538	45	3.44	1534.56	_	27	5
BH35	Showa No-1	522018	928440	1580	40	2.7	1577.3	_	29	2
BH36	Melka Hida BH-3	523848	937653	1532	80	10.55	1521.45	_	_	16
BH37	Metakoma	542260	916154	1664	420	295.45	1368.55	297.68	_	3.4
Bh38	Nazereth Trans Freight	530429	941358	1595	196	162.1	1432.9	_	30	
BH39	Naz.rehab.center	530748	940960	1593	192	149.7	1443.3	_	_	
BH40	Wonji Gefersa	523531	936474	1556	50	11.01	1544.99	_	_	
BH41	Wonji Shewa	523310	928661	1553	114	6.9	1546.1	_	30	
BH42	Yerer Flour Mill	527667	941523	1626	152	99.1	1526	_	30	
BH43	Nazereth Metal Works	526928	943518	1656	202	162.7	1493.3	_	_	
BH44	Nazereth Soap Factory	530792	940526	1618	210	172.6	1445.4	_	_	
BH45	Goro Agilo	539213	940271	1522.8	205	176.38	1346.42		45	6.5
BH46	Dibibisa	535918	945906	1483	126	99.6	1383.4	105.74		8.4
BH47	Tede	518458	946916	1865.00	192.0	166.00	1699			

Annex 2 Hydrochemical data values of all water samples in the study area

Chemical Constituents (mg/l)

Index	X	Y	Ca(mg/l)	Mg(mg/l)	Na(mg/l)	K(mg/l)	HCO3(mg/l	SO4(mg/l)	Cl(mg/l)	CO3(mg/l)	TDS(mg/l)	EC(µs/cm)	pH	NO3(Mg/l)	T.Hardness(mg/l)	F(mg/l)
BH1	527786	944511	28.2	3.8	68	11.7	278.2	6.14	10.6	Trace	310	480	7.3	1.14	86.07	1.19
BH2	528620	943662	69.7	7.6	112	15	527	16	19.2	Trace	590	911	7.5	2.55	205.36	1.77
BH3	524648	948746	8.9	8.1	33	11.1	243.02	2.67	8.64	14.4	280	435	8.4	0.9	158.9	0.9
BH4	530609	947065	22.05	3.8	79	18	316.2	9.08	10.6	Trace	330	521	7.3	0.53	70.72	1.13
BH5	536248	930836	52.6	26.3	81.6	11.9	402.6	34.1	28.4	Nil	545	838	7.8	25.3	239.67	1.98
BH6	536178	930736	87.32	19.4	81	9.9	462.62	50.75	20.2	Trace	580	883	7.4	4.17	297.96	1.6
BH7	523527	944294	43.2	7.6	55	12.1	295.7	0.267	2.9	Trace	310	487	7.3	0.2	139.18	1.4
BH8	521113	948057	35.3	10.8	44	12.8	257.7	4	4.8	Trace	286	428	7.4	0.32	132.63	0.02
BH9	537322	928164	20.2	7.7	92	10.8	310	8	13.5		374	560	7.8	3.2	82.16	3.61
BH10	546950	935538	13.4	9.7	354	27	869.4	102	90.2		1116	1686	7.8	6	73.41	5.28
BH11	533027	928447	47	17	45	8	256	12	23		679.13	1044	7.3	11	187.38	3.61
BH13	546420	933081	31.8	7.6	240	14.7	626.6	61.4	66.24	Trace	900	1320	7.8	0.91	110.71	5.3
BH14	525685	933969	17	8.4	290	20	735	55	30		1253	1927	8	ND	77.05	10.6
BH17	522014	937652	38.5	11.7	170	12	536.8	41	22.7		819.9	1260	7.8	_	144.33	3.5
BH18	525000	937000	59.9	8.66	37.5	12	339.2	5	4.26		534.38	820	6.8	ND	185.26	1.52
BH19	525000	937000	36.07	7.3	160	17	518.5	13.48	20.45		872.1	1340	6.9	ND	120.14	3
BH20	525000	935000	43	16	282	18	685	29	30		1355.1	2084	7.6	ND	173.28	8.1
BH21	528000	930000	23	3.6	32.6	11	838	16	48		1079.2	1660	7.6	ND	72.26	9
BH22	523000	928000	40	48	1200	18	3645	11	68		5199.6	_	ND	ND	297.5	4.6
BH23	528000	941000	65.33	11.18	74.94	14.08	385.6	12.97	11.7	nil	461.5	710	7.1	9.92	209.19	1
BH24	534890	932712	17.8	7.02	192	16.5	525.2	50.8	46.9		679	1017	7.8	6	73.36	3.8
BH25	532673	932328	44.5	16.7	190	20	589.3	85.8	58.2		752	1193	7.5	10.5	179.91	3.8
BH26	536580	929743	42.7	17.3	144	14.5	530	25.3	52.4		609	984	7.2	10	177.88	1.9
BH27	536813	930293	53.4	16.2	123	14.4	497	30.4	19.98		606	920	7.6	21.5	200.07	2.2
BH29	539213	940271	8.9	2.2	350	26.5	750.7	65	83.4		1032	1650	8.7	7	31.1	9.2
BH31	525688	928442	50	16	390	11	1250	1	38		1859.43	2860	7.2	1.1	190.76	2.73
BH32	525690	924757	35	6	250	12	609	56	66		1126.7	1732	7.6	1.1	112.12	11.2
BH33	527524	926601	125	40	310	24	609	144	70		1770.53	2723	7.1	2.7	476.9	2.93
BH34	523851	932126	80	45	260	21	864	466	58		1880.26	2892	7	8.1	385.1	2.03
BH35	522018	928440	35	11	240	18	669	73	49		1180.06	1815	7.8	0.6	132.71	4.26
BH36	523848	937653	60.9	9.7	61.2	11.6	366	nill	19.9		617.17	949	7.9	0.5	192.04	1.87
BH37	542260	916154	17.8	5.4	33.5	6.2	121.88	13.1	10.56	Trace	176	290	7.8	1.8	66.69	1.6
Bh38	530429	941358	20.8	4.9	156.4	15.2	439.2	12.6	28.4	0	_	_	7.3	4.4	72.12	5.5
BH41	523310	928661	53.4	10.8	248	18.5	701.99	92.4	55.7	0	909	1281	7.4	5	177.8	4.8
BH42	527667	941523	50.7	9.7	106	15	464.8	7.92	14.7	0	470	700	7.5	18.25	166.56	1.4
BH43	526928	943518	24	5	124	18	390	0	26	0	_	_	7.7	9	80.53	4

Annex 3 Hydrochemical data values of all water samples in the study area											
			Chemical Constituents (mg/l)								
Index	X	Y	PO4(mg/l	Total Fe(M	Mn(mg/l)	SIO2	Turb.(NTU)	SAR	Alkalinity	NH3(mg/l)	Year
BH1	527786	944511	0.406	0.03	3.8	ND	2	3.19	228	0.2	2007
BH2	528620	943662	0.294	Trace	7.6	ND	2	3.4	432	0.2	2007
BH3	524648	948746	0.34	trace	Trace	ND	8	1.14	223.2	0.14	2007
BH4	530609	947065	0.456	Trace	Trace	ND	1	4.09	259.2	0.22	2007
BH5	536248	930836	nil	0.04	nil	101.2	clear	2.29	330	0.06	1988
BH6	536178	930736	0.244	0.09	0.05	ND	1	2.04	379.2	0.32	2007
BH7	523527	944294	0.316	0.03	Trace	ND	2	2.03	242.4	0.25	2007
BH8	521113	948057	0.233	0.14	Trace	ND	1	1.66	211.2	0.21	2007
BH9	537322	928164	ND	0.02	Trace	ND	2	4.42	254.4	0.06	2004
BH10	546950	935538	0.246	0.02	0	ND	3	17.98	712.6	0.13	
BH11	533027	928447	ND	ND	ND	66	ND	1.43	209.97	ND	1999
BH13	546420	933081	Trace	Trace	0.02	ND	_	9.93	513.6	0.2	2007
BH14	525685	933969	ND	ND	ND	85	ND	14.38	602.83	ND	1987
BH17	522014	937652	ND	ND	ND	52.5	ND	6.16	144.33	ND	1999
BH18	525000	937000	ND	ND	ND	66.34	ND	1.2	278.2	ND	1987
BH19	525000	937000	ND	ND	ND	96.3	ND	6.35	425.26	ND	1987
BH20	525000	935000	ND	ND	ND	96	ND	9.32	561.82	ND	1987
BH21	528000	930000	ND	ND	ND	95	ND	_	678.31	ND	1987
BH22	523000	928000	ND	ND	ND	154	ND	30.27	2989.55	ND	1987
BH23	528000	941000	ND	ND	ND	ND	ND	2.25	316.26	ND	1994
BH24	534890	932712	0.328	0	0	ND	0	9.75	430.5	0.1875	
BH25	532673	932328	0.471	0.03	0.5	ND	0	6.16	483	0.1875	
BH26	536580	929743	0.164	0	0	ND	3	4.7	434.7	0.15	
BH27	536813	930293	0.431	0.03	0	ND	3	3.78	407.4	0.113	
BH29	539213	940271	0.615	0	0	ND	2	_	699.3	0.38	
BH31	525688	928442	ND	ND	ND	91	ND	12.29	1025.22	ND	1999
BH32	525690	924757	ND	ND	ND	79	ND	10.27	499.49	ND	1999
BH33	527524	926601	ND	ND	ND	74	ND	6.18	800.5	ND	1999
BH34	523851	932126	ND	ND	ND	76	ND	5.77	708.63	ND	1999
BH35	522018	928440	ND	ND	ND	79	ND	9.07	548.7	ND	1999
BH36	523848	937653	ND	ND	ND	85.5	ND	1.92	300.19	ND	1999
BH37	542260	916154	0.101	0.1	0.07	_	2	1.79	99.9	0.253	2006
Bh38	530429	941358	0	0.8	0	_	_	8.01	360.22	0.6	1993
BH41	523310	928661	0.29	0	0	_	_	8.09	575.76	0.113	2006
BH42	527667	941523	0.27	0.02	0	_	_	3.57	381.22	0.26	2006
BH43	526928	943518	0	0.06	0	_	_	6.01	319.87	0.3	1987

Annex 4 Data on water points of the study area

Index	Site Name	UTME	UTMN	Elev.(m	Depth(m	SWL(m)	GWL (m)	Temp.(oC	Ca(mg/l)	Mg(mg/l)	Na(mg/l)	K(mg/l)	HCO3(mg	SO4	Cl(mg/l)
HDW1	Wonji/Melkahida	526026	937613	1564.4	11	7.5	1556.9	20	6.2	3.2	190	26	502.3	17	16.5
HDW2	Wonji/ Kuriftu	523850	933968	1548	10	7	1537.05	22.5	5.3	1.1	395	8.8	930.6	40	64
HDW3	Wonji/Kuriftu	525328	936530	1560.6	23	22	1538.6	28.4	11.6	3.2	310	36.5	753.2	40	66.9
HDW4	Gergedi(Batitifi)	521313	935049	1550	4	1.67	1548.33		4.5	1.1	440	12.9	919.8	26	68.9
HDW5	Wonji/Bokogurabo	526178	936223	1556.4	15	14	1542.4	23.4	9	2	345	16	675	60	86
HDW6	Wonji/Gefersa	523583	936462	1540	9	6.06	1533.94		18.78	6.1	290	26.1	729.5	34	31.35
HDW7	Alem Tena(Det.DW)	523854	926598	1590	17	15	1575	32	6	3	365	18	774	44	70
HDW8	Gefersa Bedhadha Bu.	524093	934502	1547	12	9.96	1537								
HDW9	Wonji/Kuriftu(Des.DW)	523850	933968	1548	12	10.95	1537.05	31							

Annex 5 Data on water points of the study area

Index	X	Y	TDS(mg/l)	EC(µs/cm)	pH	NO3(Mg/l)	T.hard.(mg/l)	F(mg/l)	Alkalinity(mg/l)	NH3(mg/l)	PO4(mg/l)	SAR	Mn(mg/l)	Turb.(NTU)
HDW1	526026	937613	616	908	8.35	12.5	28.66	3.02	455.7	0.1875	0.659	15.44	0.07	8
HDW2	523850	933968	1096	1758	8.49	17.5	17.8	3.3	814.6	0.25	0.656	40.78	0.07	3
HDW3	525328	936530	1011	1474	8.01	11.75	42.2	3.66	617.4	0.13	0.307	20.78	0	3
HDW5	526178	936223	1320	2020	8.65	21.5	15.77	6.6	921.9	0.65	0.595	48.22	0.02	38
HDW7	523854	926598	1314.2	2021	8.07	25	30.71	15.2	553.62	ND	ND	27.09	ND	ND
HDW8	524093	934502	1253.53	1274.35	7.6	ND	72.02	10.02	598.32	ND	ND	14.87	ND	ND
HDW9	523850	933968	1411.2	2170	8.45	23	27.34	14.6	634.82	ND	ND	30.38	ND	ND

Annex 6 Data on water points of the study area

Index	Site Name	UTME	UTMN	Elev.(m)	Temp.(°C)	Ca(mg/l)	Mg(mg/l)	Na(mg/l)	K(mg/l)	HCO3(mg/l)	SO4(mg/l)	Cl(mg/l)	CO3(mg/l)
SP1	Soder.Spring(hottest)	542664	928756	1362	64	15.88	8.1	600	30	1405.44	133.5	160.3	
SP2	Sod.upper Spring	543669	927901	1335	49	24	8	457	32	1025	110	122	
SP3	Gergedi Spring(hottest)	521313	935049	1546	43.9	6.17	1.08	196	12.8	459.7	24.03	27.8	7.2
SP4	Gergedi(Hippo pool) Sp.	521000	936000	1549	_	16	5	347	26	763	22	60	24
SP6	Spring	SP6	SP6	1550	35.2	5	1	208	13	517	517	29	
SP7	Spring	SP7	SP7	1562	28.8	5	1	204	13	517	517	29	
SP8	Spring	SP8	SP8	1553	35.8	4	0.9	223	13	542	542	30	
SP9	Spring	SP9	SP9	1556	45.2	4	0.6	208	12	482	482	25	
SP10	Spring	SP10	SP10	1555	22.5	6	0.4	185	12	479	479	22	
SP11	Spring	SP11	SP11	1553	39.8	16	4	146	21	443	443	23	
SP14	Spring	SP14	SP14	1551	32.5	20	3	175	12	508	508	21	
SP16	Spring	SP16	SP16	1371	51.8	13	8	670	6	1503	1503	176	
SP17	Spring	SP17	SP17	1556	35	7	1	283	17	647	647	42	

Annex 7 Data on water points of the study area

Index	X	Y	TDS(mg/l)	EC(µs/cm)	pH	NO3(Mg/l)	T.Hard.(mg/	F(mg/l)	Alkali.(mg/l)	SAR	SIO_2	Turb.(NTU)	NH3(mg/l)	Year
SP1	542664	928756	1880	2800	7.13	0.5	72.6	11.8	1152	30.56	ND	2	0.11	2007
SP2	543669	927901	1896.96	2916	8.35	ND	92	3.96	840.68	20.64	111	ND	ND	1987
SP3	521313	935049	584	933	8.2	0.19	19.8	16.9	388.8	19.14	nd	14	0.14	2007
SP4	521000	936000	1386.8	2132	8.4	ND	60.55	10.8	665.83	19.41	109	ND	ND	1987
SP6	520150	936350			7.87		16.6	10.4	424.03	22.21	88			
SP7	520100	936400			7.89		16.6	10.3	424.03	21.79	87			
SP8	520150	935950			7.92		13.7	13.055	444.54	26.22	92			
SP9	521250	935000			7.88		12.46	15.45	395.33	25.64	99			
SP10	520050	937050			7.43		16.63	9.63	392.87	19.74	97			
SP11	518750	936750			7.62		56.43	4.47	363.34	8.46	122			
SP14	522450	937000			8.01		62.3	8.83	416.65	9.65	61			
SP16	542600	928600			7.98		65.41	9.04	1232.73	36.05	147			
SP17	521250	935000			7.88		21.6	24.1	530.66	26.5				

Annex 8 Data on Awash River sampling sites of the study area

Index	Site Name	X	Y	Ca(mg/l)	Mg(mg/l)	Na	K(mg/l)	HCO3(mg/l)	SO4(mg/l)	Cl(mg/l)	CO3(mg/l)	TDS(mg/l)	EC(μs/cm)	pH
AR1	A.R.at dow.stre.of.Sodere	542949	928943	26.5	4.9	39.5	6.9	181.5	17.09	17.3	Trace	210	333	7.5
AR2	A.R at Melkasa Reservior	537005	928388	26.5	2.7	20.5	4.8	122.97	8.24	8.64	Trace	154	242	7.8
AR3	A.R at Wonji bridge	525395	937095	27.3	2.9	40.8	6.6	183	nil	14.2	nil	306.72	497.25	8
AR4	A.R. near Koka Dam	516944	935662	27.3	2.9	28.9	5.6	158.6	nil	14.2	nil	261.97	409.33	7.3

Annex 9 Data on Awash River sampling sites of the study area

Index	X	Y	NO3(Mg/	T.Hard.(r	F(mg/l	Alka.(m	NH3(mg/l)	PO4(mg/l)	Total Fe(l	Mn(mg/l)	SIO_2	Turb.(NTU)	SAR	Year
AR1	542949	928943	1.77	85.8	1.99	148.8	0.175	0.162	0.19	0.1	ND	136	1.9	2007
AR2	537005	928388	1.35	77	1.39	100.8	0.4	0.205	0.07	Trace	nd	124	1	2007
AR3	525395	937095	nil	ND	1.92	ND	ND	ND	ND	ND	ND	ND	2	1994
AR4	516944	935662	NIL	ND	1.17	ND	ND	ND	ND	ND	ND	ND	1.4	1994

Annex 10 At Awash-Wonji river gauge from time plot separation

AR. At Wonji	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
DischargeMm3	102.9	87.6	95.1	90.3	100.3	102.9	127.1	181.9	263.7	128.7	109.2	105.5	1495.2
Base flow Mm3	102.9	77.6	95.1	90.3	100.3	98.4	105.6	113.2	108.6	76.1	61.9	71.9	1101.9
SRO Mm3	0	10.1	0	0	0	4.6	21.5	68.7	155.2	52.5	47.3	33.5	393.4

Annex11 At Awash Below Koka Dam river gauge from time plot separation

AR.below Koka	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Discharge Mm3	49.6	42.7	48.8	45.5	54.7	55.7	54.8	126.7	150.4	62.4	50.4	49.4	791.1
Base flow Mm3	49.6	42.7	48.8	45.5	54.7	55.7	54.8	110.2	69.9	62.4	50.4	49	693.7
SRO Mm3	0	0	0	0	0	0	0	16.5	80.5	0	0	0.4	97.4

Annex12 Result by subtracting Awash below koka dam from Awash -Wonji River gauge

Awash River	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Tot.net flow Mm3	53.3	44.9	46.3	44.8	45.6	47.2	72.3	55.2	113.3	66.3	58.8	56.1	**704.1**
BF.Differe. Mm3	53.3	34.9	46.3	44.8	45.6	42.7	50.8	3	38.7	13.7	11.5	22.9	**408.2**
SRO Mm3	0	10.1	0	0	0	4.6	21.5	52.2	74.7	52.5	47.3	33.1	**296**

Annex 13 Annual data of Wonji irregation consumption from Awash River(MCM)

No	User Name	year						An.mean
1	Wonji sugar factory area	2000	2001	2002	2003	2004	2005	
1.1	Wonji sugar factory	70.79	67.96	68.58	74.61	68.61	81.97	
1.2	Adulala pesant association	1.88	2.25	3.69	3.68	3.08	2.18	
1.3	Kuriftu peasant association	2.04	2.01	3.07	2.61	2.7	2.45	
1.4	Boku peasant association	1.74	2.52	2.84	3.35	2.95	3.38	
1.5	Waqe Tiyyo peasant association	1.56	1.05	3	2.67	1.9	1.25	
	Total	78.01	75.79	81.18	86.92	79.24	94.41	**82.59**

Annex 14 Adama town potable water production from Awash River Monthly data (m3)

Year	Month												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
2003	305469	300727	301962	304192	333445	290098	256318	334140	303294	300984	305025	290449	3626103
2004	325746	354181	298926	307701	374685	341904	314198	347784	298380	327624	333783	335929	3960841
2005	312502	347588	351450	357303	336685	332761	313759	345044	335306	356088	363085	369507	7586944
2006	377603	353040	357543	351819	377733	336484	313759	345044	335306	356088	363085	369507	4237011
Mean	330330	338884	327470.3	330253.8	355637	325311.8	299508.5	343003	318071.5	335196	341244.5	341348	**3986258**

Annex:15A. Pumping test data

Location: Melka Hida, Nazareth			pumping date started: 26/08/80E.C.				
Well # : 11			Discharge rate:12 l/s				
Test type : Constant			Riser pipe diametr: 2"				
Well depth: 50.50m			Type of pump:				
SWL : 11.24m(from top of casing)			Power:				
DWL :			Power source:				
Pump Position :			Datum Level:				
Casing Diam.& type: 6" pvc							
Perforated length:17.25m							
Time	Time since pumping started(min.)	water level(m)	Drawdown(m)	Time	Time since pumping started(min.)	Water Level(m)	Drawdown(m)
10:00	0	11.24	0	2.02	242	15.56	4.32
	1	13.5	2.26		272	15.58	4.34
	2	13.87	2.63		302	15.58	4.34
	3	14.05	2.81		360	15.58	4.34
	4	14.18	2.94		420	15.62	4.38
	5	14.3	3.06		480	15.64	4.4
	6	14.36	3.12		540	15.67	4.43
	7	14.45	3.21		600	15.68	4.44
	8	14.5	3.26		660	15.7	4.46
	9	14.52	3.28		720	15.72	4.48
	10	14.54	3.3		780	15.74	4.5
	12	14.6	3.36		840	15.76	4.52
	14	14.7	3.46		900	15.77	4.53
	16	14.76	3.52		960	15.77	4.53
	18	14.84	3.6		1020	15.8	4.56
	20	14.87	3.63		1080	15.8	4.56
	22	14.92	3.68		1140	15.81	4.57
	27	15.02	3.78		1200	15.81	4.57
	32	15.08	3.84		1260	15.81	4.57
	37	15.1	3.86		1320	15.83	4.59
	42	15.14	3.9		1380	15.83	4.59
	47	15.18	3.94		1440	15.84	4.6
	52	15.21	3.97		1500	15.86	4.62
	57	15.25	4.01		1560	15.89	4.65
	62	15.3	4.06		1620	15.91	4.67
	72	15.36	4.12		1680	15.92	4.68
	82	15.38	4.14		1740	15.93	4.69
	92	15.4	4.16		1800	15.94	4.7
	102	15.42	4.18		1860	15.95	4.71
	122	15.44	4.2		1920	15.95	4.71
	142	15.45	4.21		1980	15.95	4.71
	162	15.49	4.25		2040	15.96	4.72
	182	15.53	4.29		2100	15.97	4.73
	212	15.55	4.31				

Annex:15B. Recovery Test Data						
Discharge Rate: 12 l/s			Recovery Date:28/08/80E.C.			
Discharge Time:2100 min.				Time since	Time Since	
Time	Water Level(m)	Recovery(m)	Residual	pump starte	pump stopped(t')	Ratio
			drawdown(m)	(min.)	(min.)	t/t'
9.01	14.27	1.7	3.02	2101	1	2101
	13.9	2.07	2.66	2102	2	1051
	13.72	2.25	2.48	2103	3	701
	13.59	2.38	2.35	2104	4	526
	13.47	2.5	2.23	2105	5	421
	13.38	2.59	2.14	2106	6	351
	13.3	2.67	2.06	2107	7	301
	13.22	2.75	1.98	2108	8	263.5
	13.14	2.83	1.9	2109	9	234.33
	13.08	2.89	1.84	2110	10	211
	13.01	2.96	1.77	2112	12	176
	12.96	3.01	1.72	2114	14	151
	12.92	3.05	1.68	2116	16	132.25
	12.89	3.08	1.65	2118	18	117.66
	12.86	3.11	1.62	2120	20	106
	12.83	3.14	1.59	2122	22	96.45
	12.8	3.17	1.56	2124	24	88.5
	12.78	3.19	1.54	2126	26	81.77
	12.76	3.21	1.52	2128	28	76
	12.74	3.23	1.5	2130	30	71
	12.72	3.25	1.48	2135	35	61
	12.7	3.27	1.46	2140	40	53.5
	12.69	3.28	1.45	2145	45	47.66
	12.68	3.29	1.44	2150	50	43
	12.67	3.3	1.43	2155	55	39.18
	12.64	3.33	1.4	2160	60	36
	12.61	3.36	1.37	2170	70	31
	12.58	3.39	1.34	2180	80	27.25

	12.56	3.41	1.32	2190	90	24.33
	12.51	3.46	1.27	2210	110	20.09
	12.48	3.49	1.24	2230	130	17.15
	12.46	3.51	1.22	2250	150	15
	12.43	3.54	1.19	2280	180	12.66
	12.41	3.56	1.17	2310	210	11
	12.39	3.58	1.15	2340	240	9.75
	12.37	3.6	1.13	2370	270	8.77
	12.36	3.61	1.12	2400	300	8
	12.33	3.64	1.09	2460	360	6.83
	12.31	3.66	1.07	2520	420	6
	12.29	3.68	1.05	2580	480	5.37
	12.27	3.7	1.03	2640	540	4.89
	12.26	3.71	1.02	2700	600	4.5
	12.25	3.72	1.01	2760	660	4.18
	12.24	3.73	1	2820	720	3.91
	12.23	3.74	0.99	2880	780	3.69
	12.22	3.75	0.98	2940	840	3.5
	12.21	3.76	0.97	3000	900	3.33
	12.19	3.78	0.95	3180	1080	2.94
	12.18	3.79	0.94	3360	1260	2.66

Annex:16A Pumping Test Data

Owner:Nazareth Ahwan borehole

Well # : 01	Discharge rate:3l/s
Test type : Constant	Riser pipe diametr: 2"
Well depth: 182MTS	Type of pump:Lowara
SWL : 101.85MTS	Power Source:Generator
DWL :103.46MTS	Datum Level:0.5mts
Pump Position :138MTS	
Casing Diam.& type: 6" Steel	
Perforated length:	

Time	Time since pumping started(min.)	water level(m)	Drawdown(m)	Time	Time since pumping started(min.)	Water Level(m)	Drawdown(m)
10:48	0	101.85	0		660	103.41	1.56
	1	102.9	1.05		720	103.41	1.56
	2	103.19	1.34		780	103.41	1.56
	3	103.26	1.41		840	103.42	1.57
	4	103.28	1.43		900	103.42	1.57
	5	103.3	1.45		960	103.42	1.57
	6	103.33	1.48		1020	103.42	1.57
	7	103.34	1.49		1080	103.43	1.58
	8	103.35	1.5		1140	103.44	1.59
	9	103.36	1.51		1200	103.44	1.59
	10	103.37	1.52		1260	103.44	1.59
	12	103.38	1.53		1320	103.44	1.59
	14	103.38	1.53		1380	103.45	1.6
	16	103.38	1.53		1440	103.45	1.6
	18	103.38	1.53		1500	103.46	1.61
	20	103.39	1.54		1560	103.46	1.61
	25	103.39	1.54		1620	103.46	1.61
	30	103.39	1.54		1560	103.46	1.61
	35	103.4	1.55		1620	103.46	1.61
	40	103.4	1.55		1680	103.46	1.61
	45	103.4	1.55		1740	103.44	1.59

	50	103.4	1.55		1800	103.44	1.59
	55	103.4	1.55		1860	103.43	1.58
	60	103.41	1.56		1920	103.41	1.56
	70	103.41	1.56		1980	103.38	1.53
	80	103.41	1.56		2040	103.39	1.54
	90	103.41	1.56		2100	103.4	1.55
	100	103.41	1.56		2160	103.42	1.57
	120	103.41	1.56		2220	103.43	1.58
	140	103.41	1.56		2280	103.45	1.6
	160	103.41	1.56		2340	103.46	1.61
	180	103.41	1.56		2400	103.46	1.61
	210	103.41	1.56		2460	103.46	1.61
	240	103.41	1.56		2520	103.46	1.61
	270	103.41	1.56		2580	103.46	1.61
	300	103.41	1.56		2640	103.46	1.61
	360	103.41	1.56		2700	103.46	1.61
	420	103.41	1.56		2760	103.46	1.61
	480	103.41	1.56		2820	103.46	1.61
	540	103.41	1.56		2880	103.46	1.61
	600	103.41	1.56				

Annex: 16B Recovery Test Data

Owner: Ahwan Bore hole

well No. 01

Time	Time Since pumping sarte (min.)	Water Level(m)	Residual drawdown(n	Elapsed time since pumping stopped t' (min)
12.45	2880	103.46	1.61	0
	2881	102	0.15	1
	2882	101.94	0.09	2
	2883	101.85	0	3
	2884	101.84	0.01	4
	2885	101.83	0.02	5
	2886	101.82	0.03	6
	2887	101.82	0.03	7
	2888	101.82	0.03	8
	2889	101.81	0.04	9
	2890	101.81	0.04	10
	2892	101.8	0.05	12
	2894	101.79	0.06	14
	2896	101.78	0.07	16
	2898	101.78	0.07	18
	3000	101.78	0.07	20
	3005	101.78	0.07	25
	3010	101.78	0.07	30

Annex:17A Pumping Test Data						
Owner:OWRB						
Well # : Metakoma			Discharge rate:3.4l/s			
Test type : Constant			Riser pipe diametr: 2"			
Well depth: 420MTS			Type of pump:Lowara			
SWL : 295.45MTS			Power Source:Generator			
DWL :297.68MTS			Datum Level:0.5mts			
Pump Position :360MTS						
Casing Diam.& type: 6" Steel						
Perforated length:						
Time	Time since pumping started(min.)	water level(m)	Drawdown(m)	Time since pumping started(min.)	Water Level(m)	Drawdown(m)
18-09-0	0	295.45	0	360	297.47	2.02
	2	296.88	1.43	390	297.49	2.04
	4	297.07	1.62	420	297.42	1.97
	6	297.12	1.67	450	297.54	2.09
	8	297.18	1.73	480	297.56	2.11
	10	297.2	1.75	520	297.57	2.12
	15	297.24	1.79	560	297.58	2.13
	20	297.27	1.82	590	297.61	2.16
	25	297.3	1.85	620	297.63	2.18
	30	297.33	1.88	680	297.64	2.19
	40	297.35	1.9	740	297.65	2.2
	50	297.36	1.91	800	297.66	2.21
	60	297.36	1.91	860	297.66	2.21
	90	297.37	1.92	920	297.67	2.22
	120	297.38	1.93	980	297.67	2.22
	150	297.39	1.94	1040	297.67	2.22
	180	297.4	1.95	1100	297.68	2.23
	210	297.41	1.96	1160	297.68	2.23
	240	297.42	1.97	1220	297.68	2.23
	270	297.43	1.98	1280	297.68	2.23
	300	297.44	1.99	1340	297.68	2.23
	330	297.45	2	1400	297.68	2.23
				1460	297.68	2.23

Annex: 17B Recovery Test Data					
Owner: Metakoma					
well No. 01					
Time	Time Since pumping sarted (min.)	Water Level(m)	Residual drawdown(m)	Elapsed time since pumping stopped t' (min)	
19-09-0	1460	297.68	2.23	0	
	1462	295.7	0.25	1	
	1464	295.58	0.13	2	
	1466	295.53	0.08	3	
	1468	295.51	0.06	4	
	1470	295.5	0.05	5	
	1475	295.49	0.04	6	
	1480	295.48	0.03	7	
	1485	295.47	0.02	8	
	1490	295.47	0.02	9	
	1500	295.47	0.02	10	
	1510	295.46	0.01	12	
	1560	295.46	0.01	14	
	1575	295.46	0.01	16	
	1590	295.45	0	18	

	Annex: 18B Recovery Test Data				
Time	Time Since pump started t (min.)	Elapsed time pumping stopped t' (min)	Water Level(m)	Residual drawdown(n	Elapsed time since pumping stopped t' (min)
6.55pm			136.43	9.53	0
	1401	1	134.05	7.15	1
	1401.5	1.5	131.65	4.75	2
	1402	2	129.85	2.95	3
	1402.5	2.5	128.66	1.76	4
	1403	3	127.9	1	5
	1403.5	3.5	127.1	0.2	6
	1404	4	126.9	0	7
	1404.5	4.5	126.89	0.01	8
	1405	5	126.89	0.01	9

Annex:18A Pumping test data

Location: Awash Melkasa Chem.Corpora			Pumping date started: 9/04/83E.C.				
Well #2			Discharge rate:2.5 l/s				
Test type : Constant			Riser pipe diametr: 2 1/2"				
Well depth: 180mts			Type of pump:Sumersible				
SWL : 126.9mts)			Power:				
DWL :			Power source:				
Pump Position :			Datum Level:0.70m				
Casing Diam.& type: 6" pvc							
Perforated length:							
Time	Time since pumping started(min.)	water level(m)	Drawdown(m)	Time	Time since pumping started(min.)	Water Level(m)	Drawdown(m)
7.35AM	0.5	128.5	1.6		45	137.36	10.46
	1	129.5	2.6		50	137.45	10.55
	1.5	130.3	3.4		55	137.55	10.65
	2	130.92	4.02		60	137.62	10.72
	2.5	131.5	4.6		70	137.75	10.85
	3	131.92	5.02		80	137.85	10.95
	3.5	132.28	5.38		90	137.9	11
	4	132.8	5.9		100	137.95	11.05
	4.5	132.92	6.02		150	138.15	11.25
	5	133.22	6.32		200	138.26	11.36
	6	133.68	6.78		250	138.35	11.45
	7	134.1	7.2		300	138.4	11.5
	8	134.44	7.54		350	138.4	11.5
	9	134.7	7.6		400	138.44	11.54
	10	134.95	8.05		450	138.45	11.55
	12	135.4	8.5		500	138.47	11.57
	14	135.65	8.75		600	138.47	11.57
	16	135.9	9		700	138.51	11.61
	18	136.15	9.25		800	138.57	11.67
	20	136.37	9.47		900	138.57	11.67
	25	136.65	9.75		1000	138.57	11.61
	30	136.88	9.98		1200	138.32	11.42
	35	137.08	10.18		1400	138.32	11.42
	40	137.24	10.34		1600	138.32	11.42

Annex 19A:Pumping Test Data					
)wner:EEPCO power Station, Awash Melkasa			Pumping Test Duration:48hrs		
well Depth:126mts			Total Drawdon: 4.68mts		
SWL:88.05m			Pump Position: 124mts		
Measuring Point:0.40meters			Pumping Rate:5 l/s		
Test Conducted Date:19July, 2004					
Time sir started(r	Depth to water Level(m)	Drawdown(m)	Time since Pum ing started (min	Depth to wat Level(m)	Drawdown(m)
0	88.05		420	92.93	4.17
0.5	90.3	2.25	480	92.95	4.21
1	91.5	3.45	540	92.95	4.25
1.5	91.66	3.61	600	92.93	4.27
2	91.78	3.73	660	92.93	4.29
2.5	91.9	3.85	720	92.93	4.32
3	91.99	3.94	780	92.94	4.35
3.5	92.03	3.98	840	92.94	4.38
4	92.1	4.05	900	92.95	4.39
4.5	92.15	4.1	960	92.96	4.41
5	92.17	4.12	1020	92.96	4.42
6	92.22	4.17	1080	92.93	4.43
7	92.26	4.21	1140	92.93	4.44
8	92.3	4.25	1200	92.93	4.45
9	92.32	4.27	1260	92.93	4.45
10	92.34	4.29	1320	92.93	4.47
12	92.37	4.32	1380	92.94	4.52
14	92.4	4.35	1440	92.91	4.53
16	92.43	4.38	1500	92.93	4.54
18	92.44	4.39	1560	92.9	4.55
20	92.46	4.41	1620	92.92	4.55
25	92.47	4.42	1680	92.92	4.54
30	92.48	4.43	1740	92.91	4.86
35	92.49	4.44	1800	92.75	4.7
40	92.5	4.45	1860	82.74	4.69

Annex 19B: Recovery Observation Data				
Owner:EEPCO power Station, Awash Melkasa				
Test conducted: 21,July,2004				
Time sir ing stop	Time since pump- ing started t (min)	Ratio of t/t'	Depth to water Level (m)	Residual Drawdown
0	2880		92.73	
0.5	2880.5	5761	89.47	1.42
1	2881	2881	88.92	0.87
1.5	2881.5	1921	88.7	0.65
2	2882	1441	88.66	0.61
2.5	2882.5	1153	88.57	0.62
3	2883	961	88.49	0.44
3.5	2883.5	824	88.49	0.44
4	2884	721	88.47	0.42
4.5	2884.5	641	88.45	0.4
5	2885	577	88.44	0.39
6	2886	481	88.42	0.37
7	2887	412	88.4	0.35
8	2888	361	88.4	0.35
9	2889	321	88.39	0.34
10	2890	289	88.38	0.33
12	2892	241	88.37	0.32
14	2894	207	88.35	0.3
16	2896	181	88.35	0.3
18	2898	161	88.33	0.28
20	2900	145	88.33	0.28
25	2905	116	88.3	0.25
30	2910	97	88.29	0.24
35	2915	83	88.29	0.24
40	2920	73	88.29	0.24
45	2925	65	88.27	0.22
50	2930	59	88.27	0.22
55	2935	53	88.26	0.21

Annex 20 Run-off Coefficient over Different land types (After Sharma)

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

Source: Woldu Ameneshoa, hydrogeology of Nazareth, 1994.